Final Report

CALFED Water Use Efficiency Program

Yolo County Resource Conservation District Pilot Program 2001

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Executive Summary

The Yolo County Resource Conservation District undertook a one-year pilot program funded by the CALFED Water Use Efficiency Program (WUEP) from December 2000 through December 2001. CALFED staff asked the District to 1) trial and evaluate techniques for assessing the efficacy of several water conservation practices such as tailwater retention ponds, cover crops and filter strips, irrigation evaluation techniques and sediment traps and 2) conduct a survey of water suppliers and conservation professionals regarding successful techniques and partnerships for promoting on-farm water use efficiency.

The District's interest and intent in participating in the Pilot Program was to initiate more rigorous analysis of the assumed water quality benefits of practices it has long promoted: especially those of tailwater ponds, sediment traps and winter cover cropping. The actual water quality improvements associated with those conservation techniques had never been rigorously quantified. In light of the changing regulatory climate regarding farm runoff water quality, this information could prove particularly useful for informing 1) regulators of acceptable and measurable water conservation techniques that can be used to meet their goals, and 2) farmers and water managers of proven tools that they can employ in their desire to best manage the water under their control. In general, the District provides technical support for on-farm conservation with its partner the USDA Natural Resources Conservation Service (NRCS). As such, the District has the opportunity to work closely with local farmers and agricultural industry and is familiar with the stresses and realities of agricultural operations and the families that run them. The District is committed to exploring and promoting means of voluntary compliance without direct regulation that allow farmers to continue their business while properly managing public resources such as air, water, and wildlife. While this Pilot Program only provides a single year of analysis for a limited set of these practices, the District will extend this research through other CALFED (Ecosystem Restoration Program) funding.

The **CALFED Bay-Delta Program** is a consortium of State and Federal agencies with regulatory or management responsibility in the Bay-Delta that are working together to solve the San Francisco Bay-Delta region's problems regarding environmental quality and water supply in a balanced way that offers benefits for all interests.

The **CALFED Water Use Efficiency Program** is focused on water use efficiency issues in the CALFED region, working with the recognition that implementation of efficiency measures occurs mostly at the local and regional level. Their role in water use efficiency is to offer support and incentives through expanded programs to provide planning, technical, and financial assistance. The WUEP is also establishing Quantifiable Objectives for regional water conservation and monitoring progress toward those objectives.

In this Pilot Program, tailwater ponds and sediment traps entrained as much as 90% of the mass of suspended solids carried in the irrigation tailwater passing through them. Proper design and maintenance were important factors influencing the efficacy of the ponds studied. Most of the traps and ponds studied provided some nutrient capture from

irrigation water runoff primarily during early season irrigations, although that aspect of their function definitely bears further study. As nutrients are either soluble or attached to clay particles in the water, means to entrain those finest soil particles that do not easily fall out of suspension without longer residence times than those provided in the subject ponds and traps need to be explored.

The winter cover crop study demonstrated runoff flow attenuation and reduced concentrations of suspended solids in runoff. Future study of the winter runoff attenuation and water quality impacts relative to cover crop planting date and cover crop growth stage would help to gauge the most effective application of this technique. In the context of a processing tomato rotation in the Sacramento Valley, the costs of planting and incorporating a winter cover crop are typically less than the income generated from the slightly (5-7%) increased yields associated with the practice. Since initiating a cover crop runoff and yield impact study in processing tomatoes with UC Cooperative Extension (UCCE) in 1997, we have observed a gradual increase in the practice in Yolo County. In our estimation, a new practice probably requires more attraction to the average grower than simply "breaking even" to merit the inconveniences of equipment and task changes.

The water conservation professionals surveyed (8 responses out of 27 surveys sent) as part of this Pilot Program identified several existing tools for promoting on-farm water use efficiency. Of highest regard were local mobile irrigation lab programs and local workshops and publications demonstrating and detailing techniques that farmers can employ. While UCCE and NRCS provide excellent information and technical resources, the most productive agency collaboration appears to be that between local water suppliers and Resource Conservation Districts. In two of the cases surveyed, the RCD and water district function practically as one organization. In a third, multiple water districts each provide funding to an RCD to manage and implement a mobile lab for their water customers. Most regions of the state include significant numbers of farmers who rely in part or in whole on groundwater and do not depend upon a water district for their irrigation water supply. Water use efficiency is compelling for them at the very least because of increasing energy and, therefore, pumping costs. A different source of support for a local water use efficiency program such as a mobile irrigation lab will need to be identified for those regions and farmers. While CALFED may not be fully accepted as a partner by members of the agricultural community, survey respondents suggested that CALFED support of local work local work, alternatives to regulatory solutions, and effective response to water supply concerns could improve that relationship.

While the District considers the information gathered through the Pilot Program to be useful to CALFED in its aim to promote locally-led, on-farm water use efficiency programs, the Pilot Program has also provided an excellent opportunity for the District to refine its on-farm monitoring program and understanding of potential collaborations for promoting water use efficiency in Yolo County.

Table of Contents Page

Executive Summary i

List of Tables & Figures iii

Introduction ix

Tasks 1 & 3: Water Conservation Techniques Application & Evaluation 1

1. Introduction 3
2. Objectives 3
3. Cover crop trial 4
3.1. Methods and Materials 4
3.2. Results and Discussion 7
4. Sediment traps 15
4.1. Methods and Materials 15
4.1.1. Trap SM95 16
4.1.2. Trap SMCC 18
4.1.3. Trap SB64 19
4.1.4. Trap SBTC 19
4.1.5. Trap SB17 20
4.1.6. Trap SROM 21
4.1.7. Trap SRCH 21
4.1.8. Trap SRUS 22
4.2. Results and Discussion 23
4.2.1. Trap SM95 26
4.2.2. Trap SMCC 31
4.2.3. Trap SB64 33
4.2.4. Trap SBTC 33
4.2.5. Trap SB17 36
4.2.6. Trap SROM 36
4.2.7. Trap SRCH 36
5. Tail water ponds 37
5.1. Methods and Materials 37
5.1.1. Pond PMJ 38
5.1.2. Pond PMR 38
5.1.3. Pond PBHR 38
5.1.4. Pond PBOR 39
5.1.5. Pond PROM 39
5.2. Results and Discussion 40
5.2.1. Pond PMJ 42
5.2.2. Pond PMR 42
5.2.3. Pond PBHR 43
5.2.4. Pond PBOR 43
5.2.5. Pond PROM 45

6. Monitoring soil water content 49
6.1. Methods and Materials 49
6.1.1. Field A1 50
6.1.2. Field B1 50
6.1.3. Field D1 51
6.2. Results and Discussion 51
6.2.1. Field A1 52
6.2.2. Field B1 54
6.2.3. Field D1 56
7. Irrigation Evaluations 58
7.1. Methods and Materials 58
7.1.1. Field A1 60
7.1.2. Field D1 61
7.2. Results and Discussion 64
7.2.1. Field A1 66
7.2.2. Field D1 67

Task 2: Survey of Water Use Efficiency Partnerships and Communication 75

Task 4: Program Outreach 83

Conclusion 85

Appendices (Bound separately):

Appendix A: Cover Crop Trial A-1 through A-20

Appendix B: Sediment Traps B-1 through B-18

Appendix C: Tail Water Ponds C-1 through C-13

Appendix D: Irrigation Water Management C-1 through C-8

Appendix E: Survey and Outreach E-1 through E-4

List of Figures

Page Number	Figure Number and Title	
5	Figure 1	The automated water sampler (American Sigma Model 900MAX)
5	Figure 2	A picture of the study area showing a cover and non-cover crop sections
6	Figure 3	Furrow groupings and sampling station arrangements at cover crop evaluation site
6	Figure 4	Cover crop runoff measurement station with 90-degree V-notch weir, the intake tube of the sampler, and the pressure transducer
8	Figure 5	Runoff rate comparison between station #2 and #4 during the Feb. 21 rain event
9	Figure 6	Runoff from station #1 and station #2 during the Feb. 20th rain event
10	Figure 7	Average runoff from the cover crop and fallow plots during the Feb. 19th rain event
12	Figure 8	Sediment content in runoff water from stations 2 & 4 for the Feb. 21, 2001 rain event
12	Figure 9	Station 1 runoff rate and Nitrate-Nitrogen concentration for Feb. 19, 2001 rain event.
13	Figure 10	Station 2 runoff rate and Nitrate-Nitrogen concentration for Feb. 19, 2001 rain event.
13	Figure 11	Station 3 runoff rate and Nitrate-Nitrogen concentration for Feb. 19, 2001 rain event.
12	Figure 12	Station 4 runoff rate and Nitrate-Nitrogen concentration for Feb. 19, 2001 rain event.
17	Figure 13	Sediment trap SM95 at the beginning of the season.
17	Figure 14	Sediment trap SM95 filled with runoff water
18	Figure 15	Sediment trap SMCC at the beginning of the season.
18	Figure 16	Sediment trap SMCC at the end of the season.
19	Figure 17	Sediment trap SB64 filled with runoff water.
20	Figure 18	Sediment trap SBTC early during the season.
20	Figure 19	Sediment trap SBTC towards the end of the season.
21	Figure 20	Sediment trap SROM filled with runoff water.
22	Figure 21	Sediment trap SRCH filled with sediment.
22	Figure 22	A closer look at the outlet of sediment trap SRCH.
23	Figure 23	Sediment trap SRUS
28	Figure 24	Sediment capture efficiency at the SM95 trap site
29	Figure 25	Sediment content in samples collected from SM95 trap

30	Figure 26	NO3 Nitrogen concentration in samples collected from the SM95 trap site
30	Figure 27	NH4 Nitrogen concentration in samples collected from the SM95 trap site
31	Figure 28	PO4 concentration in samples collected from the SM95 trap
32	Figure 29	Sediment content in samples collected from the SMCC trap
32	Figure 30	Percent of sediment captured at the SMCC trap
33	Figure 31	Sediment content in samples collected from the SB64 sediment trap
34	Figure 32	Sediment content in samples collected from the SBTC sediment trap
34	Figure 33	Sediment capture efficiency at the SBTC trap site
35	Figure 34	NO3 Nitrogen concentration in samples collected from the SBTC sediment trap
35	Figure 35	Sediment content in samples collected from the SB17 sediment trap
36	Figure 36	Sediment content in samples collected from the SRCH sediment trap
39	Figure 37	View south across tail water pond PBHR
40	Figure 38	Tail water pond PROM
42	Figure 39	Sediment content in samples collected from the PMJ pond
44	Figure 40	Sediment content in samples collected from the PBOR pond
44	Figure 41	Percent sediment captured in the PBOR pond
47	Figure 42	Sediment content in samples collected from the PROM pond
47	Figure 43	Percent sediment captured in the PROM pond
48	Figure 44	Canvas dams slow the tailwater and allow the collection of sediment before it reaches the sediment trap and/or pond
48	Figure 45	Tail ditch showing ponded water behind canvas dams
46	Figure 46	Soil water potential from sensors at three different depths in the north row of field A1
53	Figure 47	Soil water potential from sensors at three different depths in the south row of field A1
48	Figure 48	Soil water potential from sensors at three different depths in the south row of field B1
55	Figure 49	Soil water potential from sensors at three different depths in the north row of field B1
56	Figure 50	Soil water potential from sensors at three different depths in the west row of field D1
57	Figure 51	Soil water potential from sensors at three different depths in the east row of field D1
59	Figure 52	A typical siphon-fed, furrow irrigated tomato field.

60	Figure 53	Runoff measurement using a rectangular notch weir, a pressure transducer, and the 900MAX PORTABLE SAMPLER by American Sigma.
61	Figure 54	A closer look at the weir arrangement.
61	Figure 55	A side view of the weir arrangement
63	Figure 56	Modified flashboard riser (Rectangular notch weir) installed at field D1.
64	Figure 57	Pressure transducer can be seen on the right and the water sampling intake tube can be seen on the left.
69	Figure 58	Water advance curves for a wheel and now wheel furrow at field A1
72	Figure 59	Water advance curves for a wheel and now wheel furrow at field D1

List of Tables

Page Number	Table Number and Title	
11	Table 1	Cover crop trial water samples sent for analysis
15	Table 2	Field conditions for each sediment trap site.
16	Table 3	Sediment trap dimensions
23	Table 4	Computed sediment mass values and crop information from selected sediment traps.
24	Table 5	Soil and irrigation information for each sediment trap.
25	Table 6	Sample Analysis costs from A & L Western Labs, Inc.
26	Table 7	Sediment content (g/L) in samples collected from sediment trap SM95
27	Table 8	Sediment SM95 inflow properties changes throughout the season.
27	Table 9	Sediment SM95 outflow properties changes throughout the season.
37	Table 10	Tailwater pond site conditions.
38	Table 11	Average soil bulk density from each pond
40	Table 12	Calculated tailwater pond volumes.
41	Table 13	Calculated volumes of sediment accumulated in each pond.
45	Table 14	Changes in sediment and nutrient content associated with the SROM/PROM sediment trap and pond complex
49	Table 15	Percentage of water extracted at different levels of the tomato root zone.
68	Table 16	Advance time of irrigation water across four different furrows.
69	Table 17	Field A1 inflow and outflow volume measurements
71	Table 18	Irrigation water advance time in wheel furrows in field D1
72	Table 19	Irrigation water advance time in non-wheel furrows for field D1
73	Table 20	Inflow and outflow volumes for field D1

Introduction

This report discusses the results and findings from a one-year pilot project funded by the CALFED Water Use Efficiency Program from December 2000 through December 2001. The Yolo County RCD was presented with four tasks that were initially modified after the program was funded to accommodate delays associated with the contract development process. Those tasks were:

- Research monitoring techniques and their costs for assessing the efficacy of several conservation techniques such as: tailwater retention ponds, cover crops and filter strips, irrigation evaluation techniques and sediment traps;
- Survey entities around the State that work with water delivery and on-farm water use efficiency to assess potentials for local partnerships and possibilities for improving the CALFED Ag WUE Program's delivery and efficacy for promoting on-farm water use efficiency;
- Implement and evaluate water use efficiency techniques on local farms, including:
    - Five sediment traps intercepting runoff from row crop furrow-irrigated fields before it drains into local waterways;
    - Five pre-established tailwater return systems;
    - Winter cover cropping on an annual crop (processing tomatoes) field;
    - Irrigation evaluation and soil moisture sensing techniques on three furrow-irrigated fields
- Communicate pilot program results through field meetings, literature and a final report.

The District was selected for this pilot program because of its history as an innovator in on-farm water quality improvement techniques, especially those employing native perennial grasses, wetland plants, shrubs, and trees. The District devoted at least two staff persons to the program, with a peak of activity including a full-time UC Davis Agricultural Engineering graduate student through the summer months. The District also made liberal use of the assistance of CALFED Water Use Efficiency Program staff, most notably Arturo Carvajal, who also assisted in the development of this report. Larry Schwankl of the University of California Cooperative Extension program also provided valuable direction at the early stages of the project. The techniques employed and research questions raised for the program were partly informed by previous work undertaken as part of a Total Resource Management Challenge Grant funded by the US Bureau of Reclamation from 1994-2000.

The District's intent in taking on the pilot program was to initiate more rigorous analysis of the assumed water quality benefits of practices it has long promoted: especially those of tailwater ponds, sediment traps and winter cover cropping. Before this Pilot Program, District personnel and farmers alike could easily observe sediment captured from farm runoff with ponds and traps and District staff had already documented significantly reduced storm runoff with winter cover crops (Miyao & Robins, 2000). However, the actual water quality improvements associated with those conservation techniques had never been rigorously quantified. Such measurements are critical in assessing the efficacy of and deficiencies (areas for improvement) of those practices that the District and other conservation organizations promote. While this Pilot Program only provides a single year

of analysis for a limited set of these practices, the District will extend this research through other CALFED Ecosystem Restoration Program funding.

The following report is divided into sections according to individual conservation techniques monitored (Tasks 1 & 3), and the survey and outreach tasks (2 & 4). Because of the volume of data associated with Task 3, only a portion of the data is included in the body of the report, with the balance included in an appendix.

The **Yolo County Resource Conservation District** covers over 500,000 acres (83%) of Yolo County, with terrain varying from 2,500'-high interior coast range peaks on the far west to valley floor gently sloping across the majority of the county to the Sacramento River on the east. Dominant soils are deep valley alluvium, from clay to sandy loam texture, deposited over time by the flooding of the Sacramento River, Putah Creek on the south, Cache Creek, and other minor drainages. These deep soils support a healthy agricultural economy that generates about $300 million per year in crop revenues.

The District is committed to exploring and promoting means of voluntary compliance without direct regulation that allow farmers to continue their business while properly managing public resources such as air, water, and wildlife. Several of these techniques are presented in the District publication, *Bring Farm Edges Back to Life!*

According to the District's mission statement: "The Yolo County RCD is committed to protecting, improving, and sustaining the natural resources of Yolo County. We promote responsible stewardship by:

Demonstrating conservation practices through cooperative land users,
Educating the public in resource conservation and enhancement,
Providing information and expertise."

The District's lines of business include: education, land treatment, resource assessment, and future planning. The Board consists of four farmers and one landowner, all of whom actively undertake conservation practices on their ranches and work within the community to promote resource conservation.

TASKS ONE & THREE: CONSERVATION IMPLEMENTATION AND MONITORING

1. Introduction

This section of the report describes work completed under Tasks 1 and 3 of the Water Use Efficiency Pilot Project. The tasks are complementary in that the research for Task 1 guided District staff choices for the monitoring techniques employed and assessed in Task 3. The District chose to focus on surface irrigation flow measurement because it involves relatively high volumes of runoff with potential to carry soil, nutrients and agrochemicals off-site, and is a dominant irrigation technique in the Central Valley.

Task three was divided into four elements; a cover crop demonstration site, sediment traps, tail water ponds, and irrigation evaluations, and the following discussion covers work on them in the same order. All of these practices have potential to improve farm tailwater quality (and reduce quantity) moving into local streams and sloughs. Without tailwater or drainage management, sediment can carried off the field and drain into local waterways, where it can carry agrochemicals, increase turbidity, choke channels, and smother gravel beds. With the subject management techniques, sediment movement can be reduced or collected and returned to the field at the end of the season, reducing the farmer's loss of valuable topsoil. A total of one cover crop demonstration site, seven sediment traps, five tailwater ponds, and two irrigation evaluation sites were studied. Complete data sets and graphs are provided in the Appendix. Specific discussion of the observed benefits of these practices is included at the end of this section of the report.

In implementing these tasks, the following monitoring techniques were assessed or implemented:

1. In-furrow flow measurement:
    - the installation of small flumes at furrow heads and tails;
    - flow estimation of siphon tubes according to head ditch versus furrow level and tube length and diameter;
2. Head and tail ditch flow measurements:
    - weir and water level sensors;
    - a modified flashboard riser with water level sensor; and
3. Propeller and Doppler flowmeters.

Discussion of the costs, limitations and benefits of the different techniques is included in the context of their application in the fieldwork discussed in this section of the report.

2. Objectives

The main objective of Task Three was to implement and evaluate four different water conservation techniques and at the same time to articulate some of the monitoring methods for Task One. The specific objectives were:

1. To establish three different types of demonstration sites on local farms that include sediment traps, tailwater ponds, cover crop sites, and field methods used to conserve water and improve water quality.

2. To monitor and evaluate these sites throughout one winter (cover crop only) and one irrigation season (ponds and evaluations) and communicate with the farmer cooperators.

3. To analyze the data collected from these several site and provide recommendations to CALFED regarding the efficacy of the specific practices and monitoring techniques employed.

3. Cover crop trial

3.1. Methods and Materials

The cover crop demonstration was designed as an extension of a 3-year cover crop trial conducted by Gene Miyao, Farm Advisor, UC Cooperative Extension and the RCD. The focus of this study was to determine whether cover cropping between successive years of processing tomatoes could provide a yield benefit. While the results from the UCCE/RCD study indicated that winter runoff was significantly reduced by the cover crop compared to the conventional fallow bed system, further improvement of the data collection was necessary. During the RCD/UCCE study, mechanical and volumetric flow meters, pumps, and water level recorders were used to measure runoff from both fallow and cover cropped beds. This provided information regarding total runoff volume per storm but did not allow us to sample water quality or develop hydrographs with runoff *rates.* As a result of the methods employed, acquisition of automated sampling and monitoring equipment was recommended to ease the time required to monitor the rainfall events.

RCD staff contacted potential farmer cooperators for the cover crop demonstration during October 2000 and the best candidate site was chosen that November. In November and December 2000, RCD staff evaluated different monitoring equipment options and eventually ordered four automated water samplers (American Sigma Model 900MAX) along with a rain gauge and the corresponding data analysis software. (See Figure 1 for a picture and appendix A for sampler specifications.) Considerable time was allocated to calibrating each sampler and experimenting with different sampling intervals prior to the beginning of the demonstration. In early January 2001, staff finalized arrangements with the farmer and prepared the 70-acre field for the runoff evaluation. Unfortunately, the selected farmer was unable to complete planting until December 7, 2000. (Warmer soil in mid-October to mid-November planting allows better germination and early growth.) The cover crop was seeded as a 3:1 mix of Common vetch and Dundale pea at approximately 75 pounds per acre. The field measured 2,130 feet in length and furrow centers were five feet apart. At the RCD's request, the farmer left fallow eight adjacent rows and the associated furrows were divided into two groups of four. (Figures 2 & 3)

At the low end of the field each group of four furrows was channeled into one furrow that was set with a 90 degree V-notch weir at its outlet. (Figure 4). This practice allowed for sampling drainage from a larger "watershed" than a single furrow would provide the samplers a greater volume of runoff per weir/sampling station. Staff set pressure transducers and inlet tubing (each pair linked to an individual sampling device) in each stilling basin to take water level measurements and periodic water samples as runoff collected behind each weir. The samplers were programmed to draw water samples only after water in the furrow began to flow over the weir. Additional samples were then collected at 15-minute intervals as long as water continued to flow. Eight rows of cover crop were divided in similar fashion and sample collection was performed in the same manner. The pressure transducers collected depth of water measurements (0.001-foot resolution with accuracy +/- 0.054-

inches) every minute there was sufficient water to measure. Every five minutes, the average of the previous five (one-minute) measurements was recorded. Additionally, the rainfall gage inputted precipitation data in 0.01-inch increments into one of the samplers. In late March, when the farmer incorporated the cover crop, the actual vegetative cover was an approximate mix of 65% vetch, 25% pea and 10% volunteer wheat from the previous years crop.

All collected water samples were sent to the USDA Agricultural Research Service laboratory in Corvallis, Oregon. Samples where analyzed for total suspended solids, NH_4 nitrogen, NO_3 nitrogen, and PO_4.

Figure 1: The automated water sampler (American Sigma Model 900MAX)

Figure 2: A picture of the study area showing a cover and non-cover crop sections with weir in foreground.

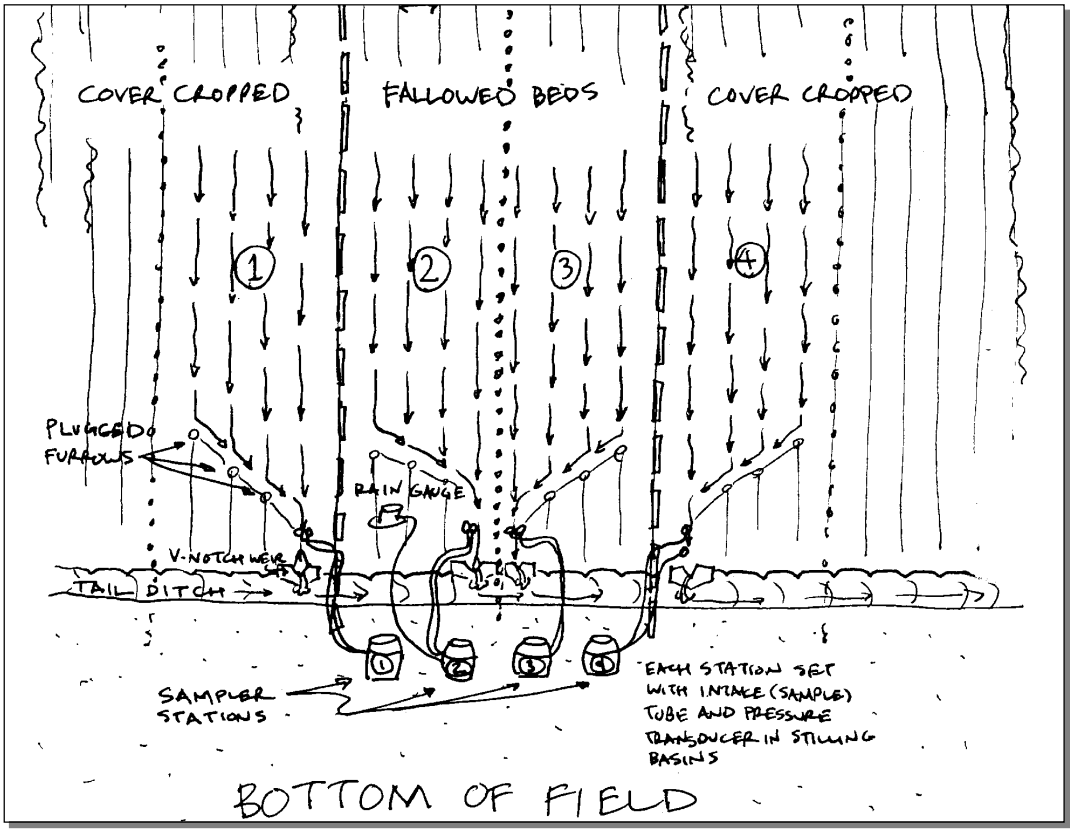


Figure 3: Furrow groupings and sampling station arrangements at cover crop evaluation site.

Figure 4: Cover Crop runoff measurement station with 90-degree V notch weir, the intake tube of the sampler, and the pressure transducer. (note inundation with sediment and Swiss army knife for scale)

3.2. Results and Discussion

Cover Crop Development

Rains came shortly after the planting, facilitating germination of the seed within one week. However, the late planting date meant lower soil temperatures and hence slower growth, resulting in less cover during the peak precipitation months of January and February. The majority of the rainfall, approximately 9 inches, fell in a period from late February into early March. The cover crop grew very slowly during the evaluation period. While there was sufficient precipitation, the cool temperatures kept the cover crop from reaching the desired growth stage of 100% cover until mid-March, after which little runoff-inducing rain fell. As the soil protection provided by the cover crop increased, we anticipated a corresponding increase in rainfall interception, and hence decreased runoff relative to the fallow treatment. However, without the benefit of significant March rains, we were unable to test that assumption during this demonstration. The sampling equipment was removed from the field at the farmer's request in late March. The cover crop was then incorporated into the field for tomato planting in early April. On the date of incorporation, RCD staff measured the wet weight of the clipped cover crop from twenty 3x3-foot quadrats throughout the field in order to estimate the biomass (3,178 lbs/A dry weight) of the cover crop and its nitrogen contribution (110 #N/A). Results are shown in Appendix A.

Runoff Assessment and Sampling

Accurately measuring low runoff rates and shallow streams such as those leaving furrows from winter rainfall is generally problematic. Runoff flows observed in this Pilot Program typically varied less than an inch in depth when spilling over the weir. The margin of error for the transducers is approximately 0.276" (in depths between 0-11') or over 25% of the measured water levels in this application. This is a novel application for such samplers and flowmeters, and despite its current weaknesses it bears further experimentation because of its usefulness in measuring flows and sampling water in surface irrigated systems at odd hours.

The UCCE/RCD cooperative study mentioned above employed a simple alternative technique for measuring run-off with mechanical flow meters (Precision Meter, 5/8 inch) connected to boat-type bilge pumps (Rule Manufacturing, model 1100). A 5-gallon bucket was used as collection sump set below the bottom of a furrow near the drain end of the field. A wire mesh, pre-screen helped reduce clogging of the pump. Approximate total cost per package was $400. This, however, provided no information regarding rates or duration of flow and no opportunity for sample collection, which led District personnel to the consideration of the automated water sampler technology.

Figure 5 compares the runoff during a storm on February 21, 2001 in cubic feet between a fallow treatment (station 2), and a cover crop treatment (station 4). Runoff arrived at the end of the furrow earlier at the fallow station than at the cover cropped station, indicating that the cover crop likely delayed runoff, slowing it and thereby reducing its erosive potential. Figure 5 also shows the total volume of runoff measured from the two stations. It can be seen that 2.1 ft^3 was measured from station 2, while only 0.6 ft^3 was measured from station 4, a 71% reduction in total runoff volume associated with the cover cropped beds and furrows during this rain event.

Figure 6 is another comparison between cover cropped and fallow beds. It compares the cover crop site (station 1) and the fallow site (station 2) during the February 20, 2001 rain event. It shows a 4% reduction in the total volume of runoff from the cover crop site, as well as a different distribution of runoff over time. A higher peak flow is associated with the non cover crop site, which indicates again that a cover crop might dampen rate of the runoff and reduce its erosive potential.

Figure 7 is another example of the effect of cover crop on the distribution of runoff over time, although the total flow from the cover cropped beds was higher in that instance than that of the fallow beds, contrary to expectation and experience. Runoff from the two fallow sites, stations 2 and 3, arrived earlier than runoff from the two cover cropped sites.

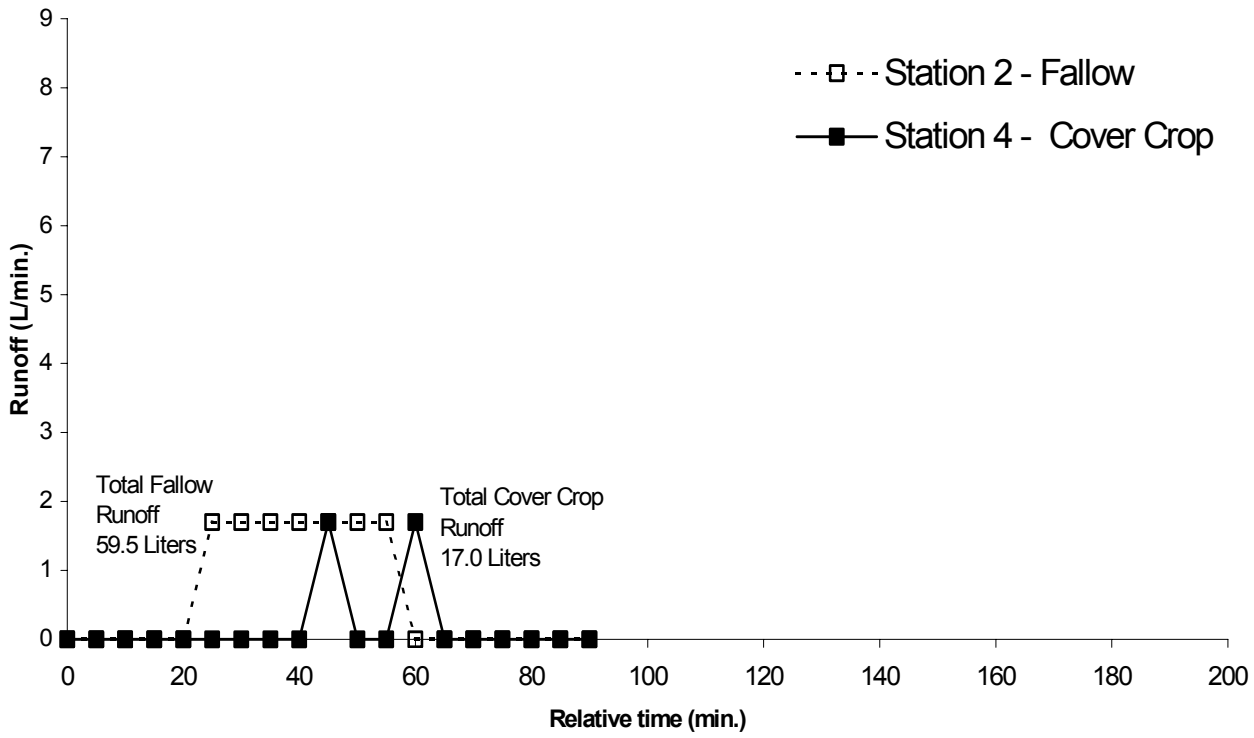


Figure 5: Runoff rate comparison between station #2 and #4 during the Feb. 21 rain event (7:30 AM - 9:00 AM)

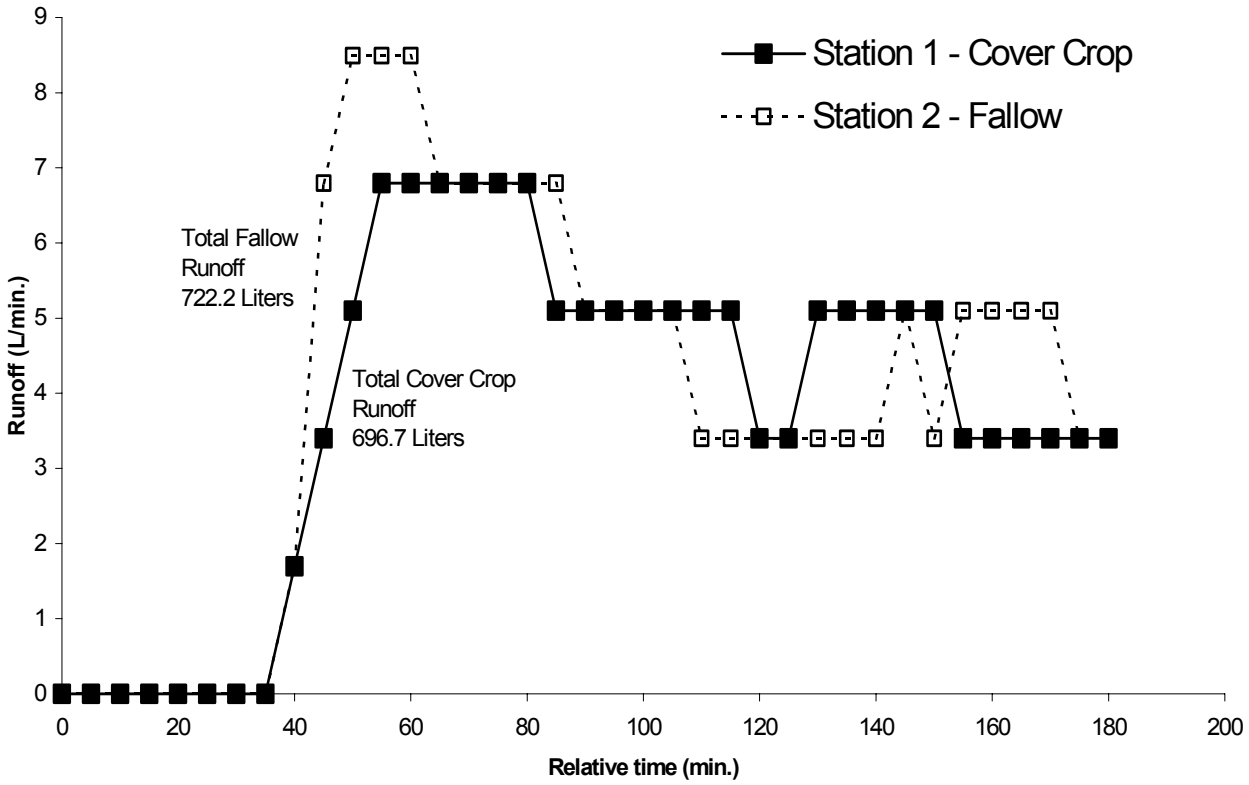


Figure 6: Runoff from stations #1 and #2 during the Feb. 20th rain event (1:00 AM - 4:00 AM).

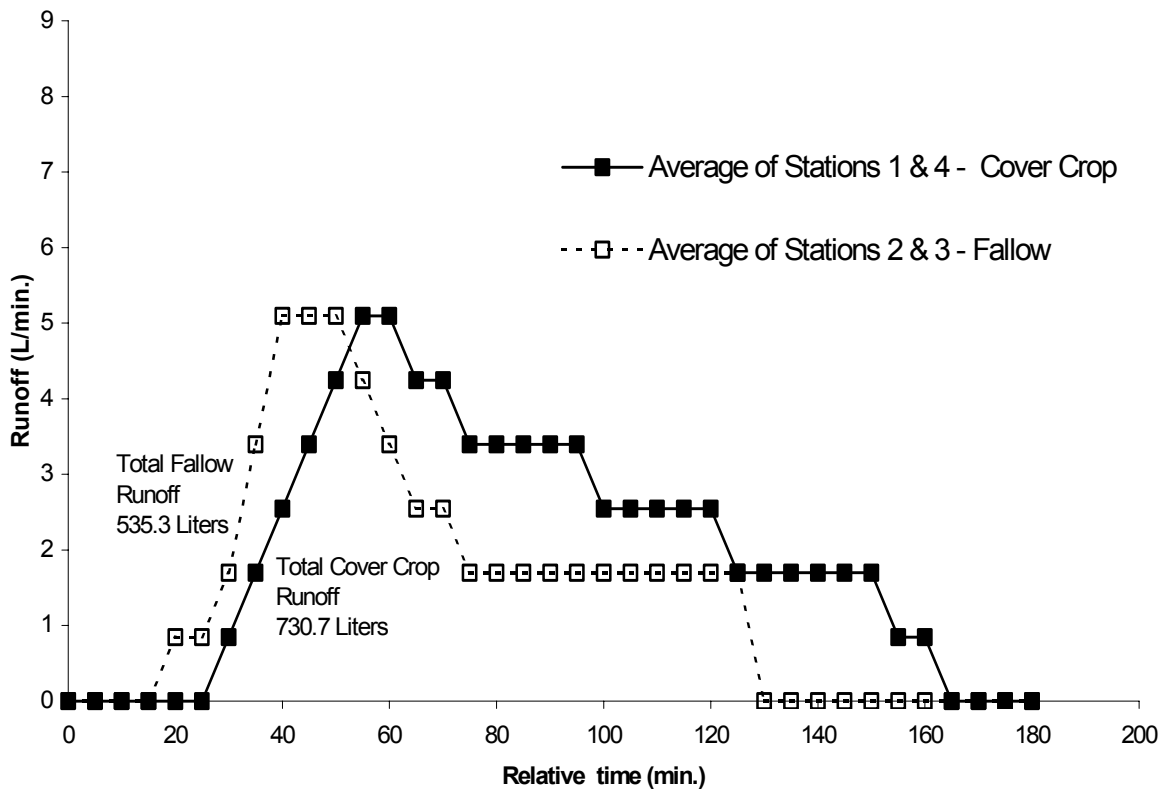


Figure 7: Average runoff from 2 different cover crop plots (stations #1 & #4) and 2 different fallow plots (stations #2 & #3) after the Feb 19th rain event (4:00 PM - 7:00 PM))

Water Quality

A total of 270 water samples were collected along with hundreds of other on-site measurements (Table 1). Water samples were sent to the USDA Agricultural Research Service laboratory in Corvallis, Oregon for analysis of nitrate, phosphate, ammonium and sediment content. Complete analytical results are presented in Appendix A.

Sediment concentration in runoff flows was slightly attenuated during some of the storm events monitored, although not consistently. A major limiting factor in gathering adequate data for comparison was our learning curve in adapting the automated water sampling devices to function in low volume and shallow flow conditions such as those in the subject field. We could not identify another acceptable means by which to gather runoff quality data relative to flows during storms that peak at odd hours, and the ultimate potential for application of this technology for monitoring shallow flows seems positive. For the season of study, due to a combination of weather and technical difficulties, data from only one or two storm events was sufficient enough to provide graphical comparison, and those are included below.

Figure 8 shows sediment content measured in runoff from the same storm (2/21/2001) that provided data for Figure 5. The figure illustrates the general trend of higher concentration of sediment in the runoff from fallow rows as compared to that of cover cropped rows (46% lower total sediment). The initial peak of the first “slug” of sediment typical in runoff measurements is also higher for the fallow treatment in this example.

Table 1: Cover crop trial water samples sent for analysis. All were analyzed for nutrient and sediment content.

Date	Station	Number of Samples	Date	Station	Number of Samples
10-Jan-01	1	0	23-Feb-01	1	0
	2	9		2	12
	3	3		3	0
	4	7		4	24
20-Feb-01	1	24	25-Feb-01	1	0
	2	20		2	0
	3	10		3	24
	4	22		4	0
22-Feb-01	1	0	3-Mar-01	1	0
	2	16		2	0
	3	0		3	24
	4	24		4	21

As for nutrient concentration, Pilot Program results were mixed. Of the one or two comparable storm events (Feb. 19, 2001 shown in Figures 9-12 below), the initial peak nitrate concentration was higher on average from the fallow treatments, making average Nitrate-N concentration higher from fallow beds even though Nitrate-N concentration was consistently slightly higher in flows from the cover crop treatment as compared to that of the fallow treatment. Possible cause of the increased levels of nitrogen in the cover cropped treatments could be from the vegetation, especially nitrogen-fixing legumes. Although the trial was designed to allow for at least some minor replication, inconsistencies in the actual sampling between the monitoring devices (combination of operator and manufacturer errors) provided us with only sporadically useful results, so the charts represented here in Figures 5-12 are best read as likely trends or observations until further research is conducted in the coming years with greater familiarity with the technology, consistent rainfall, and repeated identical trials.

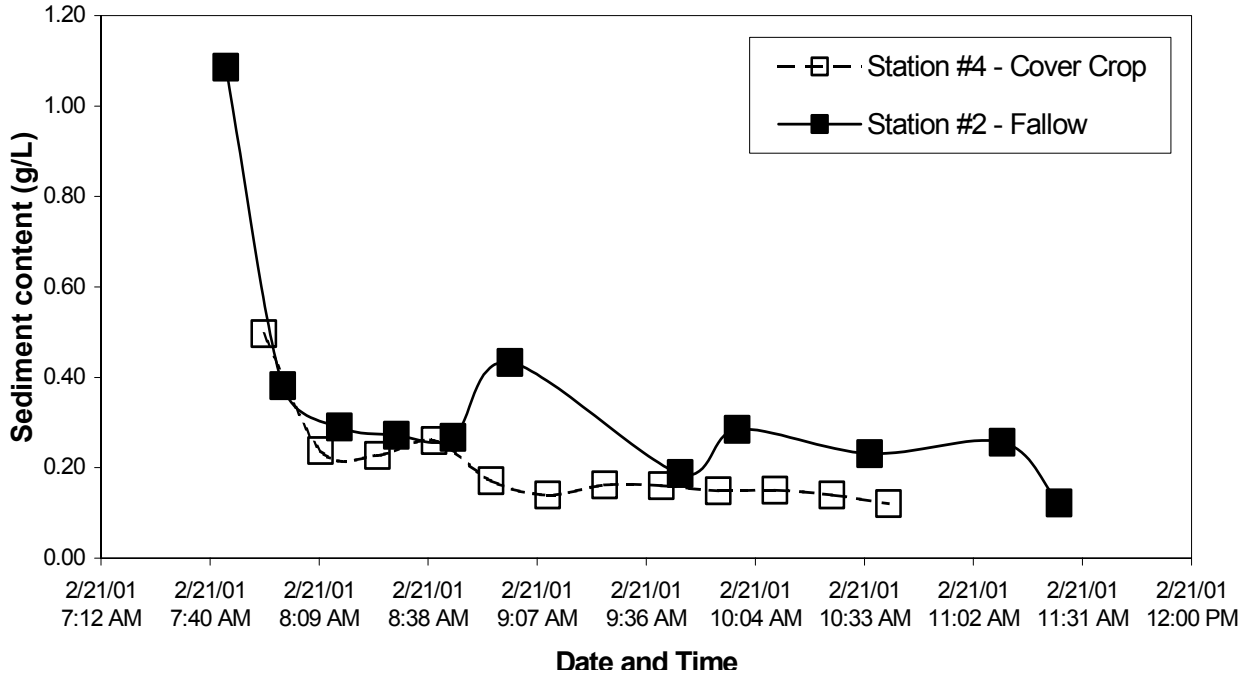


Figure 8: Sediment content in water running off at stations 2 and 4 for the Feb. 21 rain event

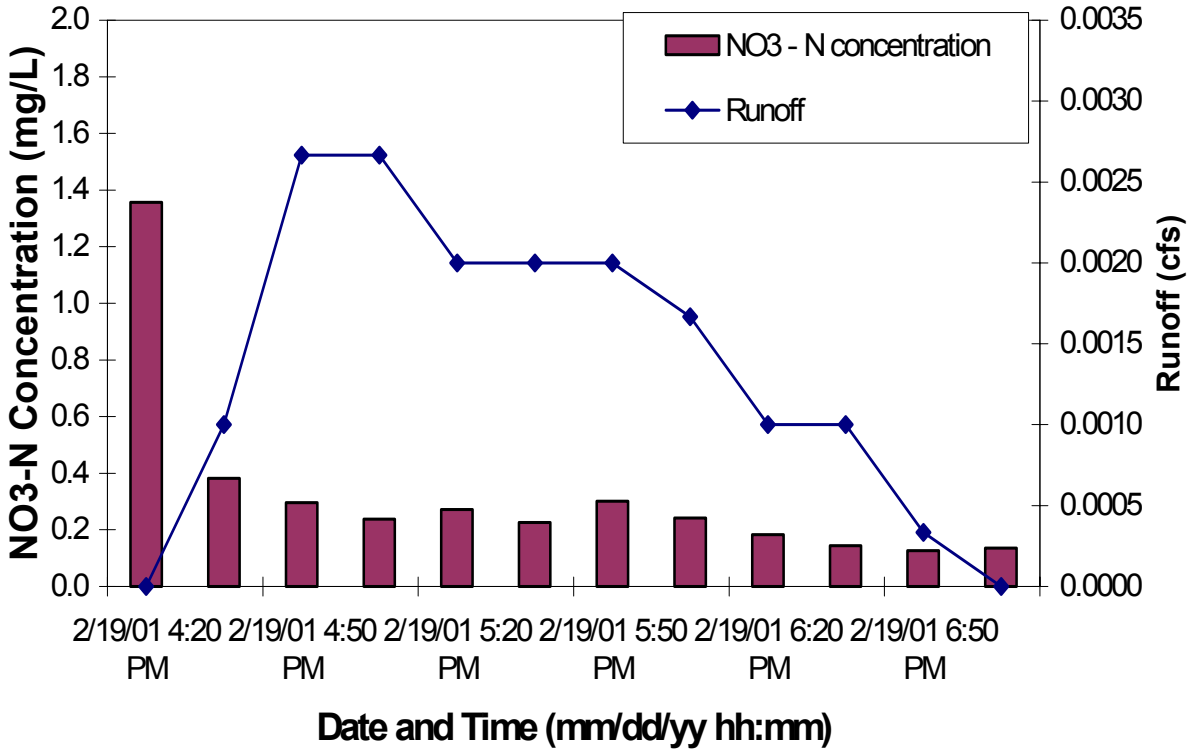


Figure 9: Station #1 (Cover Crop) Runoff (cfs) and Nitrogen concentration (mg/L) for Feb. 19, 2001 rainfall event.

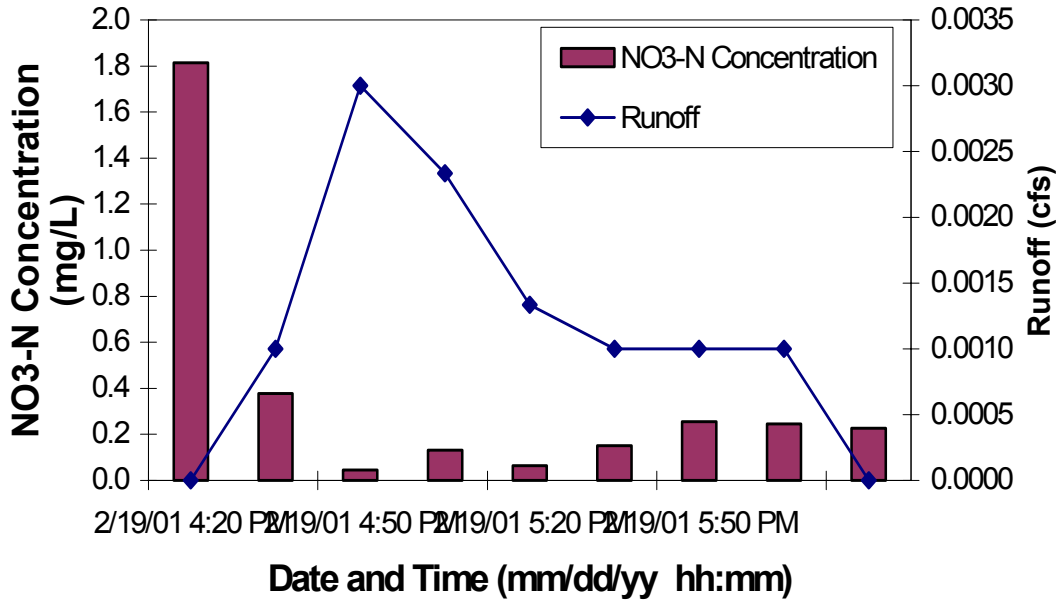


Figure 10: Station #2 (Fallow) Runoff (cfs) and Nitrogen concentration (mg/L) *for Feb. 19, 2001 rainfall event.*

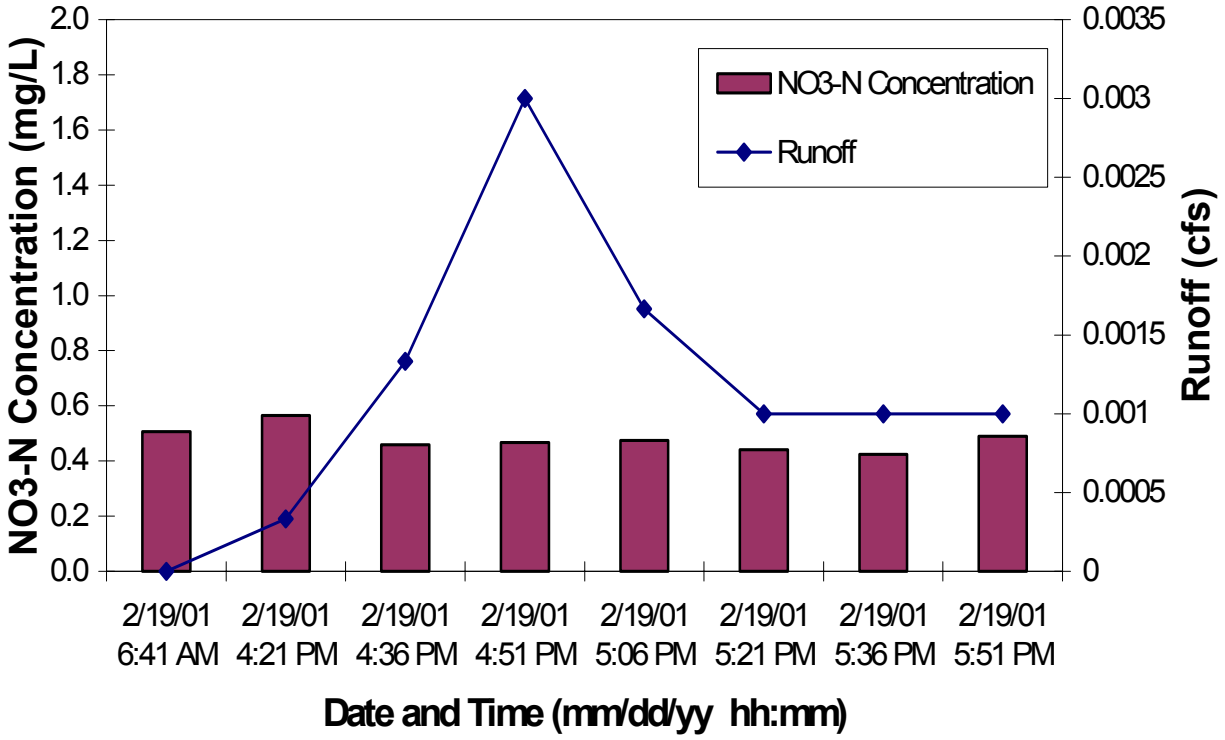


Figure 11: Station #3 (Fallow) Runoff (cfs) and Nitrogen concentration (mg/L) *for Feb. 19, 2001 rainfall event.*

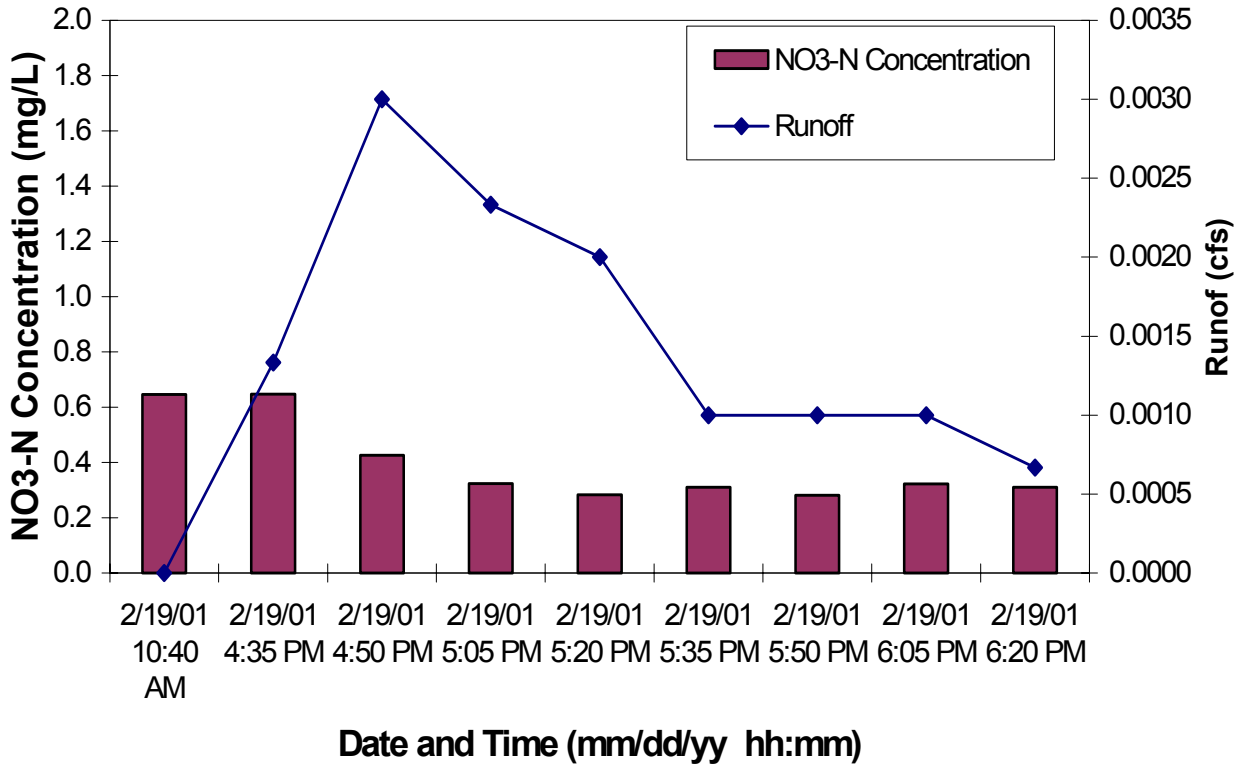


Figure 12: Station #4 (Cover Crop) Runoff (cfs) and Nitrogen concentration (mg/L) *for Feb. 19, 2001 rainfall event.*

4. Sediment traps

4.1. Methods and Materials

During this Pilot Program, eight sediment traps were constructed and evaluated. The traps were located on three different farms, identified in this report as Farms A, B, and C. Table 2 contains summary of information about each trap. Sediment traps were all constructed at the lower corner of each field. Prior to constructing the sediment traps, the RCD staff met with the farmer and/or the chief irrigator and discussed the design and location of each trap. Site selection was focused on fields where runoff drained directly into nearby sloughs. Some traps were located away from sloughs and were instead designed to protect on-farm main drain ditches from siltation. Each trap site had different dimensions and was chosen based on field size, available space, access, and crop. In addition, each trap was designed to collect sediment from one specific field, which had only one outlet. The main design parameters were:

1. to provide a wider, deeper ditch than the farmer's existing drain;
2. establish ponding and outflow control with a flashboard type outlet; and
3. to have the outflow structure lower than the inflow structure/inflow level of the trap.

The cooperating farmers excavated and installed the flashboard risers as necessary. Some farmers made use of existing structures, and the Pilot Program provided others as needed. When possible, each trap was surveyed immediately after excavation in order to estimate its initial capacity.

Table 2: Field conditions for sediment trap sites.

Trap No.	Name	Trap type	Location	Crop	Area (acres)	Soil Type	Field Slope (%)	Cross Slope (%)
1	SM95	Modified culvert	Farm A	Tomato	75.0	Silty clay loam	0.2	0.2
2	SMCC	New	Farm A	Pepper	15.2	Loamy alluvium	0.2	0.2
3	SB64	New	Farm B	Cotton	64.0	Loam	0.2	0.2
4	SBTC	New	Farm B	Cotton & Tomato	110.0	Silty clay	0.2	0.2
5	SB17	New	Farm B	Tomato	51.0	Silty clay	0.2	0.2
6	SRCH	Modified culvert	Farm C	Tomato	28.0	Loam	0.3	Not available
7	SROM	Existing	Farm C	Corn	50.0	Silty clay & silty clay loam	0.3	Not available
8	SRUS	Modified culvert	Farm C	Corn	25.0	Silty clay loam	0.3	Not available

Inflow and outflow samples were collected from each sediment trap during irrigation events throughout the period between early May and early August. Samples were then refrigerated until they were shipped partly frozen in ice chests to the laboratory. All collected water samples were sent to the USDA Agricultural Research Service laboratory in Corvallis, Oregon. Samples where analyzed for sediment weight in (g/L), NH_4 nitrogen in (mg N/L), NO_3 nitrogen in (mg N/L), and PO_4 in (mg P/L). In addition, the depth of sediment in each trap was measured throughout the season as well as the sediment trap dimensions. At season's end, sediment depth and trap dimensions were used to compute the volume of sediment collected in each of the traps. At the same time, sediment samples were then taken from all but one sediment trap and used to determine the sediment bulk density.

Table 3: Sediment trap dimensions

Trap	Dimensions (ft.)			Estimated Volume (cubic feet)	Cross-sectional shape	Acreage drained	Estimated capacity/acre
	Length	Width	Depth	V = L x W x D (x.5 if V-shaped)			Cu.ft./A = V/A
SM95	20	5	4	400	U	75.0	5.3
SMCC	30	5	2.5	188	V	15.2	12.4
SB64	110	10	3	3,300	U	64.0	51.6
SBTC	30	12	3.5	630	V	110.0	5.7
SB17	165	20	1.5	4,950	U	51.0	97.0
SRCH	25	10	5	1,250	U	28.0	44.6
SROM	50	8	4	1,600	U	50.0	32.0

Both sediment bulk density and sediment volume were used to compute the mass of sediment collected in each trap. Following is a description of each of the sediment traps constructed.

4.1.1. Sediment trap SM95

Sediment trap SM95 was 20 ft-long by 5 ft-wide and 4 ft-deep (Figure 13). This trap was constructed using an existing flashboard riser as the outlet structure for the sediment trap. No inflow structure was needed. After the first two irrigations the sediment trap filled with sediment. The farmer later cleaned the trap to allow for further usage but not before the next irrigation. While filled with sediment, the trap did not work properly until it was cleaned out. The trap filled so rapidly for two main reasons: 1) Its volume was not large enough to handle a 75-acre field; and 2) The irrigators failed in the first irrigation to manage the water flow rate from the gated pipe system they had used, which resulted in high volumes of runoff and therefore increased erosion. By the end of the irrigation season (4-5 irrigations) the trap was filled again.

Figure 13: Sediment trap SM95 at the beginning of the season.

Figure 14: Sediment trap SM95 filled with runoff water

4.1.2. Sediment trap SMCC

Sediment trap SMCC was a 30 ft-long by 5 ft-wide and 2.5 ft-deep V-shaped ditch (Figure 15). The farmer did not clean this trap during the irrigation season, even though it needed cleaning out prior to the end of the season. One flashboard riser was installed at the trap outflow (Figure 16). This trap was more of an extended drain ditch rather than a settling pond. There was space for a wider pond at this site. Widening the pond would have increased its capacity and, as a result, its effectiveness.

Figure 15: Sediment trap SMCC at the beginning of the season. Note lines over ditch for surveying.

Figure 16: Sediment trap SMCC at the end of the season.

4.1.3. Sediment trap SB64

Sediment trap SB64 was L-shaped, 110 feet long, 10 feet wide, and 3 feet deep (Figure 17). The design and dimensions of this site were sufficient relative to the area of the field (64 ac.). The trap was successful in terms of collecting sediment; however, sampling outflow was very difficult due to problems downstream of the site that caused water to pond all the time and back up into the sediment trap. (A beaver plugged a culvert downstream with debris.)

Figure 17: Sediment trap SB64 filled with runoff water. Note backed up drain outlet.

4.1.4. Sediment trap SBTC

This sediment trap was 30 ft-long by 12 ft-wide with an average depth of 42 inches and a V-shaped cross section. A drop structure was installed at the outlet of the trap (Figure 18). It was located at the bottom corner of a 110-acre cotton and processing tomato field. The size of this trap was adequately large to allow for adjustments during the irrigation season to keep it functioning without requiring cleaning. This was important because it was otherwise impossible to clean this trap because the sediment remained saturated throughout the season.

Figure 18: Sediment trap SBTC early during the season.

Figure 19: Sediment trap SBTC towards the end of the season

4.1.5. Sediment trap SB17

This trap was 165-ft long by 20-ft wide, the largest sediment trap in this Pilot Program. A drop structure was added at the outlet of this trap. Despite the size, this trap filled very early in the season, which curtailed sampling. However, it was surveyed and the sediment mass collected was estimated at the end of the season. By the end of the irrigation season, the sediment "plume" reached an additional 520 feet beyond the drop structure at the end of the trap. The farmer's irrigator attributes

the large volume of sediment to the usage of a gated pipe irrigation system, which he claims allows for less control over flow rates than other furrow irrigation systems. However, he added, this trap will be cleaned and used in the following year.

4.1.6. Sediment trap SROM

This trap (Figure 20) was 50 ft long by 8 ft wide and 4 feet deep, and was located adjacent and upstream of the PROM tailwater pond (described in Section 4 of this task). An existing flashboard riser was used as the outlet structure and a new flashboard riser was installed at the trap inlet. Water leaving the sediment trap flowed directly into the PROM tailwater pond. The contributing field was a 50-acre conservation-tilled corn field.

Figure 20: Sediment trap SROM filled with runoff water

4.1.7. Sediment trap SRCH

This trap was 25 ft long by 10 ft wide with an average depth of 5 ft and a U-shaped cross section. A drop structure was needed at the down gradient end of the trap (Figures 21-22). An existing drop structure was used at the inlet of this trap, and the outlet pipe was modified to fit a flashboard riser for ponding and control. Water from this 28-acre tomato field drains directly into Chickahominy slough. This trap filled with sediment after the first two irrigation events and was not cleaned out. Although samples were not collected after that point, District personnel surveyed the captured sediment in the full trap.

Figure 21: Sediment trap SRCH filled with sediment

Figure 22: A closer look at the outlet of sediment trap SRCH

4.1.8. Sediment trap SRUS

This trap is 25 ft long by 10 ft wide and located at the corner of a 25-acre cornfield. A drop structure was installed as the inlet of this trap. An existing flashboard riser and culvert structure were used as an outlet (Figure 23). It was. Water from this field drains directly into Union School Slough. This trap was improperly designed and constructed because the drain level was higher than the inflow

level, resulting in the trap remaining full of water throughout the entire irrigation season. No samples or data were collected from this site.

Figure 23: Sediment trap SRUS, note that the drop structure in the center of the picture is the trap inlet and the ponded water can be seen between the inlet drop structure and the outlet culverts under the road

4.2. Results and Discussion

The volume of sediment collected in each sediment trap by the end of the irrigation season was measured. In addition, sediment samples were taken from each trap to determine bulk density and the mass of sediment (kg) collected in each trap was computed. The contributing area (acres) to each sediment trap was determined and used to calculate the soil erosion in units (kg/acre), see Table 4.

Table 4: Computed sediment mass values from selected sediment traps with crop information.

Trap Name	Sediment Volume (f^3)	Density (kg/f^3)	Mass (kg)	Field Area (Ac)	Relative sediment capture (ton/acre)	Crop Type
SM95	374.97	20.11	7541.6	75.0	0.1006	Tomato
SMCC	162.05	21.97	3560.1	15.2	0.2342	Pepper
SB64	1384.67	25.46	35249.4	64.0	0.5508	Cotton
SBTC	7541.63	22.12	166848.5	110.0	1.5168	Cotton/ Tomato
SB17	3660.04	22.76	83289.9	51.0	1.6331	Tomato
SROM	2214.00	18.26	40427.6	50.0	0.8086	Tomato

As shown in Table 5, relative sediment capture values ranged from 0.1006 to 1.6331 T/acre. These values are based on sediment collected in the traps only. Sediment that escaped with runoff water was not accounted for since runoff volumes from the sediment traps were not measured. Water inflow and outflow rates of the subject fields were not measured in this Pilot Program except for the

purpose of irrigation evaluations. This missing information hinders comparison of erosion between trap-study fields that might aid in determining the factors that most contributed to erosion. To estimate the total volume of sediment that escaped each sediment trap, we would need two values: runoff water volume and sediment concentration in that runoff. While it would be attractive to attempt to estimate sediment carried in runoff based on general information about local irrigation and crop management practices, the resulting figures would likely have such large margins of error as to limit their validity or utility. Sediment trap results show that sediment content in outflow samples varied substantially throughout the season, making an average seasonal value equally inaccurate. Future sediment trap studies should include total flow information in order to rectify this.

The amount of sediment captured in the different traps of this Pilot Program appears to be related to the volume of the sediment trap. For example, traps SB17 and SBTC were among the traps with the largest capacity and they were also associated with the highest relative sediment capture, 1.6331 (T/acre) and 1.5168 (T/acre) respectively. However, since none of the ponds were large enough in size to capture all sediment for the entire season and because we did not measure flows, we cannot estimate actual erosion rates from each field or fairly compare one to another.

Table 5: Soil and irrigation information for each sediment trap

Trap Name	Captured sediment (T/acre)	Field slope (%)	Cross Slope (%)	Soil Type	Irrigation System	Furrow Delivery
SM95	0.1006	0.2	0.2	Silty clay loam	Furrow	Gated Pipe
SMCC	0.2342	0.2	0.2	Loamy alluvium	Furrow	Siphons
SB64	0.5508	0.2	0.2	Loam	Furrow	Siphons
SBTC	1.5168	0.2	0.2	Silty clay	Furrow	Siphons
SB17	1.6331	0.2	0.2	Silty clay	Furrow	Gated pipe
SRCH	Not measured	0.3	–	Loam	Furrow	Gated pipe
SROM	0.8080	0.3	–	Silty clay & Silty clay loam	Furrow	Siphons
SRUS	Not measured	0.3	–	Silty clay loam	Furrow	Siphons

Other factors that might have affected the sediment captured include irrigation management practices, type of irrigation system used, field slope, cross (drain ditch) slope, crop type, and soil type. These variables are shown in Table 5. Of the traps studied, field slope did not appear to have an effect on the erosion values. The irrigation systems used were similar in most of the fields (in most cases furrow irrigation with water supplied to the furrows through siphons). The tomato field contributing to trap SB17, however, was irrigated using a gated pipe instead of a siphon system. The irrigator of that field admitted that managing such a system is harder than managing a siphon system, and that it usually results in relatively higher runoff volumes.

As mentioned earlier, water inflow and outflow samples were collected from each sediment trap. These samples were analyzed for total suspended solids, Nitrate nitrogen, Ammonia nitrogen, and phosphorous. Sediment content values were used to determine the degree to which each sediment trap was successful in capturing the sediment carried in runoff. The efficiency of sediment capture in the trap is computed as the difference between inflow sediment content and outflow sediment content as described in equation (1).

$$\%SC = 100 * (ISC - OSC)/ISC \qquad \text{---------- (1)}$$

Where:

%SC = Sediment captured (%)

ISC = Inflow sediment content (g/L)

OSC = Outflow sediment content (g/L)

Considering that we were not able to account for all sediment lost with runoff water, the erosion values shown in Table 5 must be lower than the actual field erosion conditions. Whether the values obtained represent most of the actual erosion is unclear. What is clear, however, is that traps were able to capture sediment throughout the season and that they were easy to manage and monitor.

General Water Sampling and Analysis Methods and Costs

Assessing the efficacy of detention ponds for water quality improvement requires measurement of the target contaminant concentration at both early detention and pre-release stages. Manual grab samples can be taken on an event basis at the pond inlet and outlet, or an automated water sampler can be employed to pull samples at regular intervals or when triggered by a flow threshold. Both techniques were employed in this Pilot Program. An automated sampler can make sample collection more convenient for odd-hour events or awkward locations, while a manual grab sample obviates concerns of computer malfunctions and can be immediately transferred to the appropriate glassware or conditions necessary for preserving the sample for analysis. An automated water sampler with bottles, battery and intake tubing can cost between $2,000 and $6,000 depending on whether an integrated flowmeter or refrigerated bottle holder is required. The District assessed two different manufacturers of such samplers, American Sigma and ISCO, and chose the former for use in this Pilot Program based on user interface, affordability, and sales representative availability. Although other users of automated water samplers have made a similar choice and prefer the American Sigma model, this does not constitute an endorsement on the part of the District. In our opinion, ISCO and American Sigma provide very similar products, and under different circumstances we might have chosen ISCO samplers. Depending on the contaminant being assessed, sample handling techniques and analyses vary considerably in complexity and cost. An example of the range of costs is described below and in Table 6.

Rapid, on site analyses of nutrient concentrations can be made with anything from a simple test strip to a Cardy meter or a colorimeter, ranging in cost from $10 per test strip kit to $250 for the Cardy unit to $1250 for the colorimeter and reagents. If samples are collected properly, the quality of the results improves with the level of technology. Professional lab analysis of water samples often provides the highest quality result, and per sample analysis costs depends on the constituent as shown in the samples below from A&L Western Laboratories, Inc. In the context of this pilot project, all samples were sent to the USDA ARS Lab in Corvallis, Oregon for analysis.

Table 6: Sample analysis costs from A & L Western Laboratories, Inc.

Constituent	Typical Cost to analyze a single sample
Pesticide Residue Screens	$180 - $210 (depending on chemical)
Nutrients (P, NO_3, NH_4)	$13
Suspended Solids	$17
Salts (Sodium, Boron, Magnesium)	$15
pH	$7

Samples should be collected in clean bottles and kept refrigerated prior to analysis. If they must be sent to a lab for analysis, they should be packed in a cooler on ice to ensure they remain cool. In the course of this Pilot Program, District staff froze some of the sample bottles to serve as refrigerant for the other samples in transit. Timing of sampling for sediment, Nitrate, Ammonia, and Phosphate in runoff water should be done at the same time after the start of the irrigation each time, because sediment and some nutrient content in runoff water is consistently higher in early flows compared to later flows.

The following is a discussion of the results obtained from each sediment trap. Because of the relative consistency of the data collected from the different sites, a complete set of charts and graphs for only one representative site (SM95) will be presented in the body of this report. For all other sites, only selected data and/or graphs will be presented and discussed. The complete set of data and graphs for these sites are available in the Appendix.

4.2.1. Trap SM95

Table 7 shows the inflow sediment content (ISC), outflow sediment content (OSC), and percent sediment captured (%SC) in samples collected from the SM95 sediment trap throughout the irrigation season. %SC was computed using equation (1). Table 7 indicates that the sediment content in inflow samples was highest at the beginning of the season and decreased as the season progressed. This trend is borne out in the results obtained from the other ponds studied as well. High sediment concentrations at the beginning of the season were associated with the field's first irrigation. At this site, the irrigators did not have experience operating the gated pipe system on this field, which resulted unusually high runoff volumes during the first two irrigations. The percent sediment capture was at its peak during the first irrigation, which suggests that the sediment trap worked best when it was not already full with sediment. The %SC dropped from 86% to 59% by the end of the first irrigation. The sediment trap was almost full with sediment by the end of the first irrigation. The %SC dropped during the following two irrigations to a low of –12%, meaning sediment was eroded from the trap itself. The farmer then cleaned the trap at the request of District personnel, after which the %SC increased to 33%. By the end of the season the sediment trap was full again and the %SC was 26%. These results can also be seen in Figures 24 and 25.

Table 7: Sediment content (g/L) in samples collected from sediment trap SM95

Date	ISC (g/L)	OSC (g/L)	%SC (%)
06/28/01	28.883	3.994	86.17
06/28/01	2.927	0.536	81.69
06/29/01	2.363	0.973	58.84
07/03/01	1.489	1.550	-4.12
07/17/01	2.660	2.995	-12.58
07/18/01	1.529	1.024	33.03
08/02/01	2.335	2.025	13.25
08/03/01	2.487	1.848	25.67

Table 8 shows the nutrient concentrations (NO_3-N, NH_4-N, & PO_4-P) of the inflow samples collected from the SM95 trap, while Table 9 shows the properties of the outflow samples collected from SM95. These results can also be seen in Figures 26 through 28. The NO_3 and NH_4

concentrations were found to drop dramatically at the beginning of the season and then remain steady throughout the reminder of the season. The initial spike in NO_3 and NH_4 appears to have been attenuated by the trap, as evidenced by lower outflow than inflow values, but later irrigations appear not to benefit from the trap's presence in terms of nutrient capture. The concentration of PO_4, however, did not show an observable trend. In this case, it fluctuated between 0.127 – 0.307 mg P/L.

Table 8: SM95 inflow water properties throughout the season

Date	NH_4 (mg N/L)	NO_3 (mg N/L)	PO_4 (mg P/L)
06/28/01	0.000	10.904	0.307
06/28/01	0.859	3.961	0.182
06/29/01	0.103	1.673	0.158
07/03/01	0.121	1.955	0.169
07/17/01	0.195	1.085	0.282
07/18/01	0.013	1.787	0.127
08/02/01	0.000	1.147	0.186
08/03/01	0.056	1.000	0.167

Table 9: SM95 outflow water properties throughout the season

Date	NH_4 (mg N/L)	NO_3 (mg N/L)	PO_4 (mg P/L)
06/28/01	0.031	2.150	0.220
06/28/01	0.233	1.280	0.168
06/29/01	0.060	1.738	0.137
07/03/01	0.086	1.845	0.152
07/17/01	0.216	1.600	0.303
07/18/01	0.019	1.734	0.125
08/02/01	0.000	1.188	0.188
08/03/01	0.088	0.972	0.164

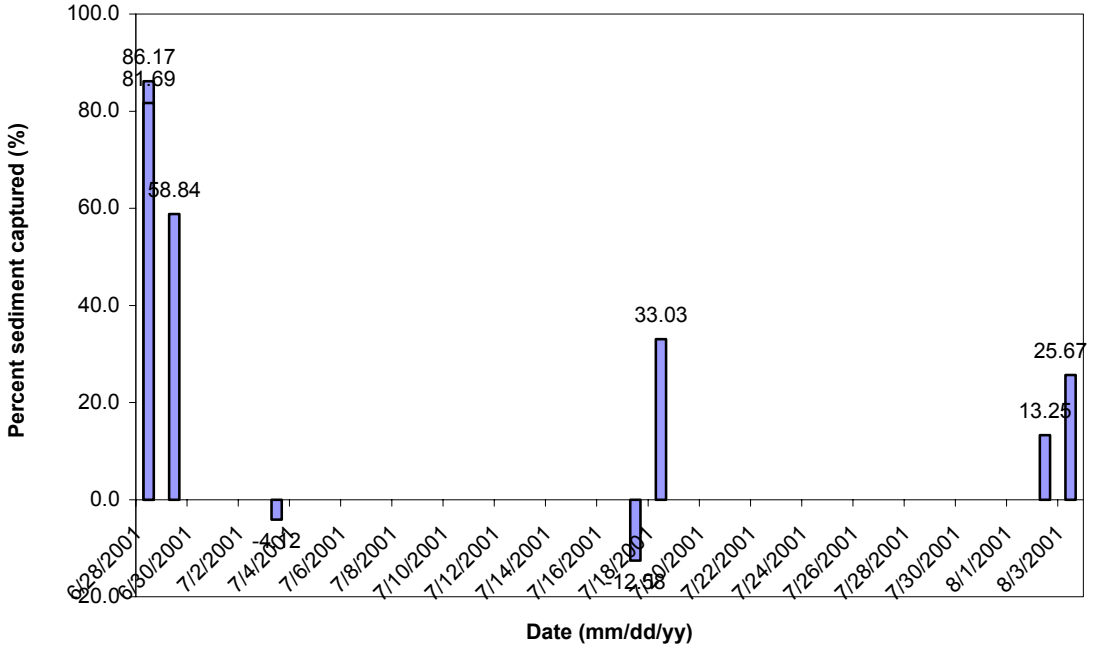


Figure 24: Sediment capture efficiency at the SM95 trap site.

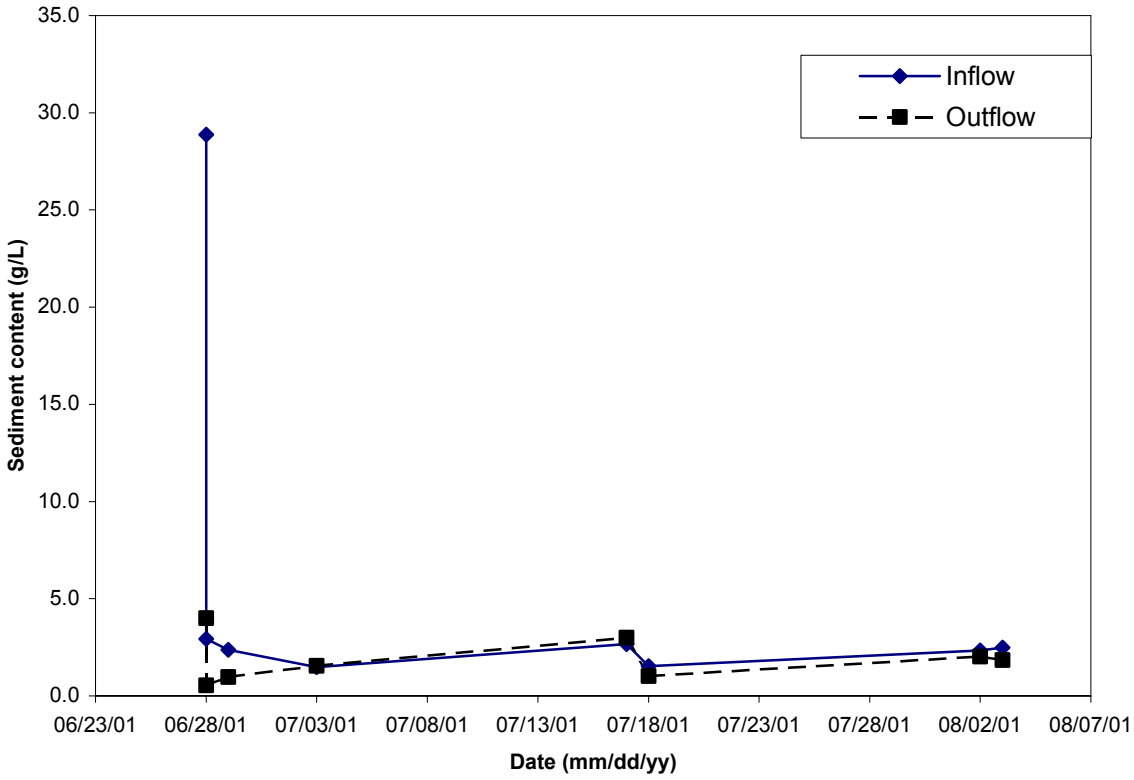


Figure 25: Sediment content in samples collected from the SM95 trap site.

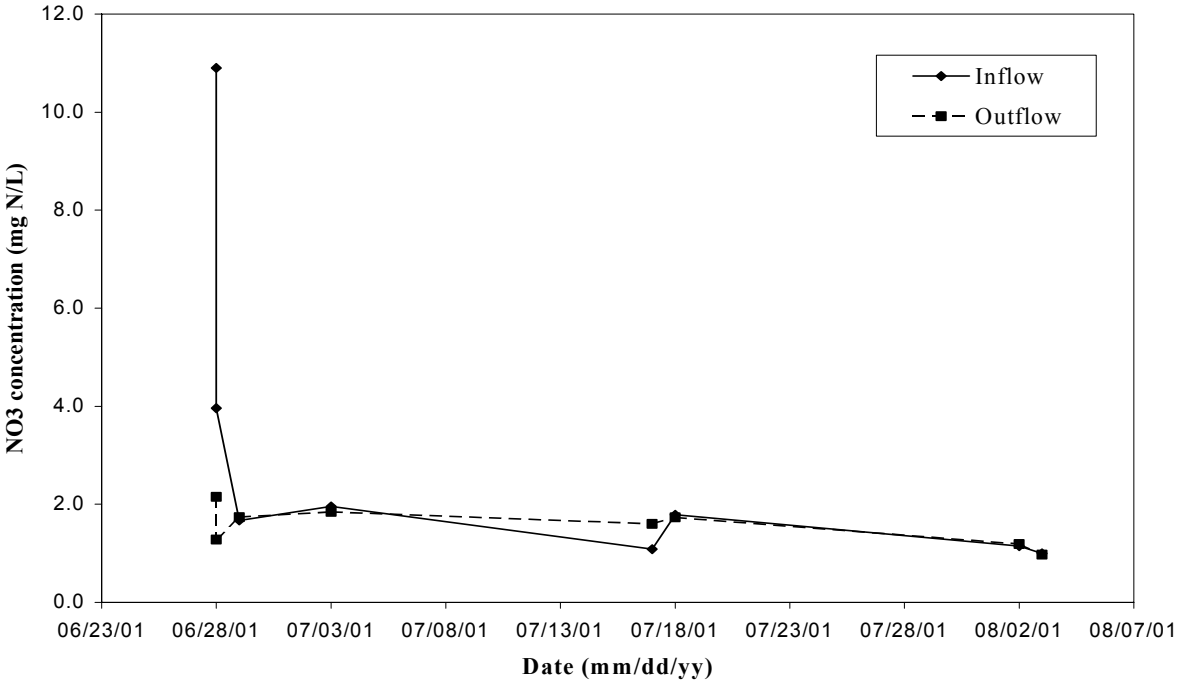


Figure 26: NO3 Nitrogen concentration in samples collected from the SM95 trap site.

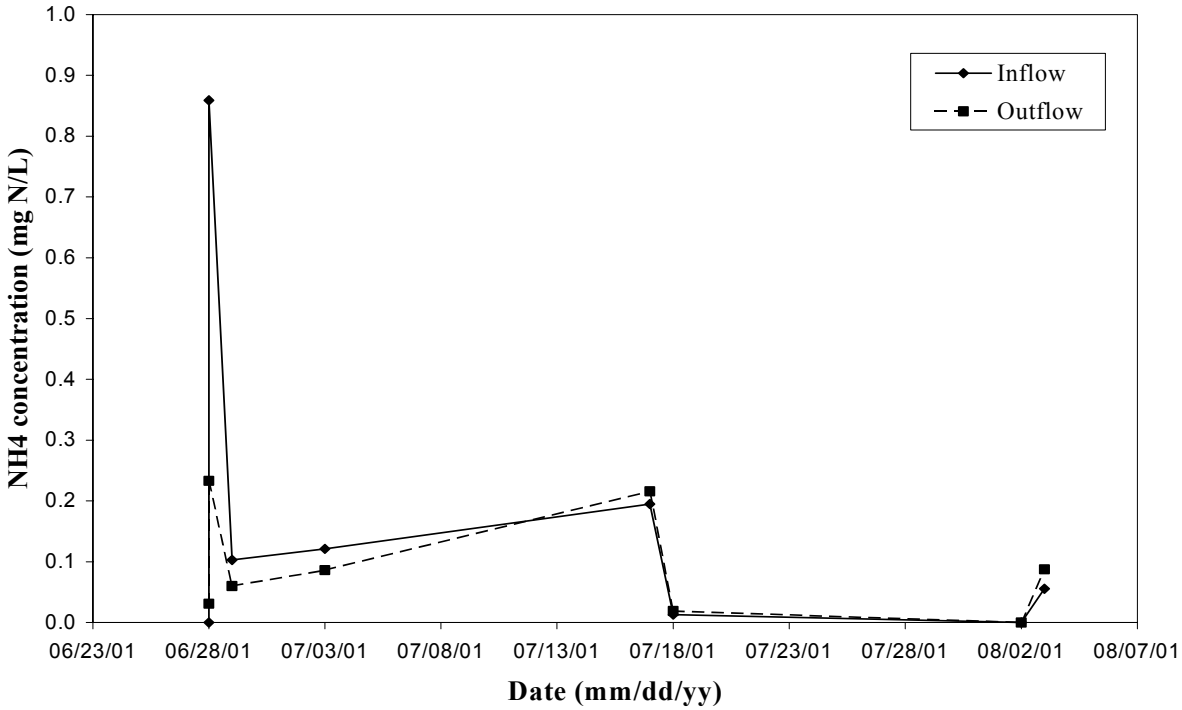


Figure 27: NH4 concentration in samples collected from the SM95 trap site.

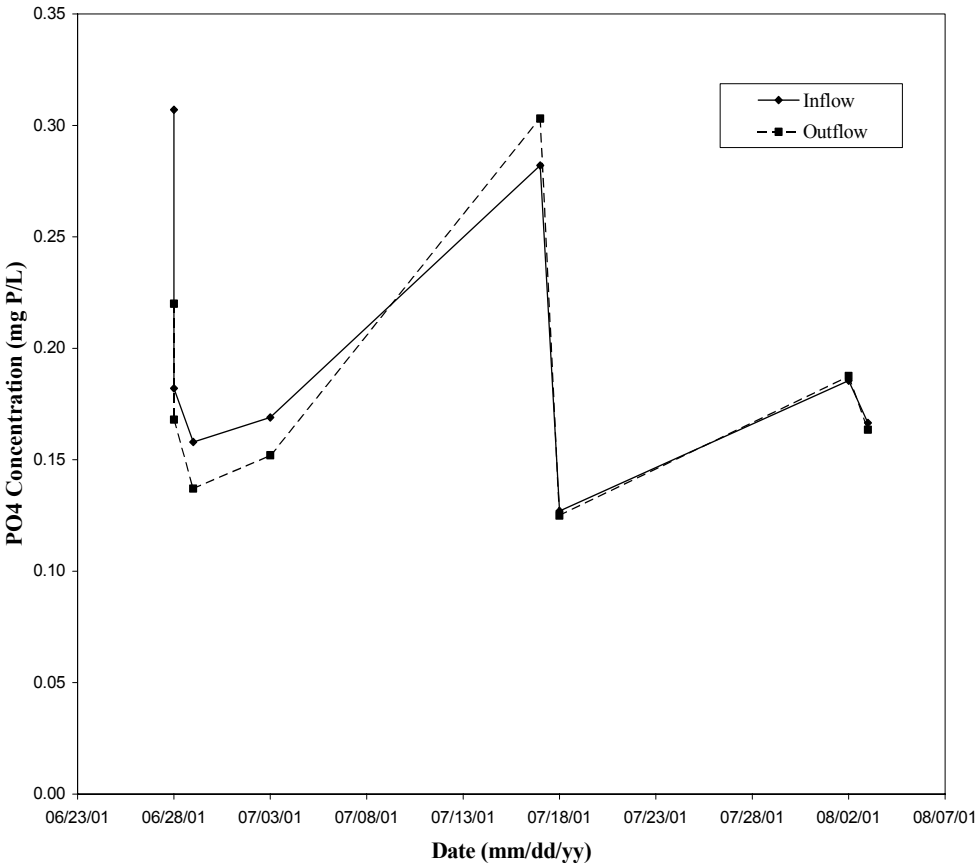


Figure 28: PO4 concentration in samples collected from the the SM95 trap.

4.2.2. Trap SMCC

The sediment content in inflow and outflow samples for this trap is shown in Figure 29. As with trap SM65, inflow sediment content decreased through the season, indicating that more erosion occurs during the first irrigations. Figure 29 also shows that the sediment content in the outflow samples was, at one point, higher than the inflow samples, corresponding to when the trap was full of sediment. In this case, cleaning out the trap before the end of the seasons was not an option for the farmer. To increase the capacity of this trap an additional board was placed in the flashboard riser, which allowed additional water to pond. The curve in Figure 29 illustrates the resulting drop in outflow sediment concentration relative to inflow sediment concentration. However, by the end of the season the trap was full again and the inflow and outflow sediment content were nearly the same. This result can also be seen in Figure 30, which shows the change in the percentage reduction throughout the season. This figure also shows that increasing the volume of the trap by adding a board to the riser increased the percentage of sediment captured and kept it elevated for the rest of the season.

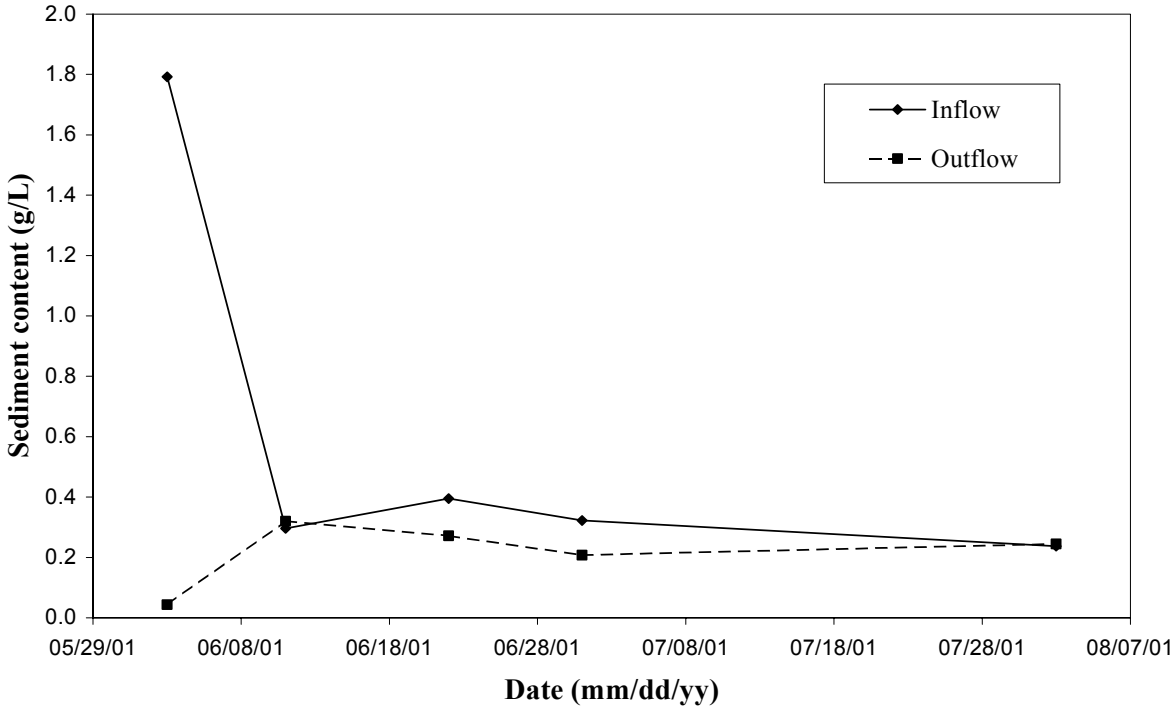


Figure 29: Sediment content in samples collected from the SMCC trap.

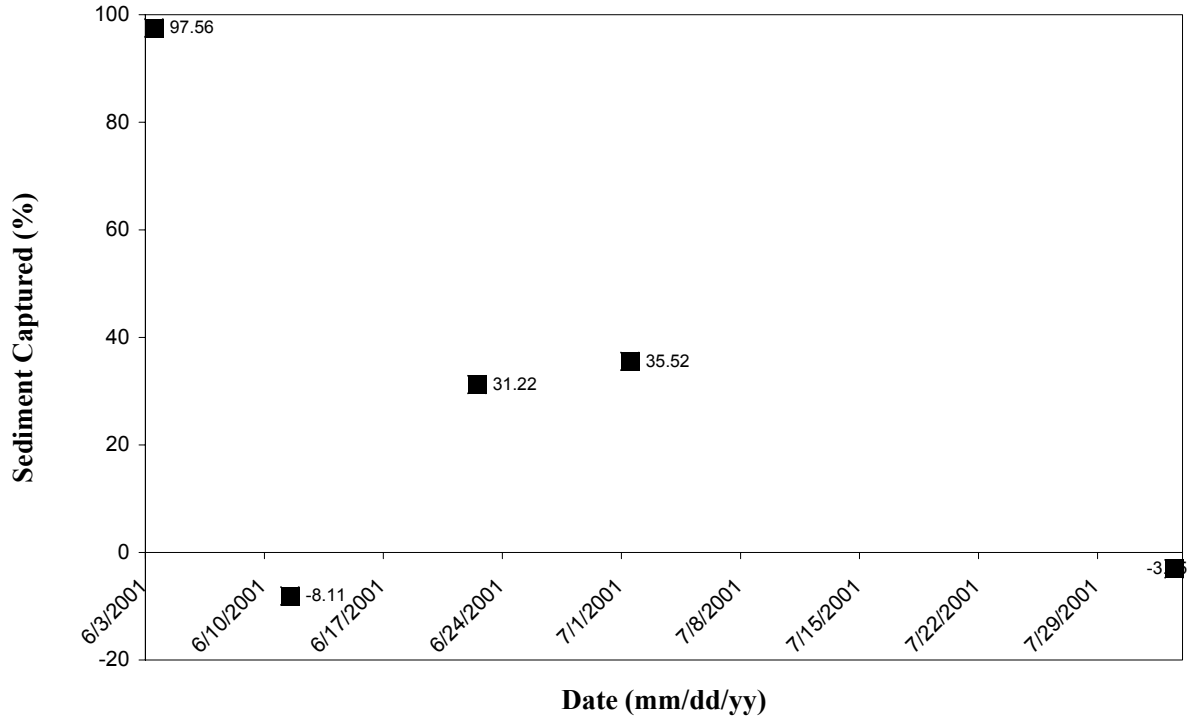


Figure 30: Percent of sediment captured at the SMCC trap.

4.2.3. Trap SB64

As mentioned earlier, this trap was successful in terms of collecting sediment. District personnel were also able to collect inflow samples throughout the season. Figure 31 indicates that the SB64 trap was successful in reducing sediment content in the outflow most of the time. Figure 31 also shows that there was one event when the sediment content in the outflow sample was higher than the sediment content in the inflow sample. This might have been due to water ponding problems downstream of the trap. Most of the time, outflow from the sediment trap was immediately mixed with stream backflow, which might have caused error in outflow sediment measurement results.

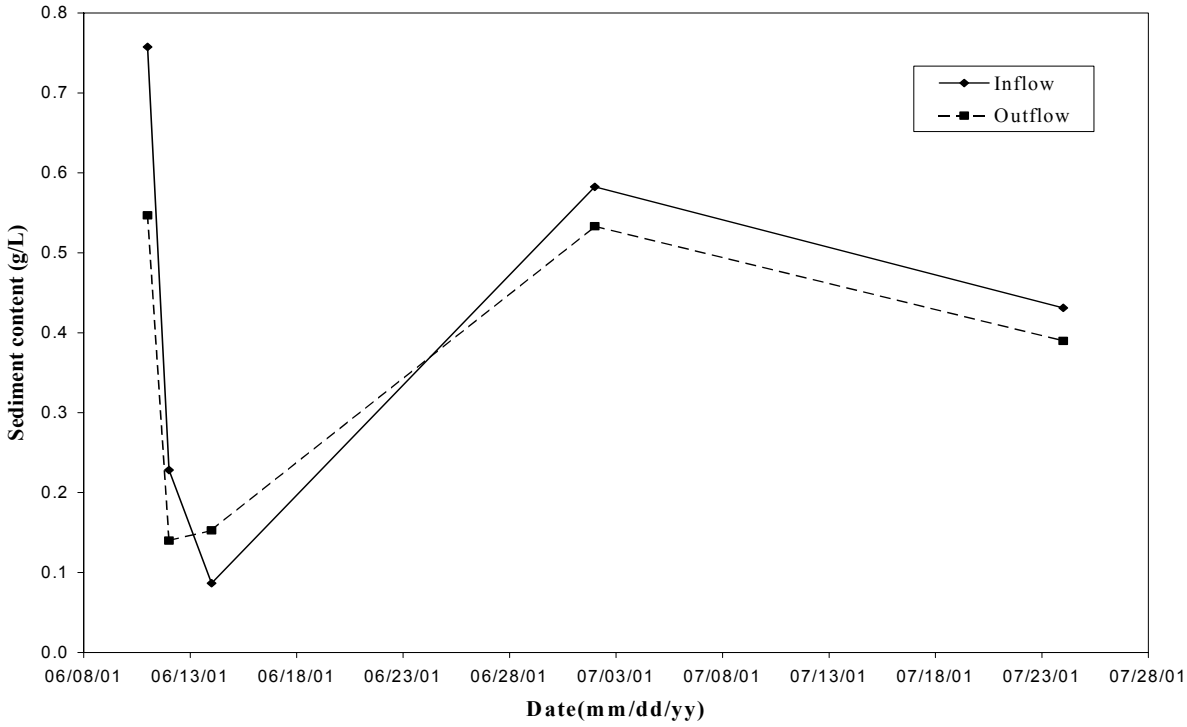


Figure 31: Sediment content in samples collected from the SB64 sediment trap.

4.2.4. Trap SBTC

Figure 32 shows that this sediment trap was successful in reducing the sediment content in runoff throughout the entire season. Although the percentages of reduction varied, it remained positive. While inflow sediment content in most of the other sediment traps continued to decrease throughout the season, it (solid line in Figure 32) shows a different pattern in the SBTC trap. This is likely because this trap received runoff from two fields, hence two drain ditches instead of one. The presence of two source fields explains the second peak in the inflow curve, which represents the first time runoff was received from the second drain ditch. Figure 33 shows the changes in percent sediment capture throughout the season. Figure 34 is another example of how NO_3 Nitrogen concentration in both inflow and outflow samples decreased gradually but not consistently throughout the season.

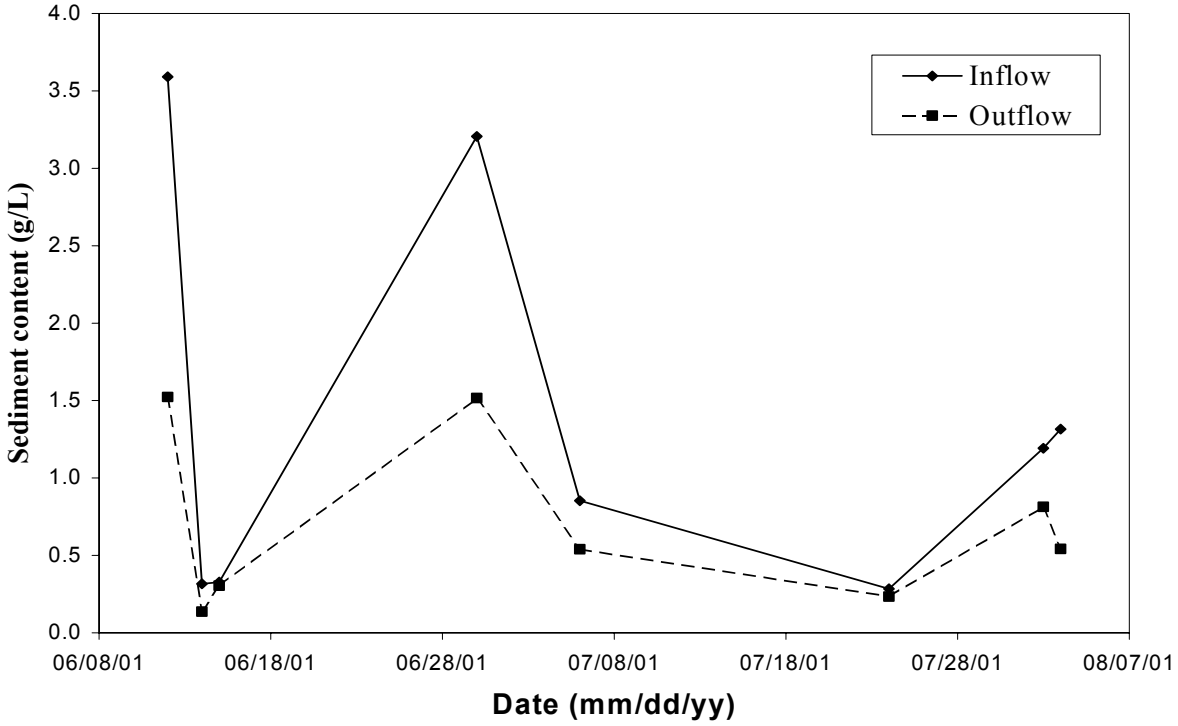


Figure 32: Sediment content in samples collected from the SBTC sediment trap.

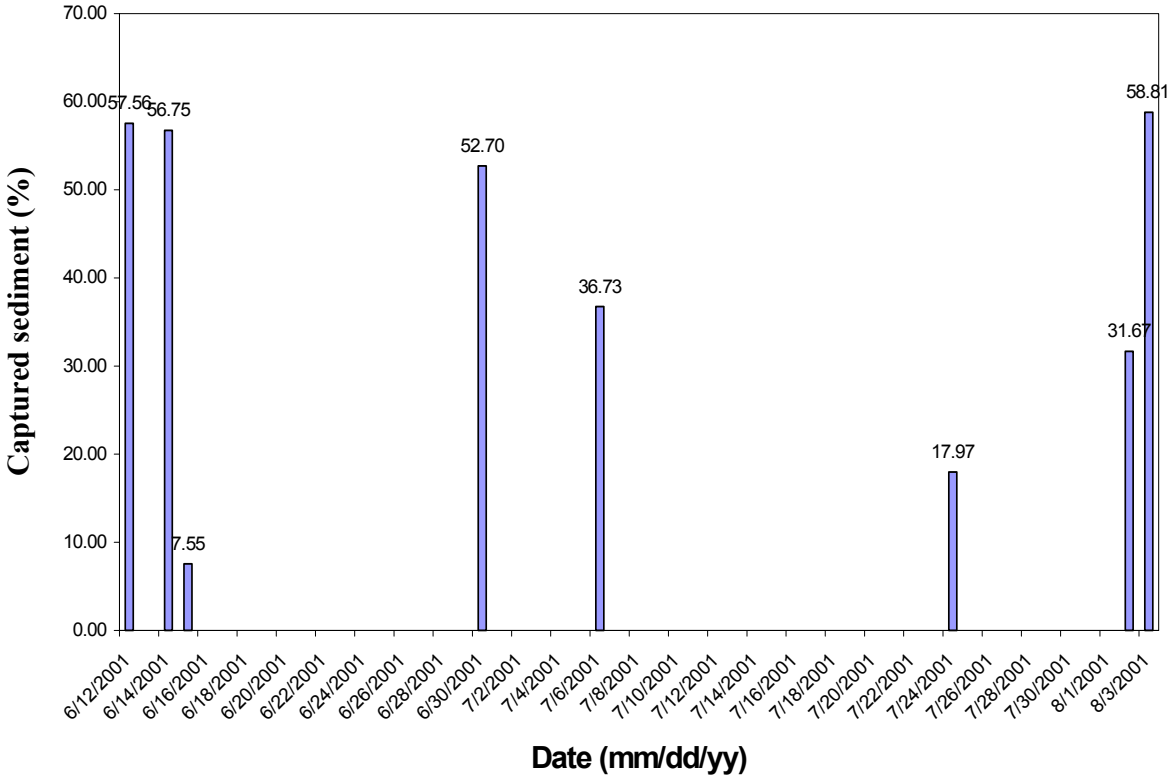


Figure 33: Sediment capture efficiency at the SBTC trap site.

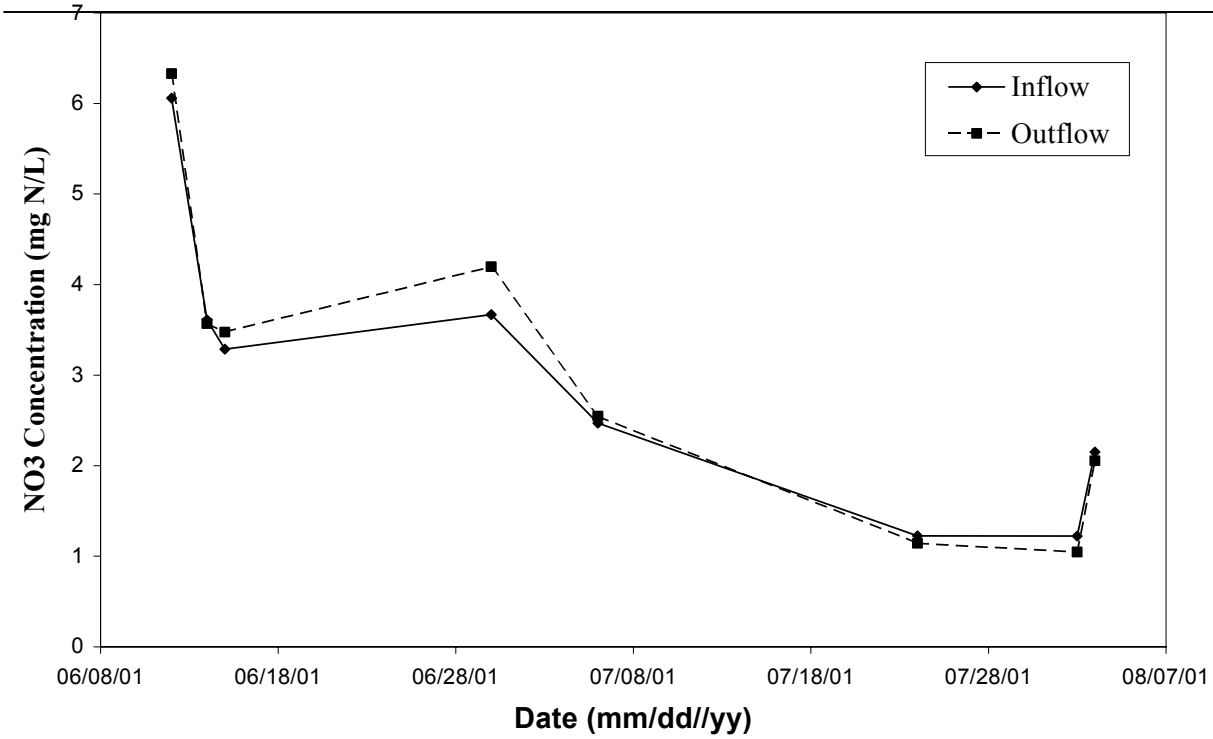


Figure 34: NO3 Nitrogen concentration in samples collected from the SBTC sediment trap.

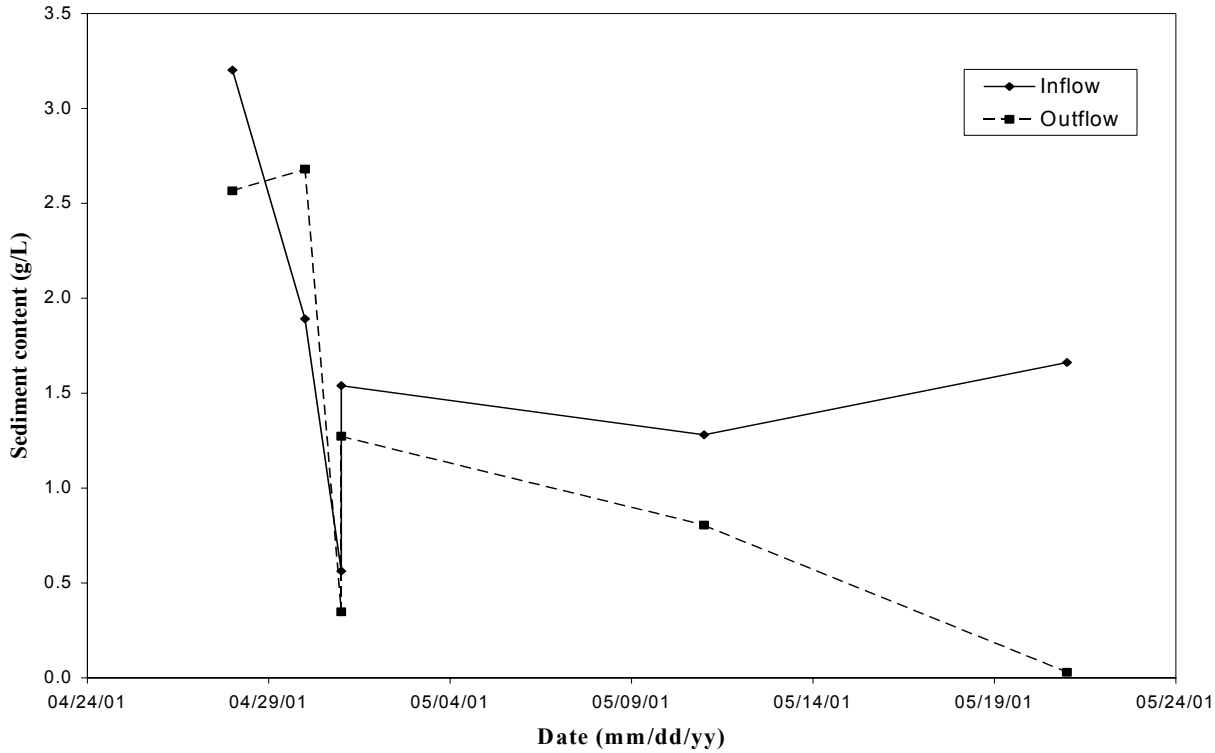


Figure 35: Sediment content in samples collected from the SB17 sediment trap.

4.2.5. Trap SB17

This trap filled very early in the season, after which we ceased sampling inflow and outflow water. District personnel surveyed the pond at the end of the irrigation season and estimated the mass of sediment. By the end of the irrigation season the sediment "plume" reached 520 feet downstream of the trap outlet. Until then, with the exception of one sampling date in May 2001, the sediment trap was consistently effective at trapping sediment. That may have been due to a variation in sampling technique (e.g., sample taken from different depth of water or outlet location), as the Pilot Program intern took over sampling at this site after that time. Figure 35 (above) shows the sediment content in inflow and outflow samples collected early in the season.

4.2.6. Trap SROM

This trap was 50 ft long by 8 ft wide, and was located adjacent and upstream of the PROM pond. The contributing field was a conservation-tillage cornfield. For more information about this site see the PROM pond portion of the tailwater ponds evaluation below. Tabular results are included in Appendix B-6.

4.2.7. Trap SRCH

This trap filled with sediment early in the season, after which we ceased sampling. Results from samples collected are shown in Figure 36. The results show that the trap was working properly before it filled with sediment. Sediment content in outflow samples was lower than that for inflow samples except for the second sample point, at which the difference in values is very small (0.02 g/L).

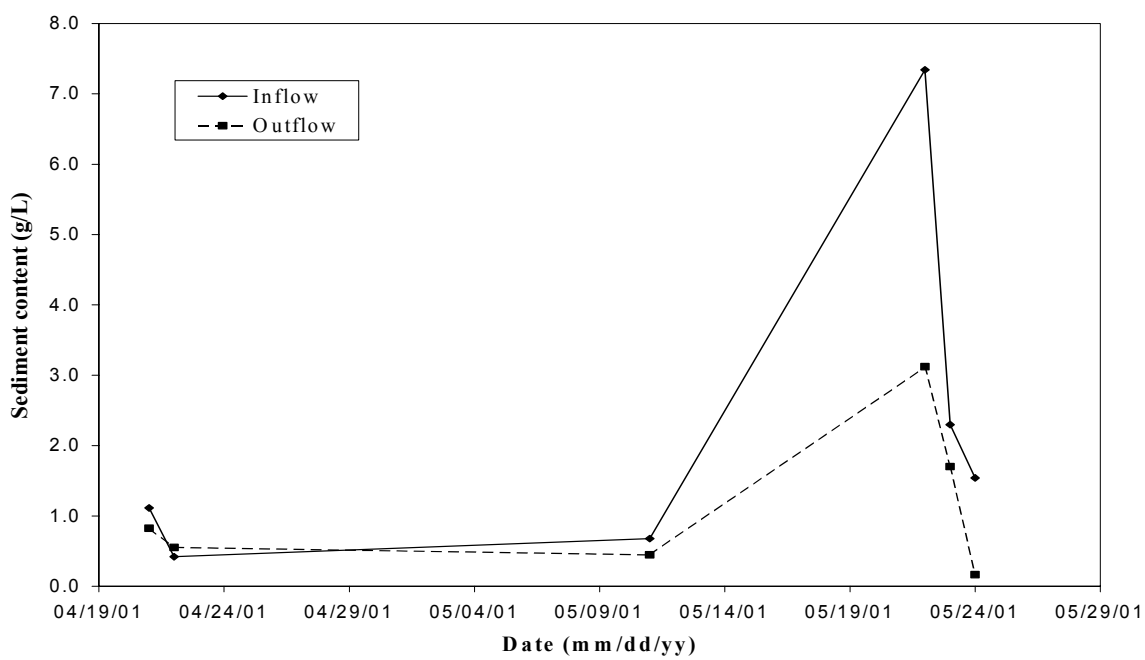


Figure 36: Sediment content in samples collected from the SRCH sediment trap.

5. Tail water ponds

5.1. Methods and Materials

Five tailwater ponds were evaluated during this study. Table 10 contains basic information about the setting for each pond.

Table 10: Tailwater pond site information

Pond No.	Name	Location	Field crop	Field area (Ac.)	Soil Type	Field Slope (%)	Cross Slope (%)
1	PMJ	Farm A	Tomato	155.3	Silty clay loam	0.2	0.2
2	PMR	Farm A	Sunflower	50.9	Silty loam, loam, clay	0.2	0.2
3	PBHR	Farm B	Tomato	43.0	Silty clay loam & Silty loam	--	--
4	PROM	Farm C	Corn	50.0	Silty clay & Silty clay loam	0.2	--
5	PBOR	Farm D	Tomato	187.0	Silty loam and Silty clay loam	0.1	--

Similar evaluation methods to those used for the sediment traps were used for the ponds. Inflow and outflow samples were collected and analyzed for the same constituents. We measured sediment accumulation by surveying the ponds before (April) and after (October) the irrigation season. The decrease in storage capacity of the pond was used to estimate the sediment volume accumulated during the irrigation season. The weight of accumulated sediment was estimated by multiplying the sediment volume by the bulk density determined from averaged samples of sediment cores taken from each pond.

The ponds were surveyed with a Nikon DTM 420 Total Station and Sokkia SDR 33 data recorder. Two arbitrary benchmarks were established at each pond site. These benchmarks were used for vertical and horizontal control in both surveys at each site. Measurement points were distributed over the sides and bottom surface of the pond based on the topography of the surface and on a maximum spacing of approximately ten feet between measurement points. The density of measurement points varied from approximately one per one hundred square feet on flat, smooth bottoms to as high as one per ten square feet on hummocky surfaces. The sides of the ponds were surveyed along contours spaced two to three feet vertically. Some ponds still held water when they were surveyed both before and after the irrigation season. For these ponds, the measurements were spaced approximately evenly over the surface using a boat and rod since the soil surface was not visible. Independent measurement points were used for the two different surveys at each site.

The survey data was analyzed with AutoCivil® commercial engineering software. The two surveys for each site were analyzed separately. A digital terrain model was created from the survey data and the volume of the pond below a reference plane was calculated by the program. The

reference plane was created at an elevation one to two feet below the top of the pond. The same reference plane was used for calculating the pond volumes from both surveys at each site. The difference between the calculated volume before the irrigation season and the calculated volume after the irrigation season is reported as the volume of sediment accumulated during the irrigation season. Using bulk density determined for sediment collected in the ponds (Table 11), we calculated the mass of sediment collected in each pond using equation (2).

Mass = Bulk density * Volume ----------(2)

Table 11: Average soil bulk density from each pond

Pond	Avg. Density (kg/f^3)
PMJ	22.95
PMR	Not measured
PBHR	Not measured
PBOR	20.83
PROM	18.26

Following is a description of each of the ponds in this study.

5.1.1. Pond PMJ

This is a small pond with a maximum capacity of 290 yd^3. This pond collects runoff water from a 155-acre field in a processing tomato rotation. The collected water is pumped back to recirculate within the ranch, but it does not return to this same field. This pond is free of vegetation and in its five-year history has never been cleaned out. No sediment trap is associated with this pond, i.e., no location pre-pond that could serve to slow water and entrap sediments.

5.1.2. Pond PMR

This pond has a maximum capacity of 2009 yd^3. Its banks are vegetated with a mix of native grasses including Purple needlegrass, Blue wildrye, and Meadow barley. The pond collects runoff water from a 51-acre sunflower field. There are two inlet drop structures to this pond and water collected is pumped back to the delivery canal albeit downstream of the field inlet. The pond is also five years old and has never been cleaned out. No sediment trap is associated with this pond.

5.1.3. Pond PBHR

This pond collects runoff water from a 43-acre tomato field and a 63.7-acre corn field (Figure 37). There are two inlet drop structures at this pond. Water collected in the pond is recycled to irrigate the tomato field using a pump and a gated pipe irrigation system. This pond has steep sides and is deeper than most other ponds in this study. The top of the west bank of this pond is planted with Creeping wildrye. This pond was constructed three years ago (fall 1998) with a total capacity of 1910 yd^3 (51570 ft^3). It was cleaned out once in fall 1999 because of instability of the north bank of the pond (steep with sandy soil). No sediment trap is attached to this pond.

Figure 37: View south across Tail water pond PBHR

5.1.4. Pond PBOR

This pond collects water from two tomato fields and a sunflower field, a total area of 187 acres. This pond has one inlet flashboard riser, and water collected in the pond is recycled to irrigate the tomato field. Total capacity of the pond is 1130 yd^3. This pond was constructed five years ago and has been partially cleaned once. The farmer estimates that no more than 10 – 15 tons of sediment was removed at that time, but he was surprised by the amount of sediment collected in the pond. No sediment trap is attached to this pond. The pond banks are vegetated with native grasses and sedges.

5.1.5. Pond PROM

This pond (Figure 38) collects water from a 50-acre conservation-tillage corn field and a 20-acre native grass field (totaling 70 acres drained). It has a maximum capacity of 1,832 yd^3. Attached to this pond is the SROM sediment trap (Task 3, Section 4). The inlet drop structure of this pond is the outlet drop structure for the SROM. The pond was constructed two years ago and has never been cleaned out. Water collected in the pond overflows into a ditch, which collects runoff water from other fields. This aggregated drain water is collected further downstream in a large pond from which it is pumped back to the top of the ranch for re-use on any field.

Figure 38: Tail water pond PROM

5.2. Results and Discussion

Table 12 lists the respective volumes of the ponds studied. A reference level of one foot below field level was used to measure volume of all ponds. For some of the pond volume calculations a number of points were added to the survey because we did not survey far enough up the sides of the pond.

Table 12: Calculated tailwater pond volumes

Site	Reference Level (ft)	Pond Volume (yd^3)
PMJ	96.2	290
PMR	99.2	2009
PBHR	96.5	1910
PROM	96.8	1832
PBOR	98.9	1130

Table 13 contains the results of our sediment surveys for the different ponds. Two of the ponds had a negative sediment accumulation, contrary to expectation. At pond PBOR, our surveys were likely not detailed enough to accurately measure the small changes in pond volume that occur over one season. (We measured between two and five percent on the subject ponds.) The PBOR pond provides an example explanation as to why the surveys do not accurately reflect sediment

accumulation. The survey data shows the pond capacity increasing by 40 cubic yards over the season, which is highly improbable considering the lack of a sediment trap upstream and the positive rates of sediment capture indicated in the runoff analysis (Section 5.2.4 below). The surface area that we surveyed was about 8,000 square feet. The forty cubic yards (1080 cubic feet) of sediment spread over the 8,000 square feet of area would be about one and one-half inches thick. It was noted during the spring survey that the pond bottom was lumpy with as much as a four-inch variation within one square foot. To accurately assess the amount of sediment collected during one irrigation season would require a survey of extremely small increments, which was not feasible for this Pilot Program.

Table 13: Calculated volumes of sediment accumulated in each pond

Site	Reference Plane (ft)	Spring Volume (yd^3)	Fall Volume (yd^3)	Sediment Accumulation (yd^3)	Pond Volume Change (%)	Field area (acre)
PMJ	95.00	204	193	+11	-5.39	155.3
PMR	97.00	1116	1088	+28	-2.51	50.9
PBHR	95.00	1517	1550	- 33	+2.18	43.0
PBOR	98.50	1021	1061	- 40	+3.92	50.0
PROM	94.35	836	832	+4	-0.48	187.0

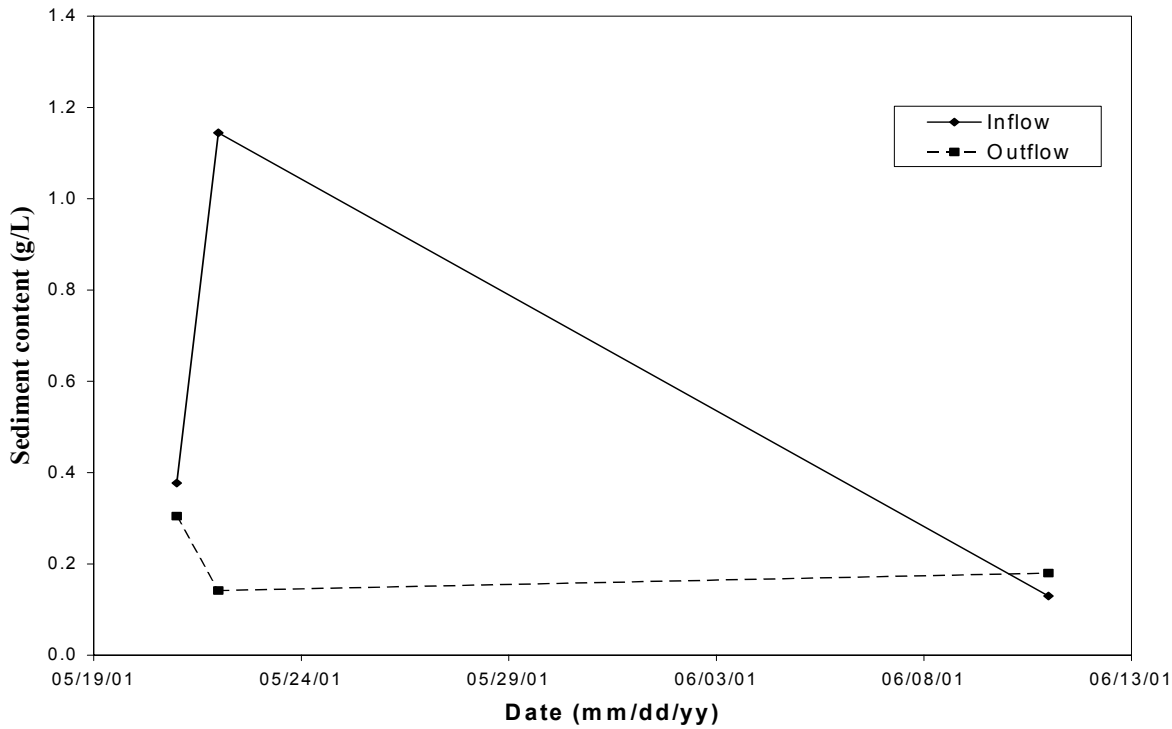


Figure 39: Sediment content in samples collected from the PMJ pond.

5.2.1. Pond PMJ

As presented on Figure 39, the outflow sediment content was lower than the inflow sediment content indicating that the pond was collecting sediment throughout most of the sampling period. The last sample collected shows a different result indicating a reverse behavior towards the end of the season. This might be due to the large amount of sediment collected in the pond becoming mobilized with late season outflow. It is a very slight difference (0.05 g/L) that may be within the margin of error. Table 13 indicates that an estimated 11 yd^3 of sediment accumulated in the pond during the irrigation season that ended in late August.

5.2.2. Pond PMR

Table 13 shows that an estimated 28 yd^3 of sediment was collected in this pond. No sediment trap is associated with this pond. The end-of-the-season pond survey was conducted using a boat since the pond was still full of water. Survey readings using a boat tend to be less accurate due to the soft muddy pond bottoms and instability of the boat. There were only two sampling opportunities for this pond (June 11 & July 1, 2001). On the first date, sediment in outflow exceeded that in inflow by .067 g/L. On the second date it was considerably lower (0.342 g/L in outflow compared to 1.114 g/L and 1.256 g/L coming from the two inlets). Nitrate capture results were equally mixed, while NH_4 and PO_4 results showed reduced concentrations in pond outflow as compared to inflow.

5.2.3. Pond PBHR

Table 13 indicates that no sediment was collected in the pond during the irrigation season. In fact, it suggests that an estimated 33 yd^3 of sediment were removed. This pond also was surveyed with a boat, which resulted in a difficulty locating the precise bottom of the pond, as mentioned above. The depth of this pond, which exceeds 15 ft at one point, added to that difficulty. Outflow samples even at the end of the season had less sediment content than inflow samples, a more precise measurement that contradicts the results of the survey. Because of the capacity of this pond, it did not recirculate water during every irrigation, and we were only able to collect pond outflow results on two occasions. A pond with such capacity as to not require constant recirculation during irrigations provides extended residence time for tailwater, and hence extended time for smaller clay particles and attached nutrients to fall out of suspension. See Appendix C-3 for graphic and tabular data.

5.2.4. Pond PBOR

Figure 35 shows the results obtained from inflow and outflow samples collected from this pond. This figure indicates that sediment content in outflow samples was lower than that in inflow samples. In addition, the sediment concentration in the inflow samples was highest at the beginning of the season. Figure 36 shows the percentage of sediment that was captured in the pond throughout the irrigation season. However, the results obtained from the pond survey show a different result. It was estimated that approximately 40 yd^3 left the pond during the irrigation season. Again, this suggests a problem in the survey technique.

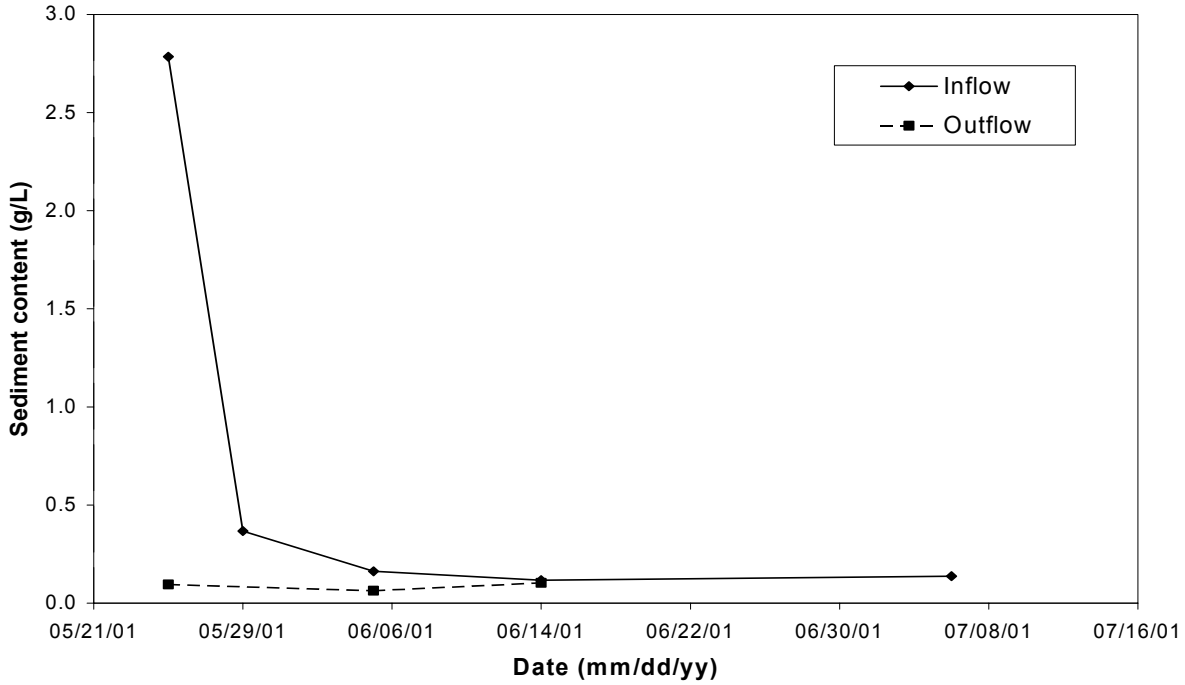


Figure 40: Sediment content in samples collected from the PBOR pond.

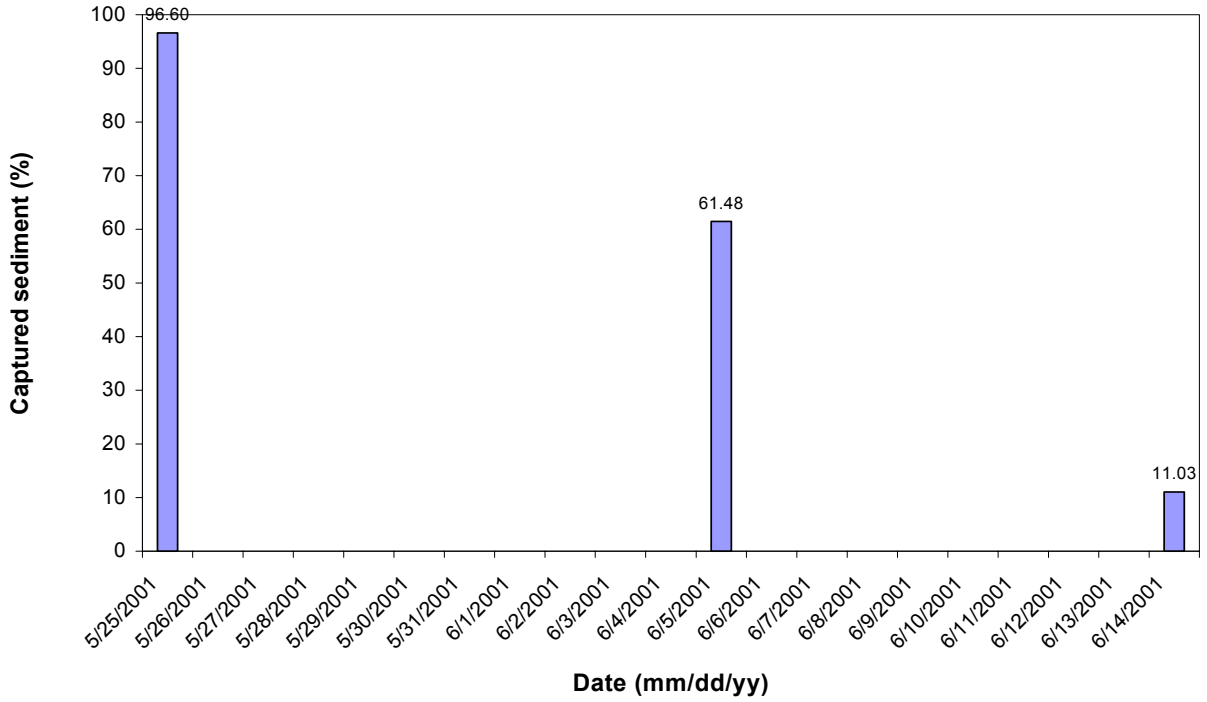


Figure 41: Percent sediment captured in the PBOR pond.

5.2.5. Pond PROM

Figure 42 shows that outflow sediment content was lower than inflow sediment content in this pond. This figure also indicates that the difference between sediment content in outflow and inflow samples decreased with time, likely because tailwater carried less sediment as the season progressed, but it could also be indicative of the pond reaching a sediment capturing capacity or threshold. Figure 43 shows the percentage of inflow sediment that was captured in the pond during the irrigation season. This figure also suggests a decrease in the percentage of sediment captured with time. Survey results show that this pond collected approximately 4 yd^3 of sediment. The small amount of sediment entering the pond is likely a result of the associated sediment trap (SROM, discussed in Task 3, Section 4). intercepting the bulk of tailwater sediment. In addition, the use of canvas dams in the tail ditch to slow water had an additional sediment trapping effect (see Figures 44 and 45). Canvas dams reduce the amount of sediment entering the trap and that eventually reaching the pond.

Estimation of the cumulative sediment and nutrient trapping effect of the PROM pond and SROM sediment trap is only possible for sampling dates common to both of them. In Table 14, below, the inflow data for the sediment trap and outflow data for the tailwater pond are contrasted for selected dates. As evident in the table, sediment entrainment is apparently enhanced by the double pond system, and Nitrate-N was lower coming out of the two-pond system on two of the three sampling dates. Ammonia-N and Phosphorous concentrations were not beneficially affected, however. It is possible that the increased residence time in the tailwater pond could encourage algae growth and as a result, increase nutrient concentrations in the water leaving the pond.

Table 14: Changes in sediment and nutrient content associated with the SROM/PROM trap and pond complex.

Sample Date	Trap Inflow Sediment Content (g/L)	Pond Outflow Sediment Content (g/L)	% Reduction in sediment content
5/14/01	9.426	0.028	-99.7%
5/15/01	0.052	0.028	-46%
7/26/01	0.631	0.065	-89.7%
Sample Date	**Trap Inflow Nitrate-N Content (mg/L)**	**Pond Outflow Nitrate-N Content (mg/L)**	**% Change in Nitrate-N content**
5/14/01	1.921	1.944	+1.2%
5/15/01	1.910	1.598	-16.3%
7/26/01	0.727	0.359	-50.6%

Sample Date	Trap Inflow Ammonia-N Content (mg/L)	Pond Outflow Ammonia-N Content (mg/L)	% Change in Ammonia-N content
5/14/01	12.413	13.677	+10.2%
5/15/01	14.419	14.677	+1.8%
7/26/01	.051	0.227	+345.1%

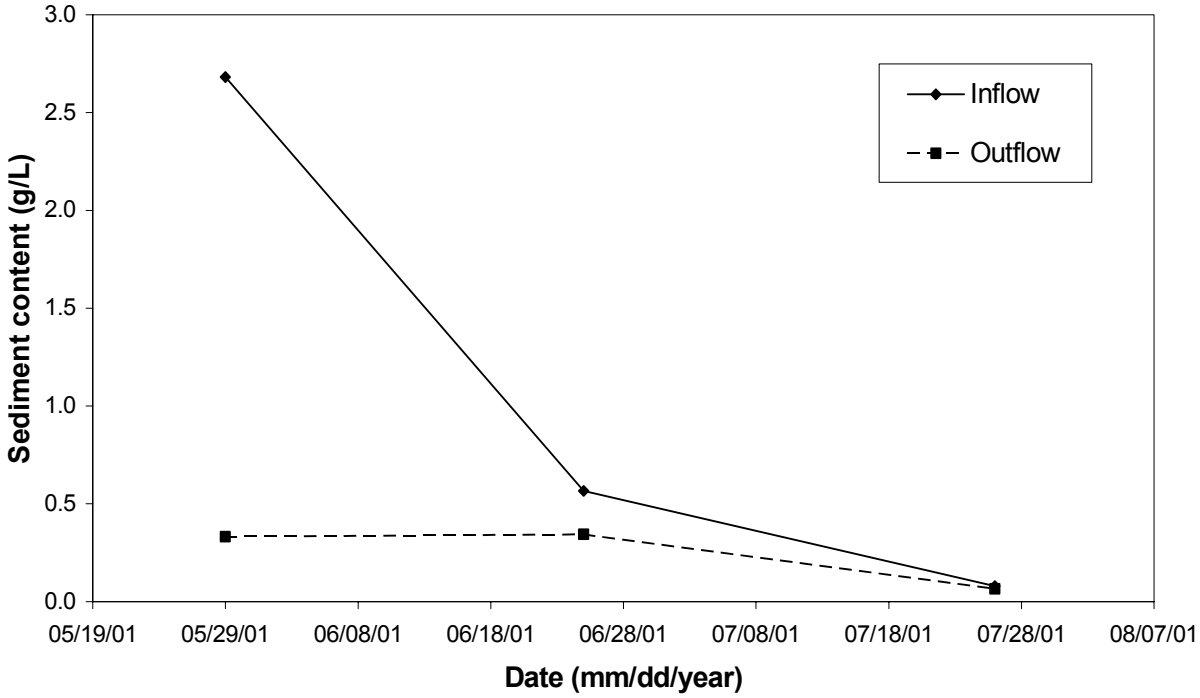


Figure 42: Sediment content in samples collected from the PROM Pond.

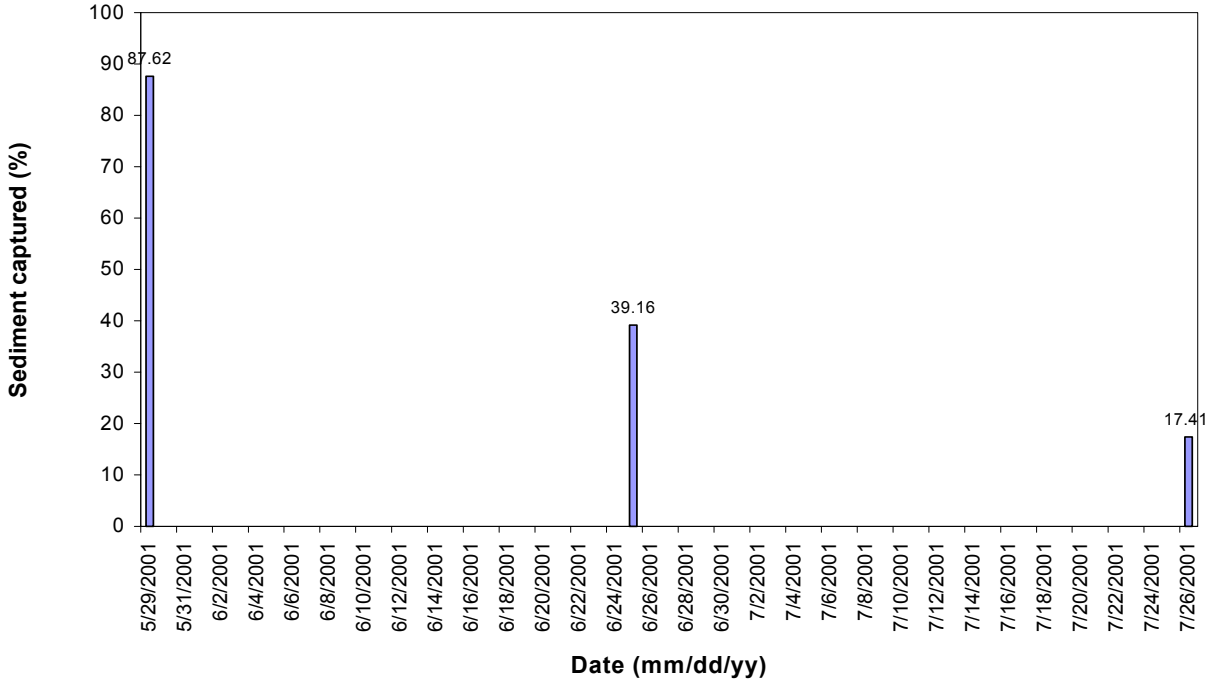


Figure 43: Percent sediment capture in the PROM Pond.

Figure 44: Canvas dams slow the tailwater and allow the collection of sediment before it reaches the sediment trap and/or pond

Figure 45: Tail ditch showing ponded water behind canvas dams.

6. Monitoring Soil Water Content

6.1. Methods and Materials

While a given irrigation evaluation is fairly simple to undertake, assessing season-long irrigation efficiency is much more challenging. This involves an evaluation of the farmer's irrigation scheduling technique, contrasting the timing and amount of water applied with the estimated crop water requirement or use. The California Irrigation Management Information System (CIMIS) provides the least labor-intensive method for estimating crop water needs based on a formula incorporating factors such as regional reference evapotranspiration rates, soil types, and unique "crop coefficients" for different crops. To gain more precise information about crop water use and availability in a given field, soil moisture sensing devices running the gamut of technology from tensiometers ($100) to neutron probes ($5,000) can be employed. This is considerably more costly in terms of labor and materials, especially in the case of neutron probes, but depending on the value of the potential improvement in irrigation efficiency or water management, the cost could be justifiable to the District.

District personnel have employed simple gypsum blocks on numerous farms over the past two decades with varying results. The blocks were relatively simple to install, and cost the RCD approximately $5-10/block and requiring roughly 8 man-hours to employ four stations (average three blocks per station) in a field with accommodating soil conditions. In an annual cropping setting, blocks are typically only good for one season, as it is cost-prohibitive to recover them. They also do not always register soil water effectively. During this Pilot Program the District employed WaterMark® sensors, a modified type of gypsum block, to measure soil moisture content at three different fields.

Three tomato fields were selected for the installation of the Watermark®[1] soil water sensors. In each field sensors were placed in two rows. In each row three measurement points were selected: close to the furrow head, midpoint, and tail end. At each of these points three sensors were installed at 1', 2', and 3' below the soil surface, a total of eighteen sensors installed in each field. These depth locations were determined based on published information[2] about the relative soil water use of tomatoes at different root zone depths (Table 15). The taproots of seeded tomato plants can go as deep as 36". Typically, the majority of water is extracted between the 0" and 24" level as also shown below.

Table 15: Percentage of water extracted at different levels of the tomato root zone (see footnote #2)

Depth of root zone (inches)	Water extracted at this level (%)	Cumulative water extracted (%)
0 - 9	40	40
9 – 18	30	70

[1] Disclaimer: Watermark® is the name of a commercial product, and Yolo County Resource Conservation District has no preference for any particular soil moisture sensor over another.

[2] Hobbs, Bryan B. "Drip Irrigating Tomatoes in the Southeast." *Crop Focus*. 1999. http:www.greenindustry.com/ij/1999/499.asp.

18 – 24	17	87
24 – 36	13	100

The Watermark® sensor is a relatively new style of electrical resistance block. The electrodes are embedded in a granular matrix material, which approximates compressed fine sand. A gypsum wafer is embedded in the granular matrix near the electrodes. A synthetic porous membrane and a PVC casing with holes drilled into it hold the block together. The granular matrix material enhances the movement of water to and from the surrounding soil, making the block more responsive to soil water tensions in the 0 to 100 centibars (cb) range. Watermark® blocks exhibit good sensitivity to soil water tension with a range from 0 to 200 cb. This makes the Watermark® sensors more adaptable to a wider range of soil textures and irrigation regimes than standard gypsum blocks.

Readings are taken by attaching a special electrical resistance meter to the wire leads and setting the estimated soil temperature. The Watermark® meter gives readings in centibars of soil water tension similar to a tensiometer. Watermark® blocks require little maintenance and can be left in the soil under freezing conditions. The blocks are much more stable and have a longer life than standard gypsum blocks. Soil salinity affects the electrical resistivity of the soil water solution and may cause erroneous readings. The gypsum wafer in the Watermark® blocks offers some buffering of this effect.

Following is a description of each of the three fields in which sensors were installed. The three fields studied are identified as A1, B1, and D1 and are located in Farms A, B, and D of this Pilot Program respectively.

6.1.1. Field A1

This is a 38-acre tomato field with a furrow irrigation system. Soil moisture sensors were installed on June 21, 2001 at six locations, at three different depths in each location. Readings were taken before and after each irrigation. This field was one of a pair of fields that were managed by the same irrigator. Irrigations were alternated between the two fields. Each irrigation lasted 48 hours and only covered every other furrow of the field. One-inch diameter siphons were used to deliver water to the furrows.

6.1.2. Field B1

This is an 80-acre processing tomato field with a furrow irrigation system. Irrigation water is delivered to furrows using siphons, either 2” and/or 1” in diameter. Soil moisture sensors were installed in two rows on June 19, 2001. While the first foot of soil was similar in both the studied rows, soil texture varied below that point, with the first row having sandy subsoil, and the second having a clayey subsoil. The farmer’s characterization of the subject field is that of one with slow water movement, heavy soil, low infiltration, and patches of alkalinity. Near the end of the irrigation season, four more stations (12 Watermark® sensors) within the alkaline areas of the field were added to provide additional data (see Appendix).

6.1.3. Field D1

This is a 75-acre processing tomato field with a furrow irrigation system. Siphons are used to deliver water to furrows. Siphons used on this field have a smaller diameter than those used on the previous two fields; ½" and/or ¾" diameter tubes were used. Irrigation duration on this field varied between 72 – 96 hours. Sensors were installed on June 20, 2001 and monitored before and after each irrigation.

6.2. Discussion and Results

Below are general observations made from working with the Watermark® sensors

- The installation process is the most critical step. It should be uniform and consistent as far as the depth of the sensors, degree of re-compacting the soil, location of the sensors in the furrow (middle or on the side).
- Installation process was lengthy; digging the holes was the toughest part. Installing three sensors (at each station) took approximately 45 minutes.
- Attaching each sensor to a piece of PVC pipe proved to be beneficial. This made the installation process much easier, and also made recovering the sensors at the end of the season very easy. To minimize the potential for preferential flow along the pipes to the sensors, care was taken to compact soil around the sensors and pipes and ensure that the pipe openings extended well above the soil surface. Removing the sensors from the soil took only minutes for each station.
- In general, sensors were as easy to install as gypsum blocks and worked properly throughout the season. The Watermark® sensors are considerably more expensive ($29 each) than standard gypsum blocks ($5-10 each), as is the associated meter ($275 versus $150), but rigging them for recovery as described above helps recover some of the increased cost, and the meter reads in actual centibars of water tension instead of a relative 0 to 1 moisture scale. With attached pipes, a 1300'-long field with six stations and sensors at three depths per station cost $550 and 12 man-hours to install.
- Sensors were installed at the center of the planting beds. It might have been better if they had been installed at the edge of the beds for two reasons. First, in the case of Field D1 we might have been able to detect moisture from applied water. Second, in the case of later season irrigations, which were typically shorter in duration and had a lower inflow rate to the field, sensors did not detect any moisture from these irrigations. If they were installed at the edge of the furrow this might have been different.
- The sensors were installed at 1, 2, and 3 ft below soil level. This meant that the 1st sensor reflected the condition of the top 1.5 ft of the soil, which is the most critical to plant growth. It was suggested that it is better to install the sensors at 0.5, 1.5, and 2.5 ft below soil level. That way each sensor would represent 1 ft of the soil.
- The soil moisture meter that was used to read soil tension was very easy to use. It was also very easy to calibrate when necessary. Calibrating for temperature is similarly simple.

6.2.1. Field A1

Results from this field are shown in Figures 46 and 47. Each figure contains the averaged sensor readings of the three stations along each subject row at the three designated depths. Irrigation events and average volume of irrigation water applied are indicated with arrows and points corresponding to the right side vertical axis. Irrigations until mid July lasted 48 hours during which every other furrow was irrigated. Later season irrigations were shorter (24 hrs long), but the sensors never registered a change in soil moisture from those latter irrigations. Soil tension was kept below 50 centibars for the most part during the season except towards the end when the farmer started preparing the field for harvest.

Apparent distribution nonuniformity was indicated by sensor readings that suggested that more water infiltrated at the furrow head than at the mid point and tail end locations.

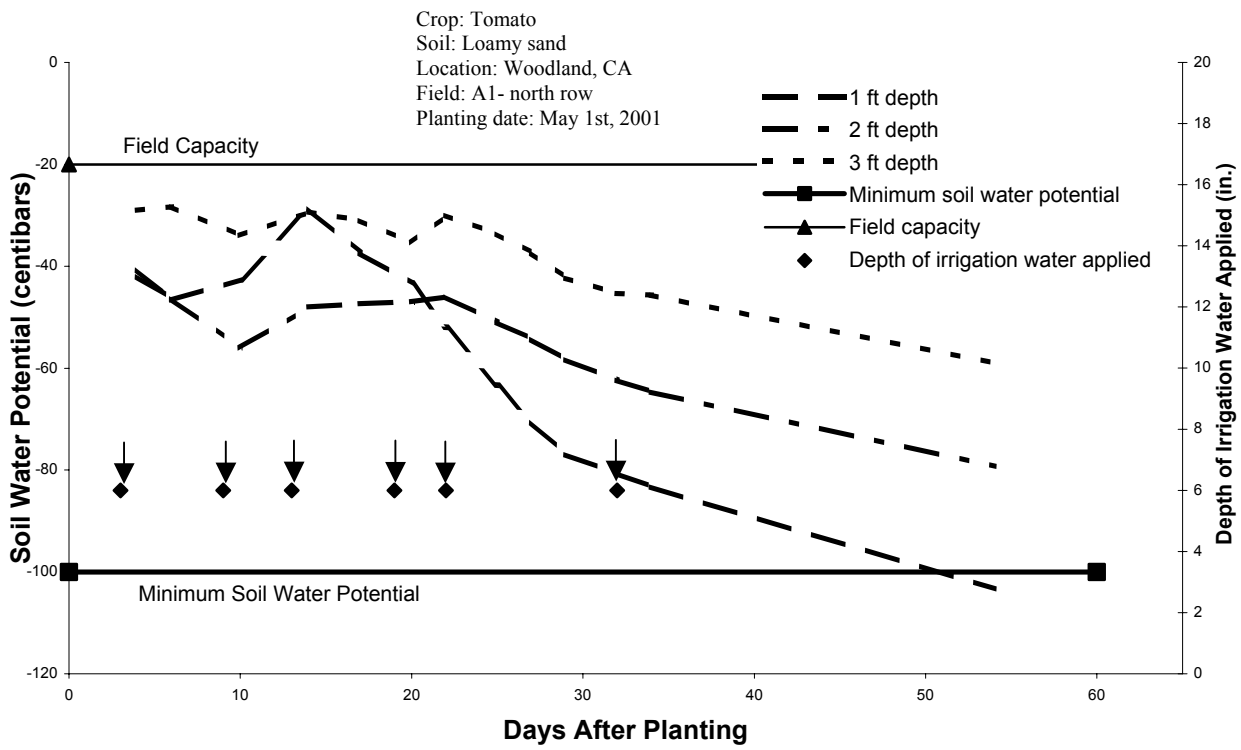


Figure 46: Soil water potential from sensors at three different depths in North row of Field A1.

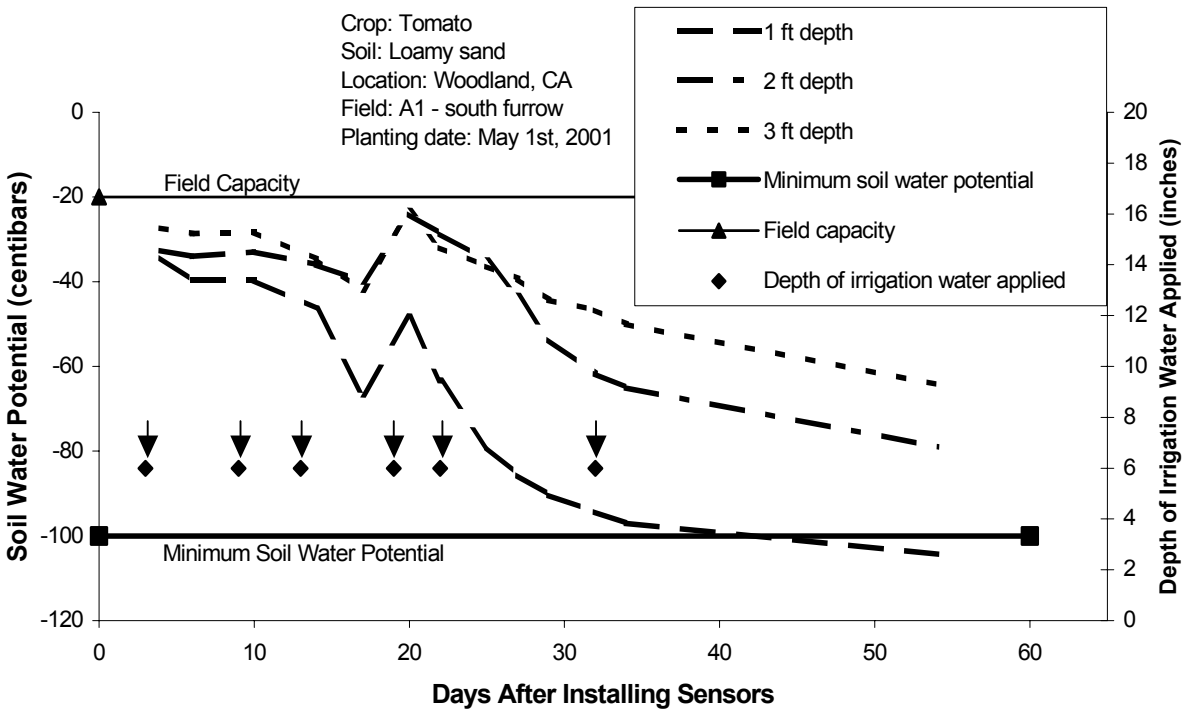


Figure 47: Soil water potential from sensors at three different depths in South row of Field A1.

6.2.2. Field B1

Results from this field are shown in Figures 48-49. Each figure contains aggregated sensor readings from the three stations along each subject row at the three designated depths.

Figure 48 shows results from the southern row. These figures show soil tension in this furrow remained below 30 centibars for most of the season. Soil tension dropped to zero after each irrigation indicating soil reached the saturation point. Soil remained saturated for a few days after the irrigation in some cases. It was noted during sensor installation that soil was a very hard clay, which might explain this behavior.

Figure 49 shows the results from the northern row. It should be noted that water didn't reach the 2-foot and 3-foot depth sensors, which explains the continuous increase of soil tension throughout the season. The two irrigations observed (not evaluated) on this row can be clearly identified from the 1-foot sensor readings. In addition, these irrigations are more apparent from the sensor reading in the field head locations and become less so in the downstream direction. This indicates a typical non-uniform irrigation pattern in which water infiltrates deeper near the furrow head than the furrow mid and tail end points because of greater opportunity time.

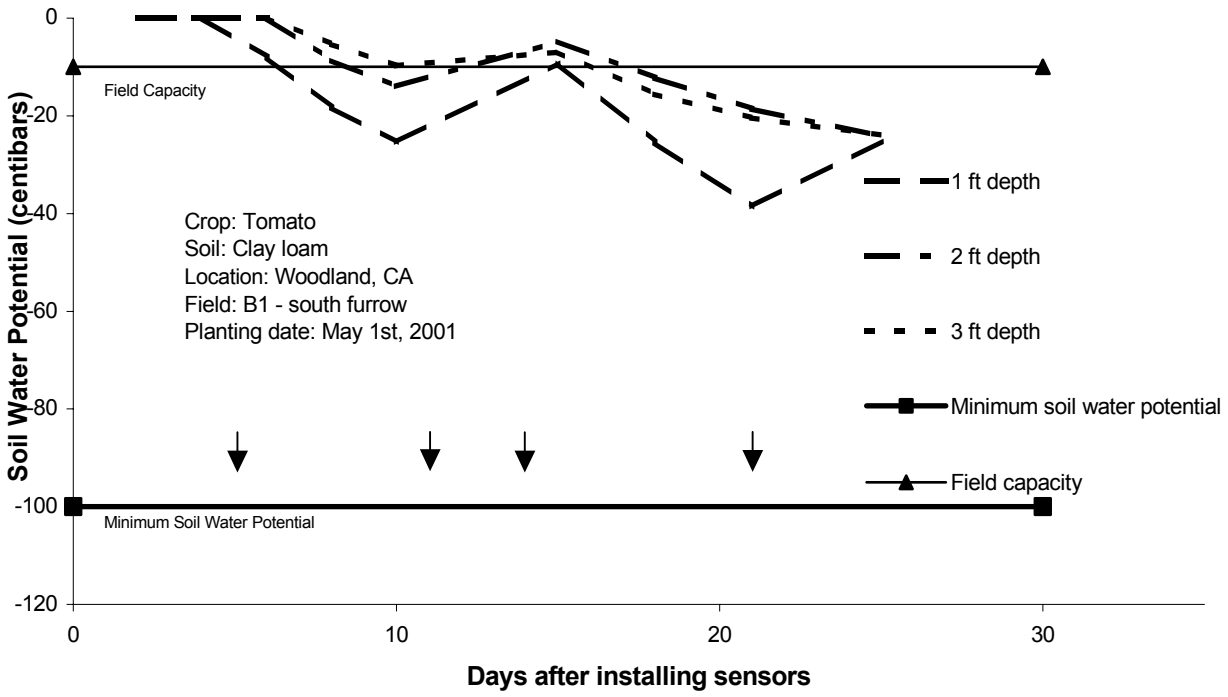


Figure 48: Soil water potential from sensors at three different depths in South row of Field B1

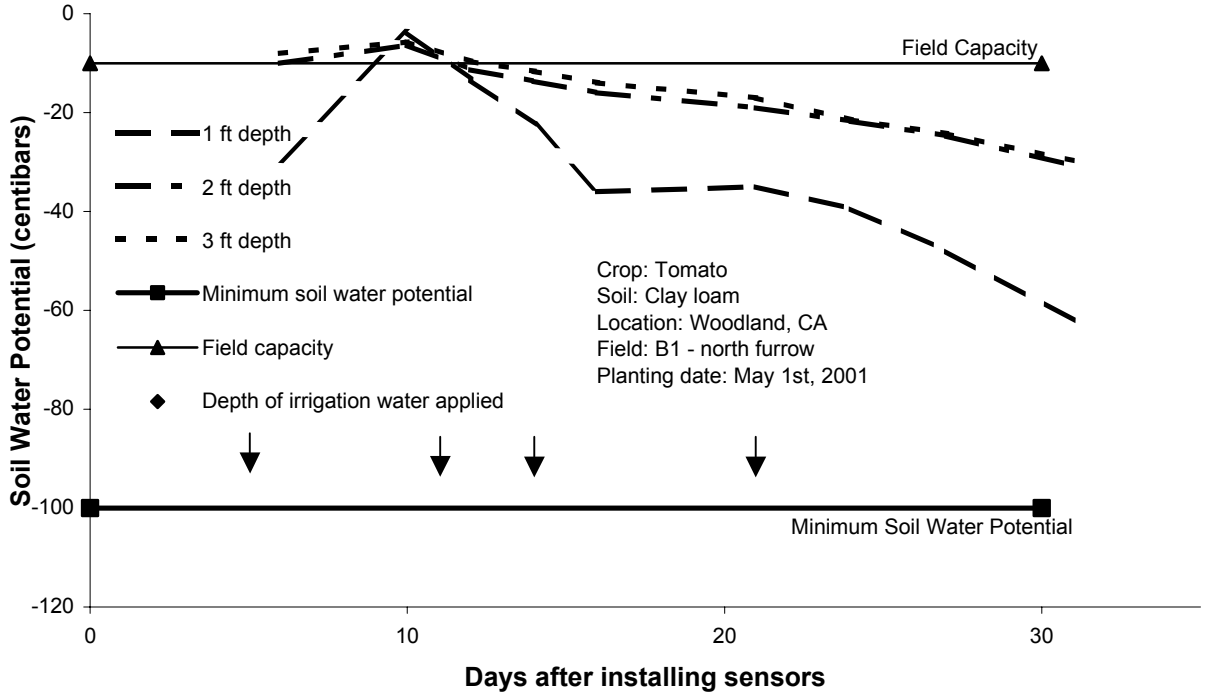


Figure 49: Soil water potential from sensors at three different depths in North row of Field B1

6.2.3. Field D1

Results from this field are shown in Figures 50-51. Each figure charts sensor readings for one of the six stations. No irrigation events are apparent from these figures suggesting that applied water never reached the sensors at the bed middles throughout the season. The crop did not seem to suffer from water stress suggesting that roots were able to reach water (likely away from the bed middles). Close inspection of one station showed that soil moisture content within the top six inches of the soil decreased from the edge towards the center of the bed. Water not reaching the sensors could also be attributed to poor sensor installation. Another reason might be minimal lateral water movement across the soil. District personnel had a similar experience with a gypsum block study in this same field in 1997. Further study of this field is needed to determine the nature of water movement within the soil.

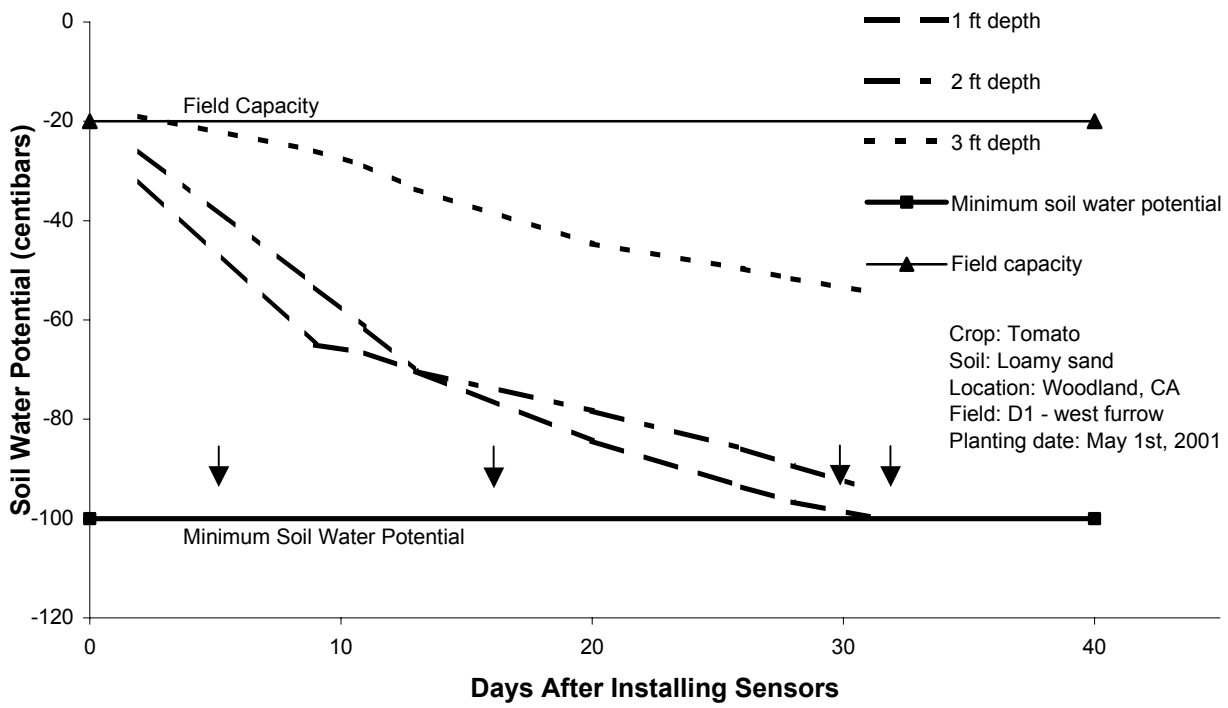


Figure 50: Soil water potential from sensors at three different depths in West row of Field D1

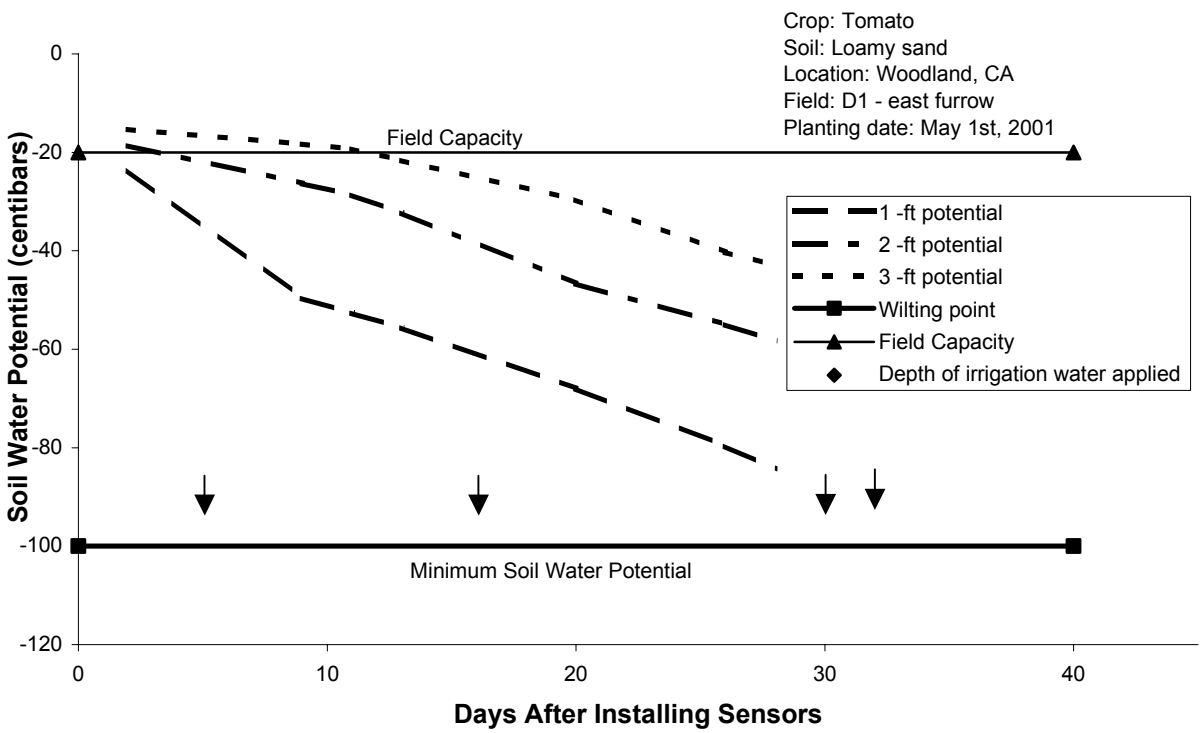


Figure 51: Soil water potential from sensors at three different depths in East row of Field D1

7. Irrigation evaluations

The efficient application of irrigation water offers great potential water savings for the agricultural sector. Assessing that efficiency involves a range of techniques, such as those promoted by the Irrigation Technology Resource Center (ITRC) at Cal Poly San Luis Obispo. Our goal under this portion of Task 3 was to employ their techniques on at least two different fields in Yolo County to assess the cost and usefulness of the information generated in coordination with installation of soil water sensors.

7.1 Methods and Materials

Irrigation Evaluation

The following input data were needed to run the evaluation software.

1. "System Description": specify type of the furrows (sloping or not) and the water delivery method to furrows (open ditch, gated pipe, etc.).
2. "Basic Information":
   - Flow rate into field
   - number of days flow is applied
   - number of furrows irrigated at once
   - typical furrow length
   - total field irrigated area
   - distance between wet furrows, and
   - wetted perimeter.

   The software usually gives two options for units, so the user must be careful entering the numbers and knowing what units are they in.
3. "Set time information" which should be for both a wheel and a non-wheel furrow. Three advance points are required only (furrow head, midfield, and tail end of furrow). This is very simplistic actually. We measured every 200ft/100 ft depending on the field. However, that is not needed for the software purposes.
4. "Tailwater Information" which includes destination of tailwater such as (recovered elsewhere, circulated, not recovered at all, etc.)
5. Additional information is needed about the ratio of wheel to non-wheel furrows, soil types, and method used to determine shut off time.

When all the required input data is entered the user can run the program, which provides a short output summary that includes the following:

- The LQ Minimum Infiltration which is the low quartile distribution uniformity
- the collected runoff as a percent of the total applied water
- the rating of infiltration strategy, and
- the percent of non-uniformity due to advance time, variation in set time, wheel and non-wheel rows, and variation in soils.

Each irrigation evaluation consisted of three major parts: 1) measuring the rate of water inflow into furrows, 2) measuring the rate of runoff water from the field, and 3) measuring the water advance rate across the field.

Flow Estimation

We considered two means available for measuring flows in-furrow: 1) Flumes placed near the top and tail of furrows, and 2) Estimating flow through siphon tubes. For the first technique, the RCD staff used small RBC (Replogle Bos Clemmens) flumes to measure furrow flow rates during two irrigation evaluations this season but found them to be a fairly time-intensive technique with problems such sediment accumulation (which might have affected the accuracy of depth readings measured) and water seepage under the flumes (see Results section). As a result, the second technique, estimating flow rate through siphons using a volumetric approach, was the primary technique used to estimate inflow during the irrigation evaluations conducted in the pilot project. The volumetric approach was found to be simple, requiring only a stopwatch and a container of known volume, and took considerably less time per measurement and per furrow than flume installation and measurement. As with the latter, many furrows were required to generate a representative average for field inflow.

Figure 52: A typical siphon-fed, furrow-irrigated tomato field

Inflow rate into furrows was measured on a volumetric basis. Siphon inflow rate was measured many times throughout the irrigation (48 – 72 hours long depending on the field). Water was collected in a gallon size container and time to fill the volume was recorded. Wheel and non-wheel furrows were monitored throughout the irrigation. When different sizes of siphons were used, water was collected from both sizes and an average value was determined for each size. The total field inflow rate was then computed based on the total number of siphons from each size. Finally, field inflow volume was computed based on the duration of the irrigation.

Runoff rate from the field was measured using a contracted, rectangular notch weir. Original fabrication of each weir by a local company cost $65. Water depth on top of the weir crest was measured using the 900 MAX PORTABLE SAMPLER. The sampler utilizes a submerged pressure transducer to measure head in an open channel flow stream. The submerged probe was mounted just upstream of the weir. As the level in the drain ditch increased and decreased, the pressure at the submerged probe varied proportionately. The pressure transducer converted the water pressure to a voltage, which was then used by the 900MAX to calculate the liquid level in the channel. After

calculating the level, the 900MAX then converted the level reading to a flow rate based on the user-defined characteristics of the primary device through which the stream flowed, rectangular notch weirs in the case of the two fields evaluated below.

Advance rate across furrows was measured in 100 ft (Field A1) or 200 ft (Field D1) increments and was found to vary between wheel and non-wheel furrows.

Irrigation evaluations were completed on two separate tomato fields under furrow irrigation. In both fields, siphons were employed to deliver water into the furrows. However, each field (identified in this report as A1 and D1) had a different irrigation pattern. On field A1, alternating furrows were irrigated at one time, and the remaining furrows were irrigated 2-3 days later. Field D1 was divided into four sets. All furrows in each set were irrigated at once. Irrigating the entire field took 4-5 days. What follows is a description of the work done on each of the fields.

7.1.1. Field A1

Field A1 is a relatively small field (38 Acres), described in earlier in Task 3, Section 6.1. Water is pumped into the irrigation ditch from a canal that flows parallel to the field on the western side. Water from the irrigation ditch is then delivered to furrows using siphons. The irrigation ditch has a constant head device (ditch trap), which keeps the water level constant throughout the irrigation. The irrigation time for the furrows evaluated was 48 hours. This particular irrigation was evaluated from 6:30 am on July 9th, 2001 through 6:30 am on July 11th, 2001.

Inflow to the field was initially measured in two ways. Initially, RBC flumes were placed in the furrows and flow estimated by measuring water levels. District personnel also estimated flow using the volumetric siphon discharge rate. Results presented for this evaluation are based on the second method, because it was found to be more accurate and less labor intensive. RCD staff measured the volumetric discharge rate of twelve siphons throughout the 48-hour period. Values were used to calculate the total inflow volume to the field.

Outflow (runoff) from the field was measured using a rectangular notch weir along with the 900MAX PORTABLE SAMPLER by American Sigma (Figures 53-55). This device was used to record water level with a pressure transducer and also to collect runoff samples every two hours. Water level values were then used to calculate the volume and rate of the runoff.

Figure 53: Runoff measurement using a rectangular notch weir, a pressure transducer, and the 900MAX PORTABLE SAMPLER by American Sigma

Figure 54: A closer look at the weir arrangement

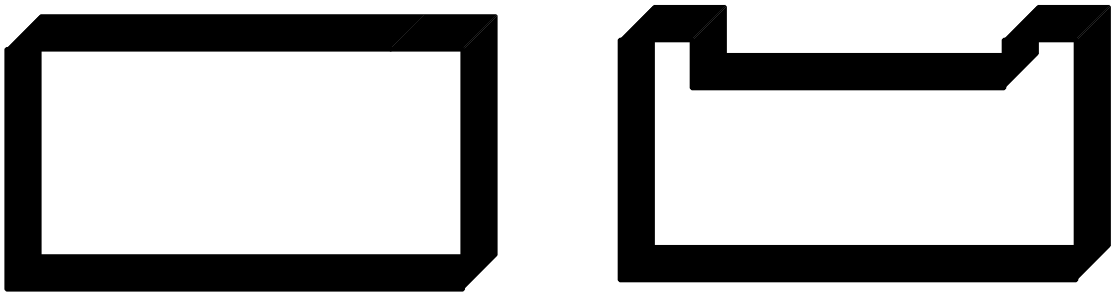
Figure 55: A side view of the weir arrangement

7.1.2. Field D1

Field D1 is a 75-acre tomato field that is divided into four sections. Either one or two sections can be irrigated at any one time. Water is pumped into the irrigation ditch from either the irrigation canal or the tailwater pond. Irrigation duration can last from 48 – 72 hours on each section of the field. Water is delivered to the furrows via ½-inch and/or ¾-inch diameter siphons, which are smaller in diameter than the ones used on Field A1 tubes were used. Field D has a much longer run (1250 ft long) compared to Field A (600 ft long), and is believed to have a lower infiltration rate.

Inflow to this field was determined by measuring siphon discharge rates throughout the irrigation. Fourteen siphons were monitored from the 4 sections.

At this site in-ditch weir installation was problematic because the ditch was already wet and we could not establish a sufficiently adequate "seal" around the weir to prevent runoff water from escaping under or around the structure. In response, RCD staff modified a flashboard to serve as a rectangular notch weir in the existing drop structure to measure 0utflow (runoff) from the field paired with the 900MAX PORTABLE SAMPLER. The weir was designed from two pieces of ½" plywood attached together to form a 1" thick piece so that it would fit tightly in the flash board structure in field D1 as seen in Figure 56 on the following page. A rectangular notch was then cut into the board (using a circular saw) as seen below. The horizontal portion of the cut mitered to a 45-degree angle to create the sharp edge effect needed in weirs.



The weir was designed based on information obtained from the following web site:

http://www.egr.msu.edu/~northco2/BE481/Weirs.htm

The formula used for estimated flow over a rectangular contracted weir was:

Q = 3.3 H 3/2 (L-0.2H)

The process of design was easy and construction was inexpensive ($50 in materials and 5 man-hours). The weir was used successfully in the field with no problems. Determining the runoff rate over the weir was accomplished with the 900MAX sampler, which measured the depth of water on top of the weir notch. This method introduces less error than using the regular flashboards that are found in the fields. This device was used to the record water level on top of the pressure sensor and also to collect runoff samples every two hours. Water level values were then used to calculate the volume of runoff.

Figure 56: Modified flashboard riser (Rectangular notch weir) installed at field D1

Figure 57: Pressure transducer can be seen on the right and the water sampling intake tube can be seen on the left

7.2. Discussion and Results

Surface Flow Measurement

While it was possible to get fairly accurate measurements of flow through the RBC flumes, variations in flow between furrows is so high that to provide any representative accuracy for a given irrigation, the flumes need to be employed in fairly high numbers. This requires considerable installation time even with ideal (slightly moist, no large clods) soil conditions. For a personnel-strapped organization such as an RCD or farmer, this is a limiting factor for its application.

In general, estimating total field inflow by measuring individual furrow flow rates has limitations. Using flumes or estimating siphon flow rate both share the common problem of variability in furrow/siphon flow rates. As expected, we observed that inflow rate into furrows has considerable variation across the field. Variation results from the different random positioning of siphons, which causes the available pressure head to differ from one siphon to another. Siphon flow rate was found to be very sensitive to that variation. In addition, clogging of siphons by debris caused some siphons to have much lower inflow rates. As a result, and in order to obtain an accurate estimate of field inflow rate one needs to monitor a high number of siphons throughout the irrigation. The time required to that is a major cost for this method.

If it is possible, measuring total field inflow or application rate by other means than measuring furrow flow rate is preferable because it negates the issue of variability in furrow flow rates. However, in the case of surface irrigated systems using ditch-delivered water, deep percolation of

head ditch water, water remaining in the ditch when irrigation is over, and water escaping the ditch when and if it breaks are limitations to "pre-furrow" flow estimation.

In measuring tailwater flow with an installed weir, care must be taken not to create such a large stilling basin as to cause ponding in the furrows upstream. With a crop such as processing tomatoes, this could exacerbate soil disease problems.

Propeller and Doppler Flowmeters

The simplest and most accurate means of flow measurement is with a flowmeter attached to a pump outlet or delivery pipe with full flow. Two options we considered during this project were those of propeller and Doppler flow meters. While a propeller flow meter can be set in an open ditch with a known cross-section to estimate flow within the ditch, we considered that technique inferior to that of a weir and water level sensor. However, a simple propeller meter for use in an open ditch for discrete readings can be purchased for approximately $1,000. More elaborate propeller flow meters with data loggers for continuous measurement cost considerably more ($1800—both prices from McCrometer). However, given that unlined ditch cross-sections are both irregular and unstable, a more reliable measurement is likely gained from a weir or flume structure.

While more than one of our evaluation sites utilized pumps and pipes for water delivery and recirculation, we were unable to find desirable locations on them for installation of an in-pipe meter. Our limitations were inadequate lengths of straight sections of pipe that maintained pipe-full flow. With a more involved project or more time, we could have modified certain pipes to include a positive slope or vertical dogleg to encourage pipe-full flow. A typical propeller meter for an 8" inside diameter pipe costs between $770 and $1110 with an additional installation cost range of $50-$500. A Doppler meter, which has essentially no installation cost because it can simply be attached to the outside of a given pipe, costs nearly $4,000. The benefit of the latter meter is that it can be used for multiple sites and different pipe sizes very easily, potentially costing less per evaluation site than a propeller meter. The model by Greyline includes a data logger with continuous recording. The primary limitation of a Doppler meter is that it requires some impurities in the water to read its flow, and so does not read reliably with very clean water (such as that coming from many wells).

Irrigation Evaluation

The irrigation evaluation protocol and software developed by the ITRC is employed by many if not most irrigation mobile labs in California, and we found it useful for application on our project sites. Our primary challenges in collecting data for these evaluations were measuring inflow and outflow on the subject fields. In general, the software was found to be user friendly, and most data needed to execute the program is easy to obtain. A perceived weakness of the program is that it will not run if any one piece of data is missing. Inputting a best estimation of the unknown data can circumvent this problem, however that could compromise the quality of the evaluation.

While many irrigation mobile labs provide such evaluations free of charge to the farmer, they do require labor time and equipment. This can be generalized with the quoted cost of such an evaluation as performed by a private contractor: approximately $650 per irrigation evaluation. This incorporates overhead costs, equipment depreciation, field time and analysis time. In the case of this Pilot Program, a typical evaluation for a 24-hour irrigation set required about 30 man-hours at a cost of about $35 per hour (billable rate estimate), or $1050 total. This includes inefficiencies in our

technique as District field staff were still learning the process and experimenting with different flow estimation techniques while performing the evaluations.

The following sections summarize the data and result summaries from the two fields evaluated using the ITRC software.

7.2.1. Field A1

7.2.1.1. General Information

System Description

- Type of furrow: Sloping
- Water delivered to furrows by: Open ditch

Basic information

- Flow rate going into field = 2,121 GPM
- Number of days flow is applied = 2
- Number of furrows irrigated at once = 168
- Typical furrow length = 1,000 ft
- Total field irrigated area = 19.2 acres
- Distance (center-to-center) between wet furrows = 5 ft
- Wetted perimeter of the wetted furrow = 9 in

Set Time Information

Number of hours for:	**Wheel row**	**Non-Wheel row**
Water applied to head of furrow (hrs)	48	48
Advance to midfield (hrs)	1.3	0.8
Advance to tail end of furrow (hrs)	3.2	2.3
Extra hours past shutoff that:		
Water sits at the head end of the furrow before disappearing	0.1	0.1
Water sits at midfield before disappearing	0.1	0.1
Water sits at the tail end before disappearing	0.1	0.1

Tailwater Information

- Destination of tailwater = Recovered elsewhere
- Do you know the percentage of applied water that ran off the field? YES
- If so, what is the percentage of applied water which ran out of field (%) = 28

Wheel Row Information

- Are only wheel row or only non-wheel rows irrigated? No
- Is every other furrow a wheel row? No
- How many furrows form a group of non-wheel, wheel, and guess row furrows (a repeatable pattern determined by the tractor tool bar width): 3

- How many of those are wheel row: 2
- How many of those are non-wheel or guess row furrows (the total of these two must equal the group total): 1
- Assume that a non-wheel row has a relative intake rate of 1.0. The wheel rows have a lower relative intake rate of … (the answer must be between 0.0 and 1.0): 0.5

Soils

- Soil type = Loamy Sand (Relative Depth Infiltrated = 5.0)
- Percentage of the field with this soil type = 100%
- Does this field have a distinct cracking-clay soil that seals up? No

Method Used to Determine Shut off

- Past History

Furrow Evaluation Results

- LQ Minimum Infiltration / Average Infiltration = 0.86
- Percent of Non-Uniformity due to:

  Advance Time (single furrow): 9
  Variation in set time: 2
  Wheel row/Non-wheel Row: 89
  Variation in soils: 0

- Collected runoff as a percent of Total applied = 28%
- Rating of Infiltration strategy = GOOD

7.2.1.2. Advance Curves

Irrigation water advance in this field was measured at 100-ft increments in four different furrows. Total length of the furrows was approximately 1000 ft as seen in Figure 58. Furrow numbers one and three were wheel furrows while furrow numbers two and four were non-wheel furrows. See Table 16 for results. In the example of furrow nos. 3 and 4, irrigation started at 6:40 am. It took the water 3 hours and 25 minutes to reach the tail end of the wheel furrow (furrow no. 3), while it took 2 hours and 25 minutes for water to reach the tail end of the non-wheel furrow (furrow no. 4). Wheel furrows tend to have lower infiltration rates than non-wheel furrows, thus it is expected that wheel furrows would have a faster advance rate. This is true however, only if the inflow rate is the same for both furrow types. This was not the case here because the irrigator used one siphon for wheel furrows and two siphons for the non-wheel furrows. This was done until water reached the tail end of each furrow and then the second siphon was pulled from those furrows.

Table 16: Advance time of irrigation water across four different furrows

Furrow #	**1**	**2**	**3**	**4**
Furrow Type	**Wheel**	**Non-wheel**	**Wheel**	**Non-wheel**
# of siphons	**1**	**2**	**1**	**2**
Location in field	**South**	**South**	**North**	**North**
Distance (ft)	**Time** (hh:mm:ss)	**Time** (hh:mm:ss)	**Time** (hh:mm:ss)	**Time** (hh:mm:ss)
0	10:30:00 AM	10:30:00 AM	6:40:00 AM	6:40:00 AM
100	10:41:35 AM	10:35:55 AM	6:44:40 AM	6:45:25 AM
200	10:59:30 AM	10:45:15 AM	6:46:00 AM	6:57:00 AM
300	11:21:15 AM	10:55:25 AM	6:58:05 AM	7:05:10 AM
400	11:43:45 AM	11:06:20 AM	7:11:40 AM	7:14:49 AM
500	12:18:55 PM	11:19:20 AM	7:26:30 AM	7:24:07 AM
600	12:55:20 PM	11:35:30 AM	7:45:35 AM	7:35:15 AM
700	1:43:10 PM	11:56:05 AM	8:07:05 AM	7:50:50 AM
800	2:42:00 PM	12:25:05 PM	8:30:50 AM	8:11:30 AM
900	3:40:00 PM	12:59:45 PM	9:05:30 AM	8:41:20 AM
1000	4:30:00 PM	2:19:10 PM	9:37:25 AM	9:06:15 AM
1025			10:05:00 AM	9:29:05 AM
Total time (hh:mm:ss)	6:00:00	3:49:10	3:25:00	2:50:00

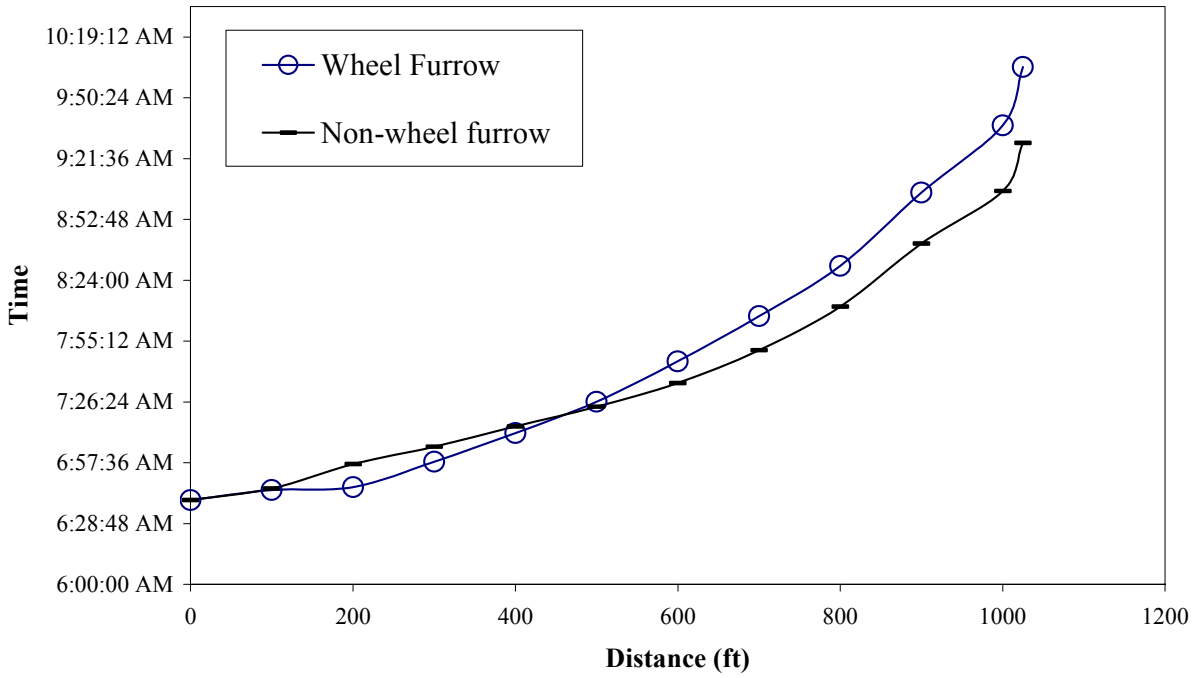


Figure 58: Water advance curves for a wheel and a non-wheel furrow in Field A1.

7.2.1.3. Inflow and Outflow Rates

Table 17 shows the results from the irrigation evaluation. During the first 16 hours of irrigation, some non-wheel furrows had extra siphons to push water down field faster, hence the two stages of the irrigation identified in the table below. This table shows that the average siphon flow rate was 5.17 gpm. The total inflow volume to the field during the entire irrigation was calculated to be 401,668.68 ft^3, which is an average of 2.32 cfs. Table 17 also presents the measured outflow volume, which was found to be 114,633.26 ft3.

Table 17: Field A1 Inflow and Outflow volume measurements

			First stage	**Second stage**
Inflow	Final Average Time	(sec)		12.26
	Volume	(gallons)		1.06
	Siphon Inflow Rate	(gpm)		5.17
	Duration	(hr)	16	32
	Number of Siphons		215	195
	Field Inflow Rate	(gpm)	1112.28	1008.81
		(ft^3/s)	2.48	2.25
	Field inflow volume	(gallons)	1067786.9	1936915.9
		(ft^3)	142741.76	258926.9
				Cumulative
	Total Field inflow volume	(ft^3)		401668.68
	Avg. Total field Inflow Rate	(cfs)		2.32
Outflow	Total Outflow volume	(ft^3)		114633.26

7.2.2. Field D1

7.2.2.1. General Information

System Description

- Type of furrow: Sloping
- Water delivered to furrows by: siphons

Basic information

- Flow rate going into field = 2,185.7 GPM
- Number of days flow is applied = 2
- Number of furrows irrigated at once = 540
- Typical furrow length = 1,200 ft
- Total field irrigated area = 75 acres
- Distance (center-to-center) between wet furrows = 5 ft
- Wetted perimeter of the wetted furrow = 8 in

Set Time Information

Number of hours for:	**Wheel Rows**	**Non-Wheel Rows**
Water applied to head of furrow (hrs)	48.0	48.0
Advance to midfield (hrs)	4.5	4.0
Advance to tail end of furrow (hrs)	12.5	10.5
Extra hours past shutoff that:		
Water sits at the head end of the furrow before disappearing	0.1	0.1
Water sits at midfield before disappearing	0.2	0.2
Water sits at the tail end before disappearing	5.0	5.0

Tailwater Information

Destination of tailwater = Recirculated

Wheel Row Information

- Are only wheel row or only non-wheel rows irrigated? No
- Is every other furrow a wheel row? No
- How many furrows form a group of non-wheel, wheel, and guess row furrows (a repeatable pattern determined by the tractor tool bar width): 3
- How many of those are wheel row: 2
- How many of those are non-wheel or guess row furrows (the total of these two must equal the group total): 1
- Assume that a non-wheel row has a relative intake rate of 1.0. The wheel rows have a lower relative intake rate of … (the answer must be between 0.0 and 1.0): 0.5

Soils

- Soil type = Loamy Sand (Relative Depth Infiltrated = 5.0)

- Percentage of the field with this soil type = 100%
- Does this field have a distinct cracking-clay soil that seals up? No

Method Used to Determine Shut off

- Past History

Furrow Evaluation Results

- LQ Minimum Infiltration / Average Infiltration = 0.85
- Percent of Non-Uniformity due to:

  Advance Time (single furrow): 18
  Variation in set time: 4
  Wheel row/Non-wheel Row: 79
  Variation in soils: 0

- Collected runoff as a percent of Total applied = 0
- Rating of Infiltration strategy = GOOD

7.2.2.2. Advance Curves

Four wheel furrows and four non-wheel furrows were monitored for the advance rate during this evaluation (7/20/01). Table 18 shows results for the wheel furrows and Table 19 shows the results for non-wheel furrows. An average advance value was computed and is shown in the last column on each table. Advance rates were measured in 200-ft increments. The average advance rate for wheel furrows was 12 hours and 27 minutes, and 10 hours and 25 minutes for non-wheel furrows. Average values are also shown in Figure 59.

Table18: Irrigation water advance time in wheel furrows in Field D1

Distance (ft)	Time (hh:mm)	Time (hh:mm)	Time (hh:mm)	Time (hh:mm)	Average Time
0	9:30 AM	9:30 AM	9:30 AM	9:30 AM	9:30 AM
200	10:41 AM	10:28 AM	10:34 AM	10:27 AM	10:32 AM
400					
600		1:55 PM	2:30 PM	2:05 PM	2:10 PM
800		4:10 PM	4:50 PM	4:03 PM	4:21 PM
1000		7:05 PM	7:45 PM	6:25 PM	7:05 PM
1200	10:10 PM	10:00 PM	10:30 PM	9:10 PM	9:57 PM
Total time (hh:mm)	**12:40**	**12:30**	**13:00**	**11:40**	**12:27**

Table19: Irrigation water advance time in non-wheel furrows in Field D1

Distance (ft)	Time (hh:mm)	Time (hh:mm)	Time (hh:mm)	Time (hh:mm)	Avg. Time
0	9:30 AM	9:30 AM	9:30 AM	9:30 AM	9:30 AM
200	10:25 AM	10:00 AM	10:10 AM	10:16 AM	10:12 AM
400	11:47 AM	11:10 AM	11:10 AM	11:40 AM	11:26 AM
600	1:50 PM			1:50 PM	1:50 PM
800	3:30 PM	2:00 PM	2:00 PM	3:05 PM	2:38 PM
1000	6:25 PM	3:47 PM	3:42 PM	5:53 PM	4:56 PM
1200	9:00 PM	6:43 PM	6:15 PM	9:45 PM	7:55 PM
Total time (hh:mm)	**11:30**	**9:13**	**8:45**	**12:15**	**10:25**

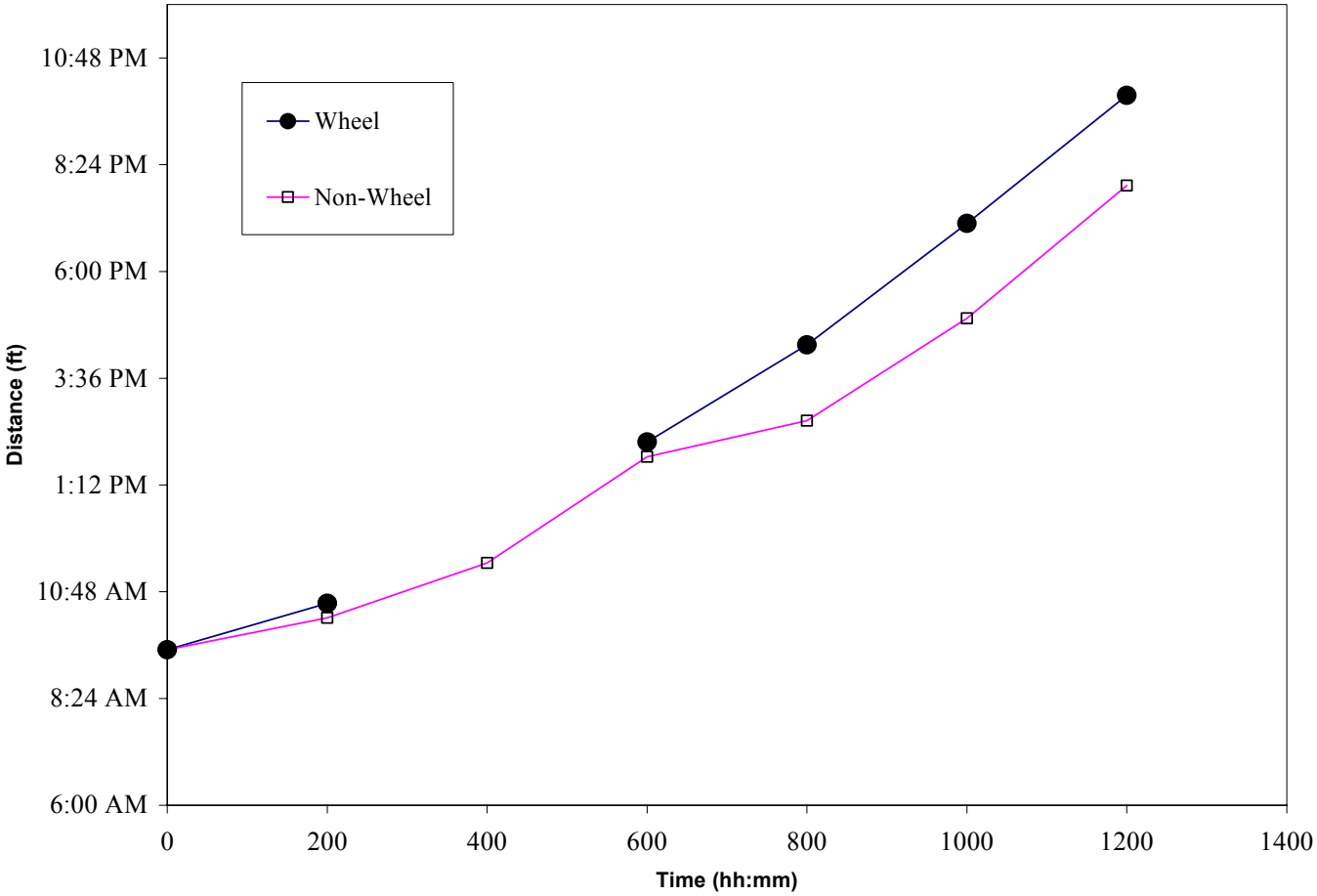


Figure 59: Average advance curves for the wheel and non-wheel furrows in Field D1 on July 20, 2001

7.2.2.3. Inflow and Outflow Rates

Table 20 shows the results of this evaluation. The total inflow volume was found to be 841,641 ft^3 and the total runoff (outflow) volume was found to be 213,394 ft^3.

Table 20: Inflow and outflow volumes for Field D1

	Small Siphons	Large Siphons	Total
Filling Time (sec)	22.5	9.80	--
Volume (US gallons)	1.06	1.06	--
Volume (ft^3)	0.14	0.14	--
Siphon flow rate (gpm)	2.83	6.49	--
Siphon flow rate (ft^3/min)	0.38	0.87	--
Total No. of Siphons	360	180	--
Total siphon flow rate (gpm)	1017.60	1168.16	2185.76
Irrigation duration (hrs)	48	48	--
Total inflow volume (gallons)	2930688	3364310.20	6,294,998.20
Total inflow volume (ft^3)			841,641.26
Total outflow volume (ft^3)			213,493.02
DU (LQ minimum)			0.85

Task Two—Survey of Water Use Efficiency Partnerships and Communication

Introduction

The purpose of this task was to survey representatives of organizations around the state that work directly with farmers regarding potential cooperative agreements between RCD's, irrigation districts and landowners to promote improved on-farm irrigation water management. Information from this survey would help inform CALFED regarding successful models to emulate in other portions of the Bay-Delta watershed.

Survey Development

District personnel held a January 16, 2001 meeting in Sacramento with CALFED WUE staff and other resourceful individuals (minutes attached in appendix) to define the desired deliverable for Task 2. After a lengthy discussion of the broad variety of on-the-ground relationships existing in the professional water use efficiency "community," the group schemed a tentative list of contacts and candidate survey questions for the District to refine. Further discussion of the task deliverable led to a "marketing plan" concept to drive the survey and the final write-up of its results. This shifted the goal of the survey to that of informing the CALFED WUE Program on the best means of encouraging organizations promoting on-farm water use efficiency to submit grant proposals in response to future CALFED WUE Program PSPs.

Following the meeting, District personnel circulated the minutes to meeting participants in order solicit additional contact information and direction for the survey. From the resulting responses as well as CALFED WUE staff editing of a draft survey in June 2001, the completed survey was developed and disseminated in September 2001. The survey questions are included in the following pages, and the original contact list is included in Appendix E (p. E-1).

Results

District staff distributed the 27 surveys three different times via email and fax, and received 11 responses, 8 of which included actual responses to the survey. While the response was disappointing, the respondents, interestingly enough, gave fair geographic representation to the different regions of California (Northern Central Valley, Central Coast, Southern Coast, Westside San Joaquin Valley, Southern San Joaquin Valley, and Southern Inland Desert—conversation only). Those that responded were forthcoming and voiced most consistent support for both local educational programs and Mobile Labs. Survey responses are summarized below (with number of correspondents corresponding to each answer in parentheses) in order of the survey questions, which were broken into three sections: 1. Local water use efficiency; 2. The role of local organizations; and 3. The role of the CALFED Water Use Efficiency Program.

SUMMARIZED SURVEY RESPONSES

Local Water Use Efficiency

1. *How do you define on-farm water use efficiency in your area? (i.e., What forms does it take? What are the end goals?)*

- Net income per unit (ac-ft) water and crop productivity per ac-ft or ac-in water (6)
- Irrigation uniformity or distribution uniformity (4)

2. What is the motivation or interest in on-farm water use efficiency in your region? What are the driving issues or problems?

- Minimize crop production costs or water costs (5)
- Limited water supply/availability (6)
- Interest in the potential reduction of water use and improved crop yield and /or crop quality (2)
- Water quality problems (3)

3. *What is the level of interest or actual application of on farm water use efficiency?*

- There are leaders with vision, followers who have more apprehension but not completely closed to the idea of change if proven worthwhile, and a third group that are largely uninformed and not apt to change anything about how they operate anytime soon, especially if it seems it may complicate their day-to-day operations. A smaller fraction of growers (maybe 10-20 percent, I have know sure way of knowing) would fall under the category of leaders. These individuals are already adopting improved irrigation practices such as conversion from flood, furrow, and hand move sprinkler to drip, buried drip, microsprinkler, and minisprinkler, and use of a variety of irrigation scheduling tools. Also, it is worth noting that it is often these progressive managers that are still expanding the landholdings they manage, so despite being a smaller fraction of the water users they may account for a larger proportion of the actual land and water management. (2)
- For certain crops and locations the interest level is very high while for others it is low. The application of the concept follows a similar trend. (2)

1. Growers, in most cases, are willing to make modifications to their irrigation systems, if such modifications are cost effective or if they are compensated for the cost of the modifications. The growers in this region are taking advantage of current incentives promoted by the District to upgrade the water delivery system.

- I've probably had more people contact me for an evaluation, not only this past season, but the one before as well, than in any other given year. Approximately 60% of the systems tested experience some degree of following through on recommendations. (1)
- Farmers are looking at production per acre-foot of water rather than per acre. (1)

- Medium level of interest. The energy crisis is a motivator, but lack of education and information regarding groundwater limitations is a problem (1)

4. *How could that be improved or increased? (Conversely: what are the limiting factors that need to be overcome or removed?)*

- Increasing the interest at the farm level demands proving that the irrigation improvements are profitable and that the risks of adopting improvements are not too high. This seems to require a fair amount of one-on-one interaction on the farm to introduce alternatives. (3)

- Better, less threatening, incentives from government agencies including water districts. (3)

- Education (e.g., further studies regarding groundwater recharge and draft balances are needed to provide educational information for growers). (2)

- Many smaller water districts have limited conveyance and staff and cannot deliver water on demand, which discourages a higher level of on-farm water management. (1)

- Pressurized irrigation methods and modern irrigation scheduling techniques require a higher level of skill among the farm labor force and among technical support providers. There is a shortage of this type of support to help growers make the transition (1)

- Probably the grower's perception of what we are providing for them [mobile lab]. It is a free service, and it behooves them to take advantage of it. A direct mailing right to the grower might help get the info into the right hands, but that would be costly. (1)

- Provide a more reliable supply. (1)

The Role of Local Organizations

5. *What is your organization's relationship with growers? What other organizations work as closely or more closely with them regarding on-farm water use efficiency?*

- UC Cooperative Extension has a long history with growers dating back to 1918. Emphasis has been of efficient farm production for many decades. In the last 15 years though, we have sought to not only encourage efficient, profitable farm production practices but also environmentally sound production practices. During the 2001 season, I have worked on-farm with buried drip irrigation of row crops in Glenn County and with the development of plant and soil – based methods of scheduling irrigations in orchard crops (walnut, almond, and prune). DWR, Northern Division, Local Assistance in Red Bluff are also active to some degree with WUE. ITRC at Cal-Poly also has outreach influencing the area, primarily at the water district level in the development of Efficient Water Management Practices and Best Management Practices. Resource Conservation Districts have recently expressed interest in on-farm WUE. (1)

- The RCD assists growers with resource issues mainly involving soil and water conservation. Through the Irrigation Mobile Lab, the district has a lot of contact with farmers in the county, as well as up and down the state. No other organizations or public companies work closer with growers than does the RCD Irrigation Mobile Lab. (2)

- Our local UCCE works with growers on various projects to promote on-farm water use efficiency as well, but on a limited basis. (1)

- We are a water district. Consultants that work on farm could work more closely. The District has always tried to provide water management information to allow District water users to manage a limited resource in the most efficient manner. (1)

- We deliver water, contribute some funding for qualifying projects, and will perform certain services such as assisting in the design and/or overview of on-farm water facilities. The local Coop Extension Service works closer with the growers regarding the growing of the crop and the application of water to the crop. The local Farm Bureau is also a source of information and coordinator of certain services to growers. (1)

- We provide education and applied research solutions. We work together with BOR and DWR and local water districts. (1)

- We provide water directly to growers. We don't deal with them for on-farm water use efficiency. We typically refer requests for water use efficiency support or information to the local RCD, and we refer crop information requests to UCCE. (1)

- USDA-NRCS works with RCDs. Other agencies include UCCE and irrigation districts (1)

6. *What is your relationship with that/those organization(s)?*

- I support DWR by assisting them with distributing real-time estimates of crop evapotranspiration for orchard crops and have provide irrigation scheduling workshops for growers. In 2000/01 over 70 water managers in Tehama and Glenn Counties attended workshops on climate, soil, and plant – based techniques for scheduling irrigations. During the 2000 and 2001 approximately 55 water users received weekly updates of real-time crop ET electronically. I have attended the ITRC training titled "Water Conservation Coordinator Workshop" for water districts and would like to support that effort more but am uncertain how to assist. Recently, the Tehama County Resource Conservation District, DWR northern Division, and myself have begun to pursue the Irrigation Mobile Lab concept. There is interest at CSU-Chico, College of Agriculture and among USBR Water Conservation staff at Willows to develop the Mobile Lab Concept. (1)

- Involved in various projects with the local UCCE. (2)

- The RCD works jointly with the NRCS through a memorandum of understanding. (1)

- We implement the water conservation program for the District. (1)

- We cooperatively provide education to growers through seminars, field days, and workshops (1)

- We have partnerships with them and sometimes serve as a resource for them. (2)

7. *What are the "capacity/ability" limitations of your organization and others regarding promotion of on-farm water use efficiency?*

- Fiscal constraints (5)
- Limited staff with interest in irrigation and budget to travel. (2)
- Need to foster a joint effort among the various entities interested in WUE as opposed to a competitive approach. (1)
- More statewide organized effort/coordination/integration. (1)
- Getting the word out to new landowners of the [mobile lab] service that is available to them (1)
- Some District water delivery facilities and a large amount of on-farm water delivery systems are ditches or cast-in-place concrete pipelines that lack the reliability and flexibility required for the delivery of water on demand. Water delivery reliability and flexibility are a prerequisite for the conversion of flood to micro-pressure irrigation systems. Although micro-pressure systems are not necessarily required to improve water use efficiency, the irrigation management demand for those systems is typically less rigorous than those of flood irrigation. (1)

The Role of the CALFED Water Use Efficiency Program

8*. Are you aware of CALFED's Water Use Efficiency Program? If so, how is it perceived in your region? What is your perception of CALFED's WUE Program? How is CALFED perceived in general?*

- Aware of the CALFED WUE program (8)
- It is not well recognized or understood among ag water users (3)
- CALFED is not trusted by local farmers (3)
- Concern that CALFED is not addressing storage issue. Until that's dealt with , there will not be full buy in from the ag community. (2)
- There is much more awareness of the ecosystem restoration, watershed, and storage CALFED components (in the Sacramento Valley region). (1)
- I think it is a good program, as it has enabled the Mobile Lab to further its outreach to landowners in other areas through the use of irrigation workshops. (1)

9. How could it (CALFED) be improved?

- Include more agricultural interest into the decision-making process. The CALFED process needs to assure agriculture and water supplier organizations that the Bay-Delta will not be fixed at agricultural water expense. (2)
- Address the issue of increased storage. (2)
- Seek to provide agricultural water users with local resources (financial, technical, exploratory) to make new, creative ideas come to fruition from within. Avoid mandating or handing down solutions solely from outsiders. Invite growers to act as test farms showing results of better management. (2)

- WUE program target should also include the contract users outside of the hydrologic provinces of the Bay-Delta. (1)

- They could improve the reliability of water south of the delta. (1)

- The larger the district, the lower their ranking for funding should be. The little guys need to be given priority. We don't have the flexibility that the big ones do. Help the ones that need it most. (1)

10. Are there any CALFED WUE Program activities in your region?

No (5)

Yes (3)

11. How could the CALFED WUE Program best support water use efficiency in your region?

- Efforts that help growers gain access to pumping plant efficiency and irrigation system performance information for their irrigation systems would be helpful. Mobile lab concepts seem appropriate to fit this void. (4)

- Follow up on pumping plant and mobile lab evaluations in workshop settings and with successive years of monitoring on-farm adaptations could lead to a comprehensive approach to addressing WUE. (1)

- Workshop trainings (3) ("fairly effective especially if it is repeated and supported with field demonstration") (1)

- Test farms/demonstration sites (3)

- The Quantifiable Objectives process has the potential to achieve its goals if it is continued and funded. The water quantity objectives for this region may not be significant, but the water quality may have positive results. (1)

- Doing a good job. Good start. Need to build on what they've done. (1)

- Provide assistance with grant writing. Simplify PSP format requirements. (1)

12. What types of outreach and communication can the CALFED WUE Program provide to increase farmer adoption and local organizational collaboration regarding water use efficiency?

- Sponsor and facilitate workshops and field days, irrigation symposiums, expos, product fairs. (4)

    - Support workshops and field days that are directly tied with written communications

- Newsletters are effective in providing information to the end user. The WUEP should set aside funding for the communication portion of the process. (2)

    - Frequent, simple communications that relate to on-farm water management practices

    - Offer resources to provide "professional appearing" communications (professional writers and editors, reproduction costs, professional support for web page development)

  - Be a long-term partner that can consistently support outreach and bring continuity to the effort.

- Funding for organizations that can undertake them (3)
    - Work through RCDs. We have excellent rapport with the agricultural and the urban communities.
    - Continue to support the ITRC programs at Cal Poly and the WaterRight web site at CIT.
    - Sponsor mobile lab teams

Discussion

The responses to the survey identified several existing tools, organizations and partnerships that successfully promote on-farm water use efficiency. Those are summarized below:

Successful tools

- Mobile Irrigation Evaluation Labs
- On-farm demonstrations linked with field days that show profitability of conservation practices as well as effectiveness.
- Educational materials

Organizations successfully impacting on farm water use efficiency

- RCDs and NRCS
- University Extension and California State University-based Education Programs
- Water Districts linked to RCDs and UCCE

These responses have been reinforced by interactions with other organizations promoting water use efficiency in California. Respondents also identified the hindrances that these organizations and programs encounter: lack of funding, insufficient staff or staff knowledge, and lack of experience in fund-raising or grant-writing. Specifically regarding CALFED's interactions with these organizations, an added hindrance is continued skepticism of CALFED within the agricultural community.

Recommendations

In light of these results, the best investment of CALFED Water Use Efficiency Program energy and funds would be to support proven programs such as Mobile Labs, on-farm demonstrations, and educational programs. The existing expertise and institutional (local and agency) experience and knowledge of such programs would make investment in them more cost-effective than developing unique programs with their associated learning curves and need for refinement. CALFED WUE Program support could bolster existing programs as well as aid in propagating similar programs in underserved areas of the CALFED region. The organizations currently associated with such programs also provide the advantage of being allied with farmers and ideologically neutral, making a more fluid conduit for CALFED interaction with the agricultural community.

To expand on-farm water use efficiency programs equitably, the WUE Program should make all efforts to improve the accessibility of its competitive grant program. Small organizations that either lack staff for grant-writing or experience in the task typically rank unfavorably to larger or more experienced organizations without such limitations in a competitive program. Development of a grant-writing or project-development support program for small organizations could help alleviate this apparent inequity and better enable CALFED to serve those regions that suffer from the vicious cycle of lacking resources because they lack the means to acquire them. Providing such a service through an independent third-party organization could limit the potential legal conflicts of such a program.

Farmers' reticence to work with CALFED-funded or supported programs may remain a hindrance to on-farm water use efficiency education programs until the perception of CALFED as "anti-agriculture" is changed. While complete acceptance or approval of CALFED by the agricultural community is an unreasonable expectation, the program can take steps to communicate support for farmers. Repeated concerns within the agricultural community and by survey respondents are that CALFED promote non-regulatory solutions to Water Use Efficiency goals and deal effectively with the need for increased water storage or supply. Some of this effort may be a matter of improved communication of the information that CALFED already has or enhanced partnerships with organizations trusted by the agricultural community such as the Farm Bureau, commodity groups or Conservation Districts. Some may involve revisiting CALFED plans to better include the agricultural community in decision-making. Some changes may be mandated through the Legislature. Either way, these concerns regarding regulation and supply need to be addressed to build confidence in the potential solutions that a collaborative multi-agency, multi-stakeholder program such as CALFED can provide for a region as large and diverse as the Bay-Delta Watershed.

Task Four—Outreach

The purpose of this task was to communicate Pilot Program results to farmers, resource agency personnel and the public through coordinated field meetings and tours at project sites and through District outreach literature.

Below is an overview of Pilot Program outreach activities:

- A descriptive article about the Pilot Program was published in spring 2001 in the RCD Quarterly newsletter and was included in general articles about the RCD in the *Daily Democrat* (Woodland) and *Davis Enterprise* newspapers.

- District personnel updated the RCD conservation guidebook, *Bring Farm Edges Back to Life!*, including the tailwater pond chapter in June 2001. The District will further modify the pond chapter as well as update the pond "page" on its website (www.yolorcd.ca.gov) with information generated during this Program when the guide is republished in summer 2002. A new cover crop article will be incorporated at the same time.

- On August 13, 2001 the RCD hosted a field meeting and tour on the Muller Ranch to communicate project activities and results with focus on the cover crop trial and sediment traps. The meeting site featured one of the Pilot Program sediment traps. The meeting was announced in both local newspapers and press invited to attend. Other than RCD staff, about ten people attended the meeting, coming from neighboring farms and other resource agencies and organizations. While the number was relatively small (attributed to meeting timing during peak tomato harvest) for RCD field meetings, the participants were very interested in the sediment traps' potential for reducing soil loss and in the function of tailwater return systems. The tailwater pond we visited on the tour also featured upper banks planted with native perennial grasses, and several participants had particular interest in the plants' role in bank stabilization and weed suppression as well. Several of the participants asked to be informed of project results (analyzed data) in the future. The meeting agenda is included in Appendix E (pp. E-2-3) of this report.

- On November 28, 2001 District staff hosted a Tailwater Pond Field Meeting at Rominger Brothers Ranch to communicate the techniques for tailwater pond development and the preliminary results of the Pilot Program evaluation of the water quality impacts of tailwater ponds and sediment traps. The meeting was located at one of the tailwater pond sites studied during the Pilot Program. About 30 people attended, representing various local, state and federal agencies, as well as ten local farmers. Following staff presentations, a tour was offered to visit an older tailwater pond with established native vegetation wildlife plantings on a nearby farm. Participants were particularly interested in our runoff analyses, and several have asked for copies of the Pilot Program Final Report, which the RCD will provide them. An agenda for the meeting is attached in Appendix E (p. E-4).

- Pilot Program staff contributed to the completion of a new District publication entitled *Monitoring on Your Farm*, which details low-tech water, soil, wildlife and insect monitoring techniques for landowners and organizations wanting to document effects of their

conservation projects or simply assess the health of study sites and properties. A copy of the publication cover and introduction is attached.

- District personnel communicated regularly with representatives of resource agencies and other RCDs regarding flow measurement techniques and challenges. Personnel also fielded periodic inquiries regarding preliminary Pilot Program results. There is an apparent high level of interest in quantified measurements of the water quality changes observed with tailwater management techniques.

Conclusion

After a single year of work, Pilot Program results can at least be summarized as observations of likely successes or matters warranting further study. The water conservation techniques examined and implemented in this Pilot Program all have merit as feasible practices for farmer adoption, but the precise nature of their benefits needs further evaluation based on replicated, multiple year studies. The District will implement such a study independent of the CALFED WUE Program over the next three years (through 2004). The survey under Task Two of the Pilot Program also represents more of a "taking off" point than a conclusive result for both the District and CALFED regarding organizational relationships and local tools for promoting on-farm water use efficiency. The District's relationship with Yolo County's primary agricultural water supplier is currently shifting to allow closer collaboration on a variety of programs, potentially similar to those modeled by other RCDs and water districts. While the District considers the information gathered through the Pilot Program to be useful to CALFED in its aim to promote locally-led, on-farm water use efficiency programs, the Pilot Program has also provided an excellent opportunity for the District to refine its on-farm monitoring program and understanding of potential collaborations for promoting water use efficiency in Yolo County.

Below is a summarization of the benefits and limitations observed of the conservation practices employed during this Pilot Program.

Winter Cover Cropping

- For the three measurable storm events in the study, total flow of runoff from the cover crop treatment was reduced by as much as 71% in one storm, but increased by 37% in another. Peak runoff in all comparable events was delayed in the cover crop treatments by 5-20 minutes. Peak runoff flow was reduced by 0-20% in the cover crop treatment in those events as well.

- Average sediment concentration in runoff from two storms was reduced by 17-46%.

- Average nutrient concentration in runoff (Nitrate and Ammonia) was beneficially reduced in one storm event by 43% and 49%, respectively. However, in that same event, higher runoff was observed from the cover crop treatment (a result not consistent with other storms or other cover crop studies), which contributed to higher total volumes of nutrients running off from the cover crop plots, as seen below.

Treatment	Sediment		**Ammonia Nitrogen**		**Nitrate Nitrogen**	
	Avg. Conc. (mg./L)	Total Volume (kg.)	Avg. Conc. (mg./L)	Total Volume (mg.)	Avg. Conc. (mg./L)	Total Volume (mg.)
Cover crop (1)	1.65	0.82 kg.	.004	2.12 mg.	.263	106.46 mg.
Cover crop (4)	1.44	0.38 kg	.0023	0.40 mg	.398	116.86 mg
Fallow (2)	1.69	0.39 kg	.011	7.18 mg	.419	36.69 mg.

Fallow (3)	0.94	0.41 kg.	.042	8.52 mg.	.738	89.92 mg.

Per acre cost of cover crop installation and incorporation for this trial was:

Item	Detail	Per acre Cost
Materials (seed)	45# common vetch @ $0.50/# + 15# Dundale pea @ $0.25/#	$26.25
Equipment and Labor	Ground preparation, planting and incorporation	$30 - $60
Total		**$56 - $86**

SedimentTraps

- The amount of sediment carried in irrigation runoff was made dramatically evident by the rate at which the Pilot Project traps were filled with sediment (many in two irrigations). Cooperating farmers were able to see the benefits of having the sediment traps because of the reduction on sediment collected in on-farm main drain ditches. They were surprised by the results and expressed heightened interest in continued use of sediment traps on their farms.

- All of the sediment traps in the Pilot Program captured sediment, but none were large enough to capture all of the "capturable" sediment (especially non-fines) leaving the different fields studied. Percent Sediment captured ranged from –13%, for a full trap actually contributing sediment to tailwater, to 98%, for a newly dug trap catching first irrigation water, in this study. Traps full of sediment increased sediment concentration in runoff until they were excavated, after which they again entrained sediment. Mid-season percent sediment capture ranged between 33-55% (by mass) in most ponds.

- Nutrient capture was inconsistent among all the traps observed except during the very early season irrigations, when concentrations of sediment and Nitrogen (Nitrate & Ammonia) in runoff were high. Only at that time did traps appear to consistently reduce Nitrogen concentrations in runoff.

- The apparent benefits of even undersized traps such as those employed in this Pilot Program was clear. To achieve maximum results, however, they must be monitored and maintained. Their function decreased over time as they filled with sediment, and did not function at all when filled completely with sediment. Proper trap design and construction will ease maintenance requirements. If space and field configuration permit, a sediment trap should be sized to capture all of a given season's sediment without completely filling. Further study will provide better information regarding proper trap capacity and sizing.

- Limitations to trap design and siting include location of field bottom roads, lack of space between field bottom and drain, height of the drain relative to the field, concern about backing water into the furrows, and height of downstream drains.

- The longitudinal slope of the field tail ditch slope appeared to be an important factor affecting field erosion. While we rarely observed significant erosion in furrows themselves, we did see it consistently in their intersections with the tail ditch (typically a 6"-12" drop

that induced headcutting into the furrow), and along the length of the tail ditches, especially those cut deep with steep slope. Careful or gradual tail ditch construction would likely have reduced the amount of soil erosion on the fields observed.

- In tail ditches, canvas dams served as a remedy to this problem, slowing the runoff and collecting sediment that extended the utility of the sediment traps (i.e., the traps filled more slowly, thereby functioning longer). The use of canvas dams along the tail ditch slows the erosion rate, providing miniature sediment traps. This has the added benefit at the end of the irrigation season of leaving the collected soil nearer to its origin than a sediment trap would.

- Trap installation cost was approximately $600 - $1000, including cost of flashboard risers and culverts ($200 - $600 depending on the site) and excavation (approx. $200 - $500 depending on site).

Tailwater Ponds

- Because of their much larger capacity, none of the tailwater ponds studied filled with sediment during the study period. In fact, we found them difficult to monitor for single-year volume changes because the volume of sediment captured was so small relative to the ponds' total capacities. Observation of cumulative sediment capture over several years would provide more reliable results.

- % Sediment Capture during the growing season in the ponds studied ranged between 11% and 97%, with one anomalous reading of –39%. Because of their volume or recirculation system, the ponds did not always have measurable outflow, rendering likely sediment capture nearer to 100%.

- In the one tailwater pond built in combination with a sediment trap, combined % sediment capture was consistently higher, ranging between 46% - 99.7%. Such a configuration ultimately reduces the pond maintenance requirement as the traps capture much of the sediment that would otherwise fill the pond more rapidly over time. This allows other beneficial uses of the pond such as wildlife plantings.

- Pond construction cost depends on pond size and type of return system (if included). The range of costs found in the Yolo County area for ponds with capacities between 1.5 and 4 acre-feet is $4,000 - $12,000 for pond and inlet/outlet structures. Addition of a return system with 1800' of pipe typically runs between $10,000 and $16,000, with much of the price variation dependent upon pump size. Addition of native vegetation on the area around the pond would add an additional $1,000 - $3,000 for material, labor, and irrigation system.

Irrigation

- It was observed that flow from gated pipe systems was more difficult to manage than siphon systems on the subject fields of this study.

- The quality of irrigation practices varied widely between the fields studied. While some irrigators had their technique refined to match the field and could carefully control water

application and runoff, other irrigators with apparently inferior management practices seemed to be a primary cause for excess runoff, resulting in additional soil erosion.

- Short of water delivery system changes, costs for improved irrigation management are primarily those of management time and education for the farmer and his/her irrigation crew. Costs for soil water sensing devices are included in the table below.

Monitoring Costs

A summation of the costs, quality, and ease of use of the monitoring techniques employed in this Pilot Program and other District programs is included below.

Parameter & Tool	Material Cost	Installation Cost	Data collection time requirement	Quality of data	Ease of use
In-furrow flow					
Flume	$285/ea. for fiberglass RBC flume	½ man/hr per furrow	Very quick if gauge is easily visible (1 min./furrow)	Depends on the number of furrows observed to account for variability. Per furrow information is good.	Installation is time intensive, especially for multiple furrows. Potentially disruptive to furrow & soil
Siphon flow estimation	Container of known volume and stop watch	None	~5 min./furrow. Check periodically during irrigation	Same as above	Simple, but wet.
Bucket sunk in furrow w/ pump and flowmeter	~$400/installation	~2 hours/site	Simple and quick	Accuracy to 0.10 gal. Measures total flows only	Simple
Ditch flow					
Weir	Starting at $50+ depending on size and need for footing	1-2 man-hrs each (more w/ footing/armoring)	Quick with visible gauge. Setup and download time only with datalogger (2 man-hrs.)	High	Easy
Water level sensor (see ITRC publication comparing sensors & dataloggers at www.itrc.org)	$500 - $5000	Stake and wire minimum. May need stand or box for data logger.	Setup and download time for datalogger. 1-2 man-hrs excluding technical difficulties	High—resolution depends on type and quality of sensor	Varies between brands. Software and datalogger can be easy or cumbersome

Parameter & Tool	Material Cost	Installation Cost	Data collection time requirement	Quality of data	Ease of use
Pipe flow					
Propeller meter (8" dia. Pipe)	$770-$1110	$50-$500	Simple	High	Easy
Doppler	$4,000	Negligible	Setup and download time from datalogger—1-2 man-hrs.	High for water with impurities. Less useful for very clean, or well water	Easy
Soil water					
Gypsum block	$5-10/each + $150 meter	One three-block station: 1-2 man/hrs.	Easy with dry access. Messy in wet field. 5 min./station	Measurements are relative soil-water tension only	Relatively easy
Watermark®	$29/each + $275 meter. Blocks can be retrieved and reused if installed with pvc pipe attached	One three block station: 2 man/hrs. & ~$5 (including pvc pipe and glue on each)	Easy with dry access. Messy in wet field. 5 min./station	Good. Measurements in centibars. Less accurate in sandy soils that dry quickly.	Relatively easy
Tensiometer	$100+	1 man-hr.	Easy	Good, but can lose tension if soil dries completely	Easy. Reusable.
Water sampling					
Grab samples	Minimum: cost of mason jar ($1)	None	Depends on site	Good if sample handled according to lab specifications	Depends on site. Small channels or bodies easy. Larger channels awkward.
Automated sampler	$2,500 and up	Depends on site. Minimum installation time is 1-2 man/hrs. w material cost of a stake. Higher cost associated with sampler shelter.	Depends on quality of software. Min. setup and download time 1-2 man-hrs. Sample handling and shipping to lab addnl 2 man-hrs per batch + transport costs	Good if sample handled according to lab specifications	Excellent for collecting samples at odd hours and remote or inaccessible locations. Software and datalogger can be easy or cumbersome

Parameter & Tool	Material Cost	Installation Cost	Data collection time requirement	Quality of data	Ease of use
Lab analysis	See Table 6 on page 35 for range depending on constituent	N/a	N/a	High	N/a
Cardy meter	$250	None	0.5 man-hrs/ sample	Good. Best to "calibrate" with lab results	Straightforward. Can be used for several nutrients
Test strips	As low as $10/kit. Nutrients & pH.	None	0.5 man-hrs./sample	Low	simple
Colorimeter	$1250 including reagents	None	Straightforward	High	Good.

Survey

The water conservation professionals surveyed as part of this Pilot Program identified several existing successful tools for promoting on-farm water use efficiency. Of highest regard were local mobile irrigation lab programs and local workshops and publications demonstrating and detailing techniques that farmers can employ. While UCCE and NRCS provide excellent information and technical resources, the most productive agency collaboration appears to be that between local water suppliers and Resource Conservation Districts. In two of the cases surveyed, the RCD and water district function practically as one organization. In a third, multiple water districts each provide funding to an RCD to manage and implement a mobile lab for their water customers. Most regions of the state include significant numbers of farmers who rely in part or in whole on groundwater and do not depend upon a water district for their irrigation water supply. Water use efficiency is compelling for them at the very least because of increasing energy and, therefore, pumping costs. A different source of support for a local water use efficiency program such as a mobile irrigation lab will need to be identified for those regions and farmers. While CALFED may not be fully accepted as a partner by members of the agricultural community, survey respondents suggested that CALFED support of local work, alternatives to regulatory solutions, and effective response to water supply concerns could improve that relationship.