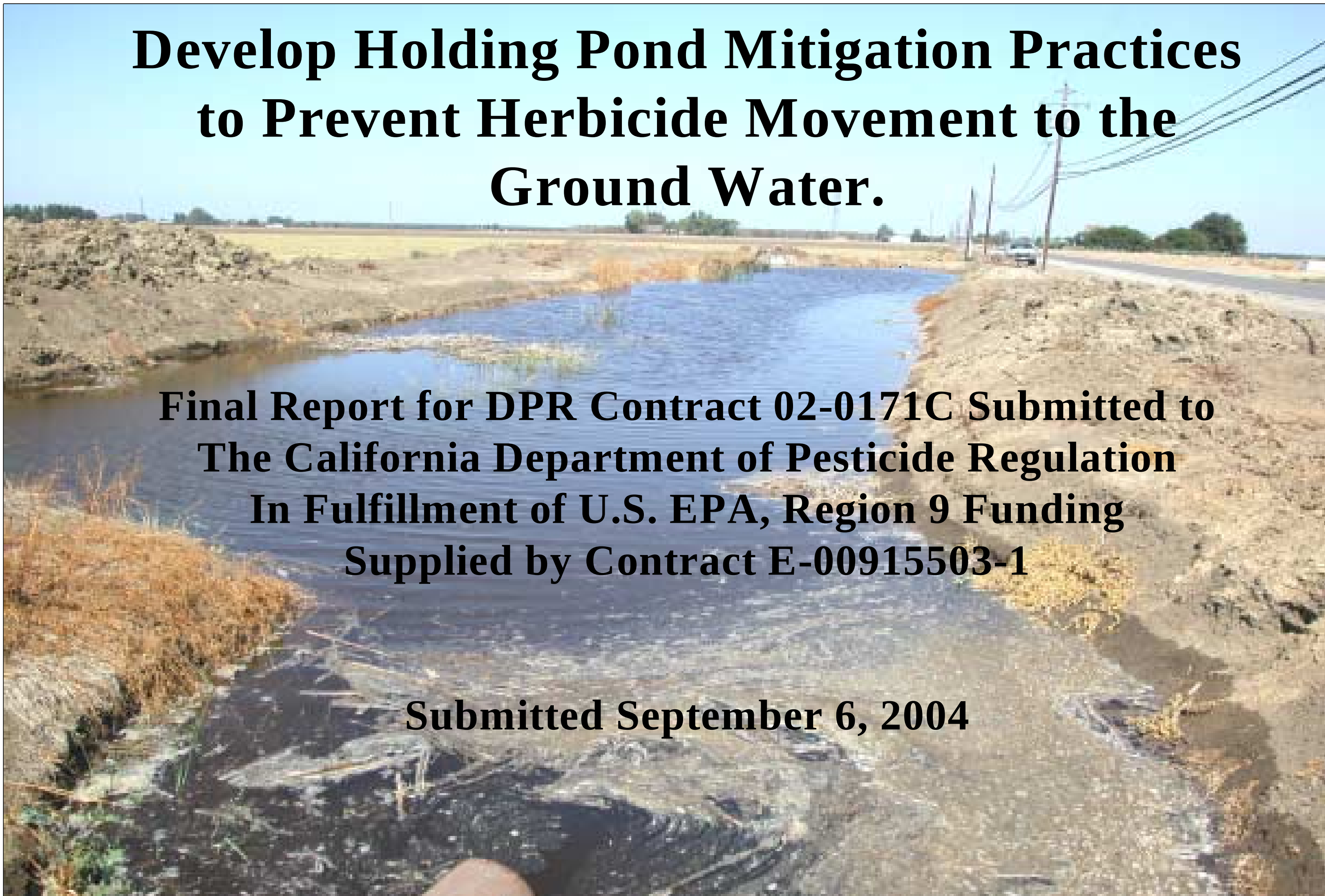

Develop Holding Pond Mitigation Practices to Prevent Herbicide Movement to the Ground Water.

Final Report for DPR Contract 02-0171C Submitted to The California Department of Pesticide Regulation In Fulfillment of U.S. EPA, Region 9 Funding Supplied by Contract E-00915503-1

Submitted September 6, 2004

by

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EH 04-03

University of California Cooperative Extension

California Department of Pesticide Regulation
Final Report, September 6, 2004

Project Title:
Develop Holding Pond Mitigation Practices to Prevent Herbicide Movement to the Ground Water.

Principle Investigator: Terry Prichard, UCCE Water Management Specialist, UC Davis

Co-Principal Investigator: Larry Schwankl, UCCE Irrigation Specialist, UC Davis

Co-Investigators: Mick Canevari, Agronomy & Weed Science Farm Advisor
UCCE San Joaquin County

John Troiano, Environmental Monitoring, DPR

Statement of Problem:

Pesticide residues have been detected in a contiguous area of shallow ground water near Tracy, in San Joaquin County, California. The area contaminated with residues of currently registered pesticides represents 6 square miles. This area could increase as more wells are sampled in adjacent sections. Commonly detected pesticide active ingredients are atrazine, diuron, and hexazinone, which are pre-emergence herbicides. The contaminated area has been determined through methodical sampling of mostly domestic, single family wells. Crops grown in this area are alfalfa in rotation with row crops such as beans. Since Hexazinone could have only been used on alfalfa, agricultural use was indicated as the source for contamination. Diuron is also used on alfalfa but, along with atrazine, it could be used on other rotational crops grown in the area. Thus, there are numerous non-point sources for potential offsite movement to ground water.

In response to these detections, the California Department of Pesticide Regulation (DPR) conducted a cooperative study with Terry Prichard, a University of California Cooperative Extension Irrigation Specialist and Mick Canevari, a UCCE Weed Farm Advisor, to determine the exact pathway for movement of the residues to ground water. The study was conducted in a cooperating grower's field. The soil was a cracking clay soil so movement could have been through the large cracks formed in the soil. Soil coring conducted throughout the spring indicated very little downward movement of residues of diuron and hexazinone that were applied in December. Most of the fields in this area have ponds located on one end of the field to collect rain and irrigation runoff water. Measurements of the water movement from the ponds to the shallow ground water indicated that this was the most direct route for residues in the runoff water to contaminate ground water.

One mitigation measure is to re-circulate water collected in the ponds by pumping the water back onto the field. This proposed study will develop the pond water management strategy and provide data to demonstrate the effectiveness of those procedures. Increased awareness and management of pond water will result in decreased ground water contamination by pre-emergence herbicide residues.

Project Objectives:

1. Conduct a survey of pond existence and grower water management methods.

2. Measure:
   - water volume into pond and out of pond;
   - estimate volume, which is not recycled (transducer and vol./depth relationship);
   - concentration of herbicide inflow and resident water (not recycled).

3. Prepare "best management" practices educational materials including costs of options.

4. Conduct:
   - meetings to "inform" and use industry magazines;
   - work with Ag Commissioner in dealing with Ground Water Protection Area's

Procedures:

This project consists of two phases. Phase I involves concurrent field trial establishment and conducting a grower survey as to pond existence and management methods. The survey will allow prediction of the magnitude of the problem and potential impacts of mitigation practices. The field trial will demonstrate the cost and management requirements of the mitigation practices as well as their effectiveness.

Phase II includes the preparation of educational materials, holding grower awareness/project success meetings in the area of concern. Additionally, these materials will be available to the County Agricultural Commissioner for inclusion in the permitting process in established ground water protection areas.

Accomplishments by Objective:

Objective 1. Conduct a survey of pond existence and grower water management methods.

A survey was prepared to assess existing pond water management practices in the Tracy area. It was reviewed by two growers and a UC Davis team specializing in conducting surveys. The survey was concise (one page) to encourage participation (Appendix I). Twenty-six surveys were mailed to growers and landowners who were identified as growing alfalfa in the Banta-Carbona Irrigation District located in the Tracy, California area. Thirty percent of the surveys were returned with usable information. The specific survey questions and responses are available in Appendix II. The responses represented 5888 acres clearly a majority of the alfalfa

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acreage in this area estimated to be 10,000 acres. The average acreage farmed by a respondent was 736 acres with an average field size of 73 acres. The field size range was 60-100 acres. The majority of growers utilize a tailwater pond to catch irrigation runoff in all or most of their fields; however some respondents do not collect runoff. The average alfalfa field per pond was 60 acres; however, most growers return water from other fields to the pond. Concerning the catching of winter rainfall, the results are mixed since many growers in the area do not receive enough rainfall to allow for runoff.

Average wetted pond size was 198 feet long, 52 feet wide and 9.8 feet deep. Most all ponds were self designed and none utilized NRCS cost sharing. Electric drivers represented 70%, while diesel was 30%. Growers were split on the returning of the residual water in the pond after collecting runoff from the last set.

These responses allow for cost comparisons to be made using typical or average sizes and practices. The survey also points out areas of management which can improve to reduce residue movement to ground water sources.

Objective 2. Monitor a typical grower-operated, tailwater-recycling pond in a Tracy alfalfa field.

A tailwater pond was selected in the Tracy area which served an 80-acre alfalfa field. hexazinone at the rate of 0.5 lb a.i. per acre and diuron at 1.8 lbs a.i. per acre were applied on December 20, 2002. Both herbicides had been applied in previous years at approximately the same rate. Other non-alfalfa fields (tomato, beans) also use this pond to collect tailwater. Water caught during irrigation was returned to the field from which the runoff occurred. The pond was approximately 36 feet wide, 290 feet long. The operational depth was 2.5 feet. Greater depth could have been used; however this operation was dictated by the grower. An electric-driven pump was used to return the tailwater to the field's pipeline turnout structure. The 80-acre field was split in two by an irrigation ditch and a supply ditch. Both 40-acre fields were irrigated at the same time draining runoff into the tailwater pond.

The pond and ground water depths were monitored using pressure transducers installed in ridged copper pipes. Pond discharge flow was measured using Doppler water meters. An empirical relationship developed between pond water depth and volume, derived during periods of pond pump down allowing for unattended monitoring of the pond (Figure 1). The relationship developed allowed subsequent pond and pump discharge volumes to be recorded by data logger. This was necessary, as the pond required an average of 10.5 days from the initial filling to empty. A depth sensor controls the pond pump back, turning on the pump when a set pond depth is reached. The pond is pumped down to the pond minimum depth determined by another depth sensor. On occasion the irrigator opted to run the return manually to facilitate close control on the supply head. Generally, two to three irrigation sets are required to bring the pond to the turn on depth. Six individual alfalfa irrigation events took place from April through September (Table 1). Five of the six were monitored. The June 19 irrigation was not monitored due to data logger problems.

Figure 2 shows the level of the pond and ground water over the season relative to the soil surface. Only alfalfa runoff events are shown. A single irrigation lasted on average about 5 days from irrigation initiation to cessation of runoff usually consisting of 8 sets. The length of the irrigation and the number of sets varied due to the available head, soil moisture deficit and seasonal water penetration. Simultaneous measurements were made of pond water depth and ground water depth, which was measured near the pond using pressure transducers installed in the pond bottom and in the ground water table accessed via soil boreholes. The shallow ground water measured near the field surface 30 ft from the pond edge was relatively constant until the first irrigation at which time the depth from the surface decreased sharply (Figure 2). It appears that the ground water level near the pond was strongly influenced by the infiltrating water and that the travel time from pond to ground water was short. During the June irrigation, the ground water level was at the sensor level in the pond.

Figure 1. Relationship between Pond Depth and Volume, Tracy 2003

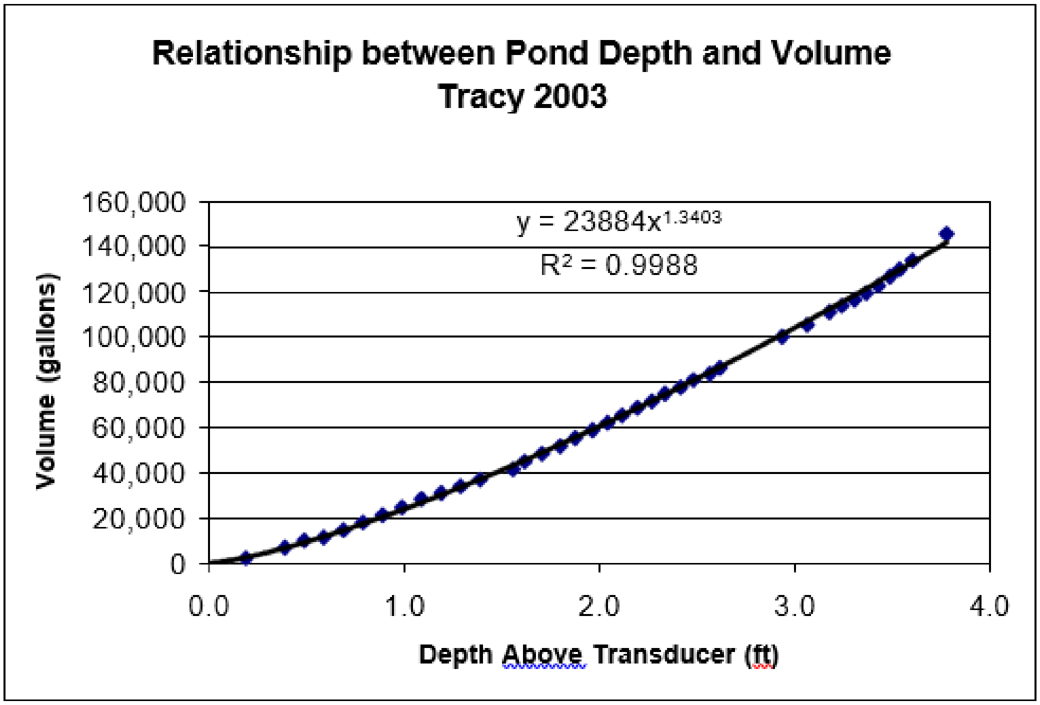

Table 1. Alfalfa Irrigation Dates
4/27/04
5/27/04
6/20/04
7/19/04
8/20/04
9/22/04

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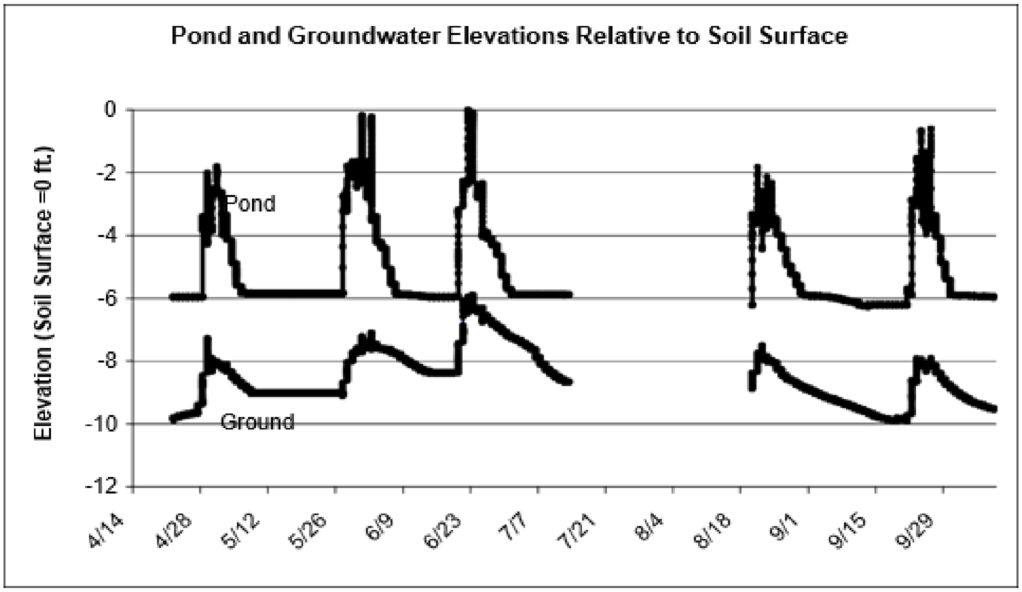
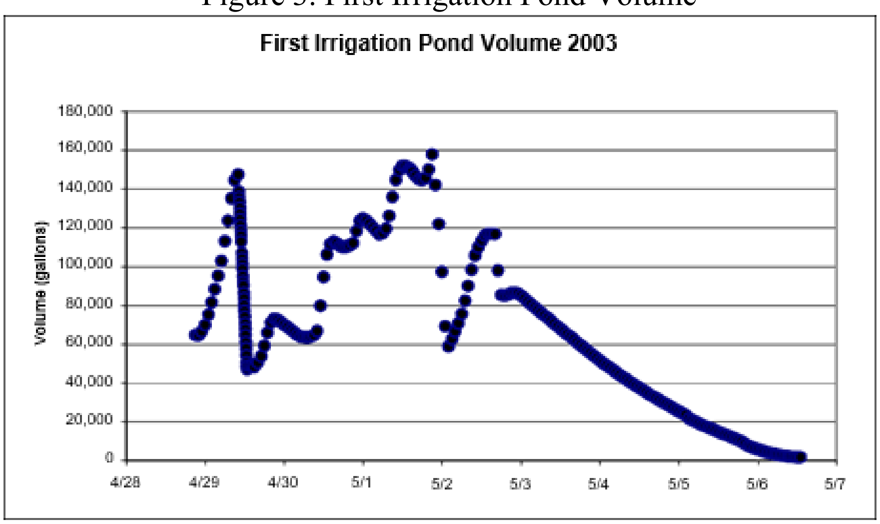
Figure 2. Pond and Groundwater Elevations Relative to Soil Surface



First Irrigation

Pond volume increased with the inflow of runoff following the first few sets to a near 148,000 gallons (Figure 3). At that time, we requested the pond be pumped down to a low level to calibrate the pond pressure transducer to pond volume. The pond level again began to rise as a result of four more runoff events to near 160,000 gallons. The pond was then pumped to its normal "pump off" level as controlled by the pump control sensor. The pond level again rose to near 120,000 gallons when it was pumped at the end of the set until the field irrigation ceased. As a result, water remained at 85,000 gallons which is above the normal pump down level of 60,000 gallons.

Figure 3. First Irrigation Pond Volume



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Other Irrigations

Four other irrigations were monitored and found to be similar in operation varying only in the number of pond pump downs and the length of the individual irrigation. Pond filling, pump down and infiltration ranged from 9 to 13 days with an average of 10.5 days. Figure 6 shows the time course of the pond volume for the last irrigation of the season beginning September 22. Note the similarity between the irrigations.

Recycled Water Volumes

The volume of the water recycled was calculated from each pump down which occurred during the beginning of an irrigation set after runoff has ceased. Table 2 shows the calculated volume of recycled water for the first and last irrigation. The other irrigations were similar (Figure 2).

Infiltrated Water

Infiltration of water through the pond sides and bottom begins upon the initial filling and continues until the pond is empty. To account for the infiltration during the irrigation, the infiltration rate was measured between the pumped out level and the transducer 0 point (Figure 5). The rate equaled 1500 gallons per hour at the pumped down level (60,000-gallon level). The slope of the pond infiltration after runoff ceased and this relationship is similar leading to the conclusion to use this rate to determine the infiltrated water when the pond is above the 60-gallon level. This infiltration rate was multiplied by the hours the pond contained water at or above the pond pumped down level to yield the infiltrated water down to the transducer 0 point. Once runoff ceased, the entire pond volume was available for infiltration and evaporation. The volume to the 0 transducer was 85,000 in both the first and last irrigation. Additionally, since the pond bottom was not level and lower in elevation than the pump and transducer 0 point, 67,600 was available for infiltration/evaporation.

The pond bottom had been non-uniformly cleaned of silt accumulation. The volume below the transducer 0 point was measured using standard grid survey techniques using the transducer 0 point as the base level. Figure 4 depicts the pond bottom below the transducer measuring level. Evaporation of pond water was calculated during the infiltration period which averaged 10.5 days. Evaporation was calculated using 1.2 × daily CIMIS ETo values for the Tracy area using the CIMIS Station near Manteca. Total infiltrated water was near 270,000 gallons as a result of the first irrigation and near 260,000 gallons in the last irrigation (Table 2).

University of California and U.S. Department of Agriculture Cooperating
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Figure 4. Last Irrigation Pond Volumes

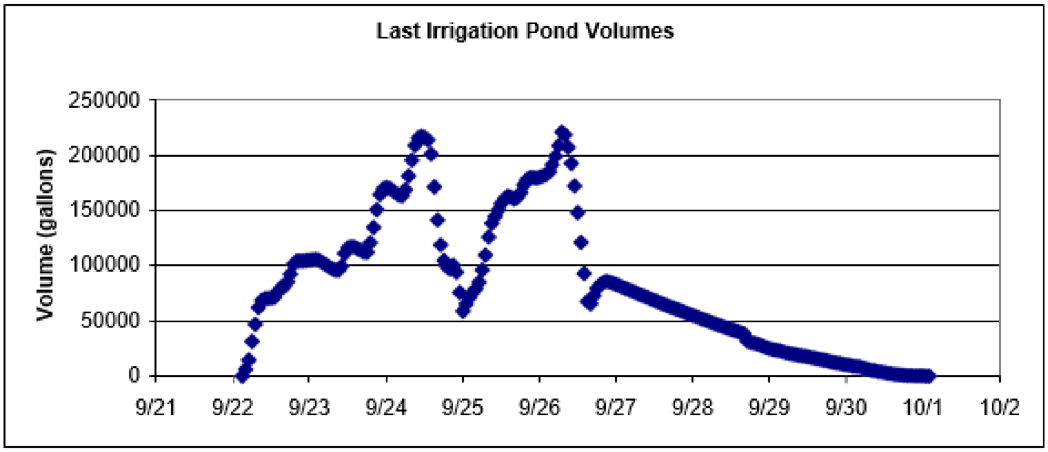
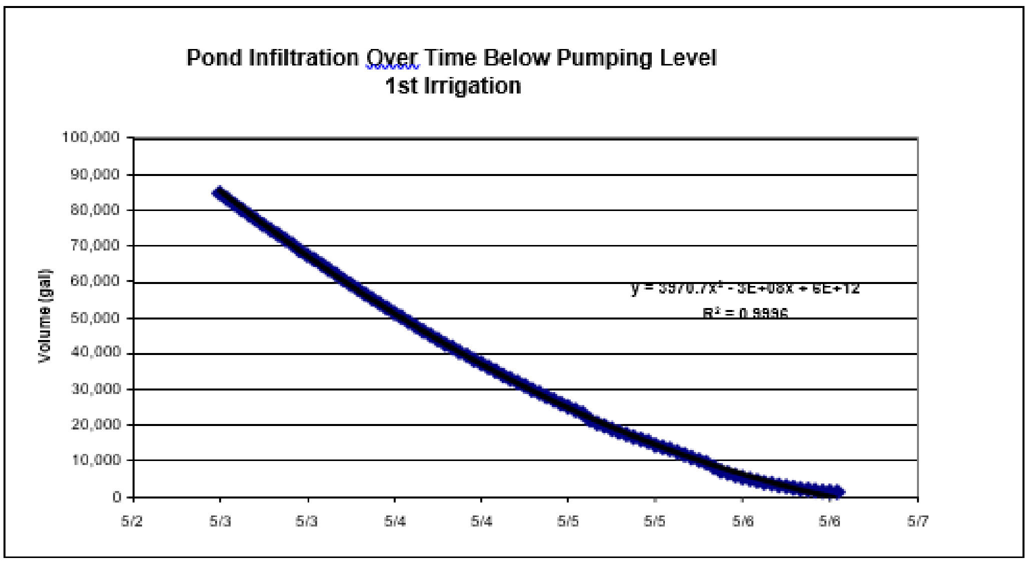


Figure 5. Pond Infiltration Over Time Below Pumping Level 1st Irrigation



Recycled Water

The volume of recycled water was calculated by summing the infiltrated water, the water volume recycled and that lost to evaporation. During the first irrigation the pond captured 536,000 gallons and recycled 219,000 for a 40.9 percent recycling efficiency (Table 2). In the last irrigation, the pond captured 611,000 gallons, recycled 297,000 for 48.6 percent efficiency. The seasonal recycling efficiency was 45 percent. The runoff volume accounted for 6% of the irrigation onflow volume.

Figure 6. Pond Bottom Elevations

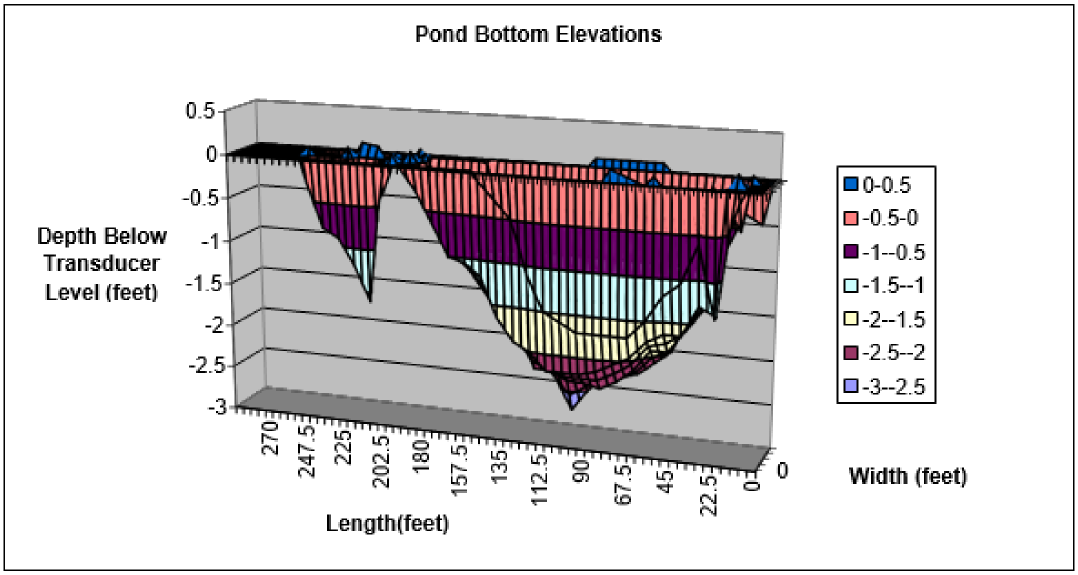


Table 2. Recycled Water Calculations

	Irrigation	
	First Gallons	Last Gallons
Recycled Water Volume	218,961	296,962
Infiltrated Water		
Pump off to Transducer 0	85,000	85,000
Residual Pond Water	67,639	67,639
Infiltrated water during Irrigation	141,000	138,000
Total Infiltrated Water(above – Evaporation)	270,239	267,239
Evaporation during Irrigation and Infiltration	23,400	23,400
Total Runoff Captured	536,000	611,001
	Percent	Percent
Percent of Runoff Returned	40.9	48.6
Percent of Runoff Returned Using BMP	69.3	73.6

Concentration of Herbicide in Pond Waters

The herbicide concentration of the pond was determined by sampling at the pump turn on level, which was usually after 4 irrigation sets. The mass of both diuron and hexazinone in the infiltrated pond water was calculated as the product of the concentration of the pond waters and

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the calculated infiltrated volume. Without recycling, diuron would have infiltrated via the pond totaling 45.0 grams while hexazinone would have totaled 2.8 grams for the irrigation season.

By recycling an average of 45% of the runoff captured, the diuron was reduced to 24.8 grams while hexazinone was reduced to 1.5 grams for the irrigation season. When viewed as a percent of the applied mass for the entire 80 acres, diuron was at 0.038% and hexazinone was at 0.009% of the original application rate. The concentration of both diuron and hexazinone decreased in a non-linear fashion in the captured runoff waters as the cumulative runoff increased (Figures 7 and 8). The figures show the decline in herbicide concentration as runoff accumulated over the season in the 2003 study. For contrast, the 2000 study runoff was plotted on the same figure using the function developed from that study. The agreement is good despite the fact only the first two irrigations measured in the 2000 study.

Improving Recycling Efficiency

The volume of water remaining in the pond after the final set pond pump down and the volume of runoff captured have a significant influence on the recycling efficiency. In this study pond, 85,000 gallons remained in the pond which could have been recycled. An additional 67,639 gallons were not recyclable due to the pond silt removal below the pumping level. If these two volumes were recycled in each of the six irrigations the recycling efficiency would increase to a seasonal average of 72 percent. The practice of pumping down the pond after each irrigation set would also minimize the infiltrated water by reducing the pond wetted area. A generalized estimate of recycling efficiency if all these practices were implemented is 85-90%. An increase in recycling efficiency is directly related to a decrease in herbicide residues infiltrating to ground water.

Figure 7. Concentration of Diuron in Runoff Waters as a Function of Cumulative Runoff

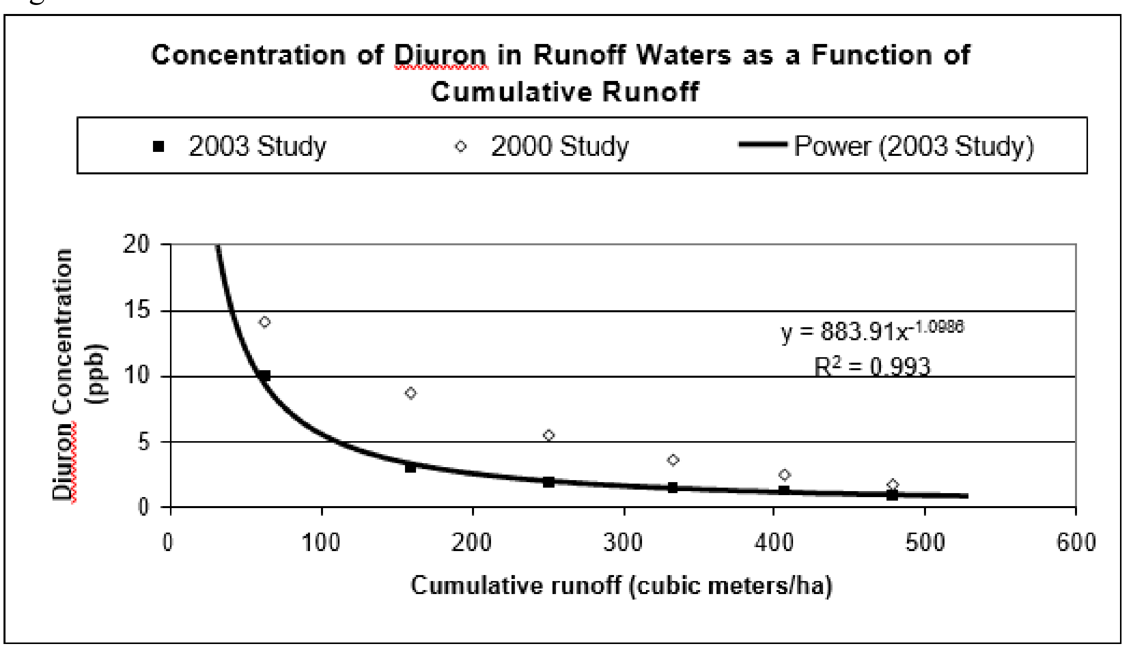

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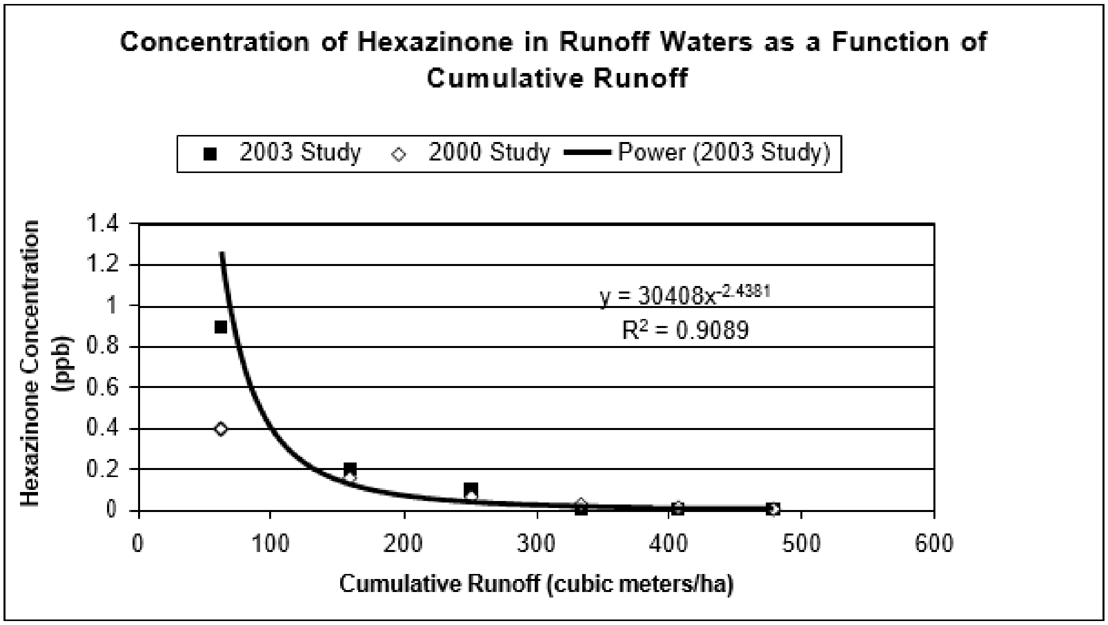
Figure 8. Concentration of Hexazinone in Runoff Waters as a Function of Cumulative Runoff



Objective 3. Prepare "best management" practices educational materials including costs of options.

A draft of a best management practices publication has been prepared (Appendix III). The publication addresses the potential for movement of herbicides used in alfalfa production and the pond management practices which can reduce or mitigate the problem. It also presents a cost evaluation of three recycling systems. The evaluation uses a typical pond as determined in the survey of alfalfa growers.

Objective 4. Conduct:

- meetings to "inform" and use industry magazines;
- work with Ag Commissioner in dealing with Ground Water Protection Area's

An article, *Tailwater return systems are gaining in popularity on farms*, was prepared in cooperation with Eric McMullin which appeared in the February 25, 2004 of Ag Alert. Ag Alert is a weekly publication of the California Farm Bureau Federation. The article discussed the progress of the trial and the importance of the work in relation to the proposed and now implemented ground water protection areas. A meeting of alfalfa growers is planned this fall to coincide with the San Joaquin County Alfalfa Day to discuss the results of the study and the pond management options.

Meetings are planned for County Agricultural Commissioners in November in six locations within California. We will address the Ground Water Protection Areas and mitigation practices to minimize surface and ground water pollution using this study as an example.

APPENDIX I

Survey Letter on Pond Water Practices to Alfalfa Growers in Tracy Area, CA

420 South Wilson Way, Stockton, CA 95205 209/468-2085 Fax: 209/462-5181 email: tlprichard@ucdavis.edu

University of California Cooperative Extension

February 6, 2003

Dear Alfalfa Grower:

The University of California Cooperative Extension has been conducting studies in the Tracy area to gain knowledge on the operational use of short-term water storage ponds in alfalfa. The purpose of the study was to evaluate the effectiveness of short-term storage ponds in mitigating ground and surface water degradation. Our findings have shown positive results with the proper use of these ponds.

As an alfalfa grower, we seek your assistance in this *anonymous* survey that will be used to determine the extent of use and typical management practices for the ponds. We will only use the information to determine the costs of various management options including the installation of the pond, the return system and other related cost of operations. No other use of this information would be allowed.

The Tracy area was selected as a pilot project because of the large amount of alfalfa production and the widespread use of ponds. This survey has been presented to the Banta Irrigation District Board for their comments prior to our mailing.

Please take the few minutes to fill out this survey. It will help us develop Best Management Practices and demonstrate the positive practices that growers are now using to manage tail water. If you have any questions, please contact Mick Canevari or Terry Prichard at (209) 468-2085.

Sincerely,

Terry L. Prichard
Water Management Specialist

Mick Canevari
County Director/Farm Advisor

UNIVERSITY OF CALIFORNIA ALFALFA IRRIGATION SURVEY

1. How many total acres of alfalfa do you farm? _____ acres

2. What is your typical alfalfa field size? _____ acres

3. Do you use a pond to catch irrigation runoff?
   _____ all fields _____ some fields _____ how many of your fields? _____ none

4. How many acres of alfalfa are typically irrigated per pond? _____ acres

5. Do you catch significant winter runoff in the pond? _____ Yes _____ No

6. Is runoff from fields other than alfalfa caught in the pond? _____ Yes _____ No

7. Do you return the pond water to the same field being irrigation or another field?
   _____ same field _____ another field _____ no return

8. In order to determine the volume of water the pond could contain, what is the approximate pond length, width and depth wetted by water?
   L = _____ ft W = _____ ft D = _____ ft

9. What is the source of pond design assistance that you use?
   Self Design ___ Irri/Pump Dealer ___ NRCS ___ Was it a cost share? _____

10. Is the return pump electric or diesel powered? _____ electric _____ diesel

11. Do you pump all the water out of the pond at the end of irrigation?

_____ Yes _____ No

Thank you for your participation in this survey. If you have any questions, please call Terry Prichard, Water Management Specialist, or Mick Canevari (UCCE Farm Advisor) at 209/468-2085. Please return this page in the enclosed postage-paid envelope to:

Terry Prichard, Water Management Specialist
University of California Cooperative Extension
420 S. Wilson Way
Stockton, CA 95205

APPENDIX II

Results of Survey on Pond Water Management Practices for Alfalfa Growers in Tracy Area, CA

University of California Cooperative Extension

ALFALFA IRRIGATION SURVEY - Feb. 2004

Survey sent to 26 growers on 2/6/04

Questions	Grower 1	Grower 2	Grower 3	Grower4	Grower 5	Grower 6	Grower 7	Grower 8	TOTAL	AVG
How many total acres of alfalfa do you farm?										
Acres	360	300	55	520	3200	546	347	560	5888	736.0
What is your typical alfalfa field size?										
Acres	60	80	55	55	80	100	65	90	585	73.1
Do you use a pond to catch irrigation runoff?										
All Fields	1	1	1	0	0	0	0	1	4	0.5
Some Fields	0	0	0	1	1	0	1	0	3	0.4
How many?	0	0	0	0	0	0	1	0	1	0.1
None	0	0	0	0	0	1	0	0	1	0.1
How many acres of alfalfa are typically irrigated per pond?										
Acres	60	0	55	50	80	0	25	200	470	58.8
Do you catch significant winter runoff in the pond?										
Yes	0	1	1	0	1	0	0	0	3	0.4
No		0	0	1	0	1	1	1	5	0.6
Is runoff from fields other than alfalfa caught in the pond?										
Yes	1	1	1	0	0	0	1	1	5	0.6
No	0	0	0	1	1	1	0	0	3	0.4
Do you return the pond water to the same field being irrigated or another field?										
Same field	1	1	0	0	1	0	1	1	5	0.6
Another field	1	1	1	0	0	0	1	0	4	0.5
No return	0	0	0	1	0	1	0	0	2	0.3
What is the approximate pond length, width and depth wetted by water?										
Length (ft)	120			200	400		150	120	990	198.0
Width (ft)	40			40	80		40	60	260	52.0
Depth (ft)	8			10	15		6	10	49	9.8
What is the source of pond design assistance that you use?										
Self design	1	1	1	1	1	0	1	1	7	0.9
Irri/pump dealer	1	0	0	0	0	0	0	0	1	0.1
NRCS	0	0	0	0	0	0	0	0	0	0.0
Was it a cost share?										
Yes	0	0	0	0	0	0	0	0	0	0.0
No	0	1	0	0	0	0	0	0	1	0.1
Is the return pump electric or diesel powered?										
Electric	1	1	1	0	1	0	0	1	5	0.6
Diesel	0	0	0	0	1	0	1	0	2	0.3
Do you pump all the water out of the pond at the end of orrigation?										
Yes	1	0	1	0	0	0	0	1	3	0.4
No	0	1	0	1	1	0	1	0	4	0.5
Other comments		Usually fresh water is added to the mix & used on any cambo of fields								

APPENDIX III

Draft Best Management Practices to Address the Potential for Movement of Herbicides Used in Alfalfa Production and the Pond Management Practices Which Can Reduce or Mitigate the Problem.

University of California Cooperative Extension

OPTIONS FOR MITIGATING SURFACE AND GROUND WATER POLLUTION FOR ALFALFA IN THE TRACY AREA OF CALIFORNIA

Terry L. Prichard, Water Management Specialist, UC Davis
Larry Schwankl, Irrigation Specialist, UC Davis
Mick Canevari, Field Crops Farm Advisor, UCCE San Joaquin County

This publication addresses the need to mitigate off-site movement of agricultural pesticide residues. It offers specific mitigation practices and costs of those practices, which can markedly reduce chemical residues reaching surface and ground waters. Tracy is centrally located on the western side of the Central Valley of California (Figure 1). The area under which these practices were developed and tested is unique in that the soils are predominantly cracking-clay soils with a shallow (15 feet) water table. Additionally, recent work performed in this area has identified the pathway of herbicide movement to ground water and evaluated methods to reduce the risk. The practices discussed here may be appropriate for other alfalfa producing areas with similar soils and conditions but may take significantly longer to reach ground water.

Figure 1. Location of Tracy, California

Alfalfa Irrigation Systems

The majority of alfalfa fields are irrigated using the border check method of surface irrigation. This method relies on borders to conduct water from the upper high end of the field to the lower end. Water is applied to each check allowing gravity to move the water down the check. Soil characteristics of texture, surface structure and porosity control the rate at which water infiltrates the soil. The rate of irrigation water delivered to the top of the check and the water infiltration rate into the soil determines the rate of the waters advance towards the field end. After the water begins to exit the end of the check, additional irrigation time is necessary to improve the distribution of water from top to bottom of the check. In order to attain adequate depth and uniformity of infiltrated water in the field, runoff is necessary. In fields where uniformity of water application is good, 10 to 15% of the irrigation water is collected as runoff. A typical 12-hour irrigation set with a 2200 gallon per minute onflow rate equates to nearly 240,000 gallons as runoff. Runoff water is disposed of by channeling into surface watercourses or by containment in a tail water pond where water could percolate to ground water, or by recycling the water back onto the field.

Link Between Irrigation and Movement of Chemical Residues

Studies have concluded herbicide and insecticide residues contained in the runoff can exit the field (Prichard, et al. 2004 and Foe and Sheipline 1993). Agricultural residues present in the tail water can affect surface water through direct channeling of the runoff into surface watercourses or it can affect ground water through containment in a tail water pond where runoff water percolates to ground water. If discharged to a surface watercourse or allowed to infiltrate into the ground water, these residues can pose a human or aquatic organism health risk. Recycling of the runoff water back onto the field is an effective method to prevent contamination of surface or ground water.

The physical and chemical characteristics of pesticides influence their tendency to interact with the soil and to dissolve in irrigation water. Characteristics used to determine pesticide fate include water solubility, soil half-life and soil organic carbon sorption coefficient.

Water solubility describes the amount of pesticide that will dissolve in a known amount of water. The higher the solubility values of a chemical, the more soluble the pesticide will be. Highly soluble pesticides are more likely to be removed from the soil by runoff or by moving below the root zone with excess water. For most pesticides, water solubility is not low enough to limit their dissolution and eventual offsite movement in irrigation or rain runoff water.

The half-life of a pesticide is a measure of its potential persistence in soil. Some pesticides require long soil half-lives for effective applications. For example, many pre-emergence herbicides require absorption by emerging weeds. Since they are applied prior to weed emergence, they must have a relatively long half-life in order for soil concentrations to be high enough to be effective. Pesticides can be degraded by light, which is called photolysis, by hydrolysis, which is a simple reaction in water, and by microorganisms present in the soil. In addition, soil half-life values are affected by climatic conditions where low light and low soil temperatures slow down the degradation processes.

The soil organic carbon sorption coefficient (Koc) describes the tendency of a pesticide to bind to soil. For most pesticides, the organic carbon present in soils is the most important portion of the soil that interacts with pesticide residues so organic carbon content is an important indication of a soils potential to sorb residues. Clayey soils usually contain more organic carbon than sandy soils, which is why application rates are greater in clayey than in sandy soils. Sorption retards movement and may also increase persistence because the pesticide is protected from degradation. All chemical residues do not interact with soil at the same rate so they do not move through soils at the same rate. Those with higher Koc values are absorbed more strongly to soil particles and so they are more resistant to offsite movement as dissolved residues. Koc is derived from laboratory data

The Pesticide Contamination Prevention Act of 1985 required the Department of Pesticide Regulation (DPR) to use a screening method to determine the potential for pesticides to pollute ground water. The procedure relies on Specific Numerical Values established by DPR to determine whether or not a pesticide is a potential “leacher” or has the potential to pollute ground water and thus listed in Section 6800 of the California Code of Regulations, Title 3 Food and Agriculture (Johnson, 1991). A pesticide’s potential to pollute ground water is described by its potential be **mobile**, which is measured by either its water solubility or Koc values, and its potential to be **persistent**, which is measured by its hydrolysis half-life or aerobic or anaerobic soil half-lives (Clayton, 2002). Table 1 lists commonly used chemicals in alfalfa production along with an indication of whether or not they are listed in section 6800 and whether or not they are considered mobile or persistent.

Table 1. Pesticides commonly used in alfalfa production

Common Name	**Potential Leacher as Listed in 6800**	Mobile	Persistent
2,4-DB dimethylamine salt (4)	Yes	Yes	Yes
Benefin	No	No	Yes
Bromoxynil octanoate ester (4)	No	No	No
Carbaryl	Yes	Yes	Yes
Carbofuran	Yes	Yes	Yes
Chlorpyrifos	No	No	Yes
Cyfluthrin	No	No	Yes
Cypermethrin	No	No	Yes
Dimethoate	Yes	Yes	Yes
Diuron	Yes	Yes	Yes
EPTC	Yes	Yes	Yes
Hexazinone	Yes	Yes	Yes
Imazethapyr (4)	Yes	Yes	Yes
Lambda-cyhalothrin	No	No	Yes
Malathion	Yes	Yes	Yes
Norflurazon	Yes	Yes	Yes
Paraquat dichloride salt	No	No	Yes
Permethrin	No	No	Yes
Sethoxydim	Yes	Yes	Yes
Trifluralin	No	No	Yes

Soil properties influence the rate of movement through the soil as well as the potential for surface runoff concentrations. Soil texture relates to the particle size makeup of the soil. Infiltration rate is dependant on the texture and structure of the soil. Sandy soils have larger particles than clay soils and thus tend to have higher infiltration rates. The higher infiltration rate generally produces less runoff but a greater potential for deep-water percolation passing below the root zone.

Another factor that effects water infiltration is the soil surface condition. Crusting of the surface reduces infiltration and increases potential for more runoff. Clay pans or hardpans in the sub-surface profile allow residue-laden waters to move along these impervious pans until a fracture in the hardpan layer allows movement to the ground water. Improving irrigation management can be accomplished by adjusting the onflow volume to the soil infiltration rate and the field slope. This improves irrigation efficiency, achieves good distribution of infiltrated water and minimizes runoff.

Residues Found in Runoff

Residues are more likely to be higher in runoff waters shortly after pesticide application. As time passes, decomposition takes place to reduce the concentrations. The rate of decomposition is sensitive to variations in site, soil, and climate. The best estimate of decomposition rate is the half-life

A common detection method for organophosphate (OP) insecticides in water is the survival of a test organism Ceriodaphnia dubia (water flea). It is sensitive to parts per trillion of the OP insecticide. In a study of 22 alfalfa fields sprayed with label rates of chlorpyrifos in the delta region of California, the runoff measured 22 to 62 days after application resulted in 100% mortality of C. dubia (Long, et al. 2002). In a previous study, DeVlaming (2001) found C. dubia mortality in chlorpyrifos-treated fields up to seven irrigations after application.

A study conducted in 2000 and 2003 in the Tracy area found a nonlinear decline in herbicide concentrations of diuron and hexazinone in the runoff water (Prichard, et al. 2004). Since a higher concentration of herbicide occurs in the runoff resulting from the first irrigations, mitigation practices are more effective in reducing the mass of herbicide moving off site at this time.

Once chemical residues move below the active root zone, there is little continued decomposition since most of the factors affecting decomposition, such as temperature and microbial activity are optimal in the upper profile of the root zone. Pesticides in the soil are primarily broken down by microbial activity. Soil microbial activity and pesticide breakdown are largely linked to soil temperature and moisture.

Residues Found in Ground Water

To date, 16 pesticide active ingredients or breakdown products have been detected in ground water from legal agricultural applications and, hence, from nonpoint-source applications in California (Troiano, et al. 2001)

More specifically, residues of pre-emergence herbicides were detected in seven wells sampled within a 6 square mile area located near the city of Tracy, California: atrazine was detected in 5 wells at 0.16 to 2.8 ppb, diuron in 1 well at 0.06 ppb, and simazine in 1 well at 0.098 ppb. The predominant cropping pattern was a rotation of alfalfa with corn and beans. The residues were related to agricultural applications.

A study was conducted in the Tracy area in 2000 to determine the pathway by which pesticides move to ground water. Two potential pathways were considered: percolating water during irrigation and infiltration of runoff water collected in a holding pond. Ground water in this area was shallow, located at approximately 15 feet from the soil surface, so excavation of the pond provided a shorter distance to ground water. The herbicides diuron and hexazinone, which were applied in December to a three-year old alfalfa crop, located contaminated wells.

Movement through Soil

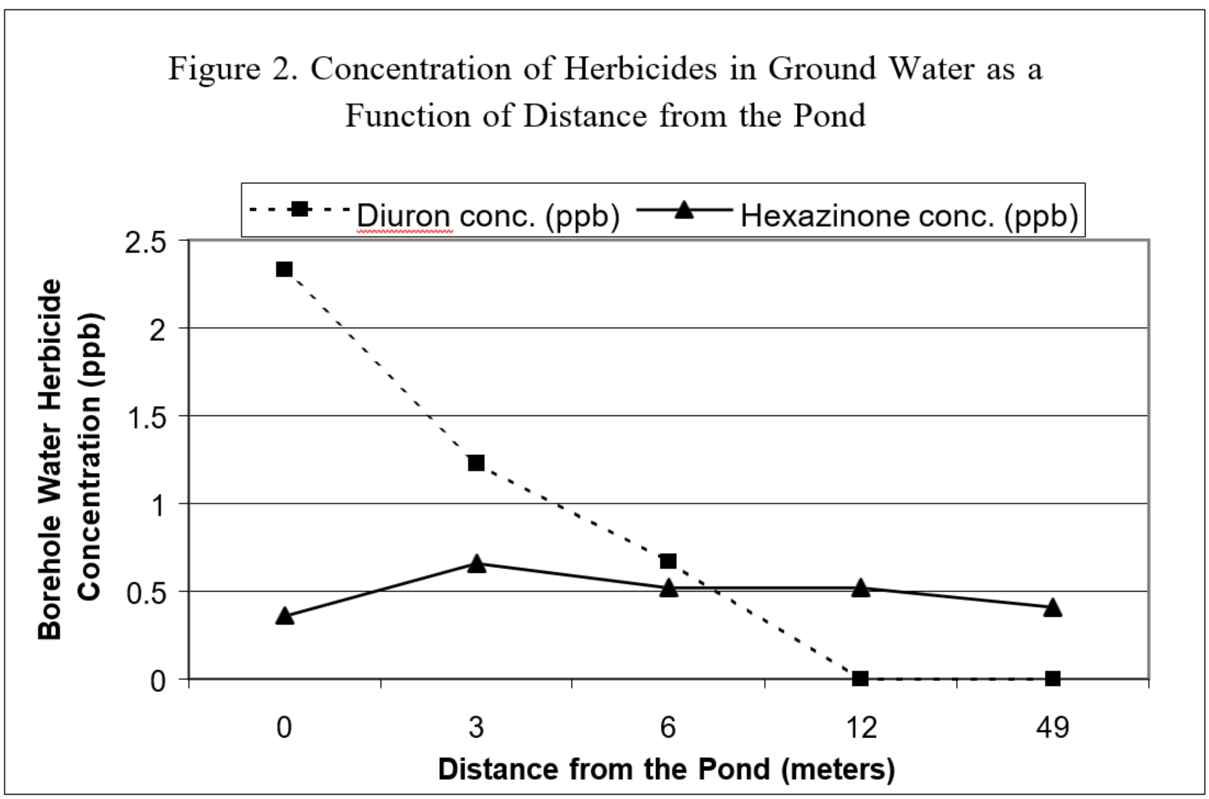
Soil samples were taken within the field prior to herbicide application and at 106 days and 198 days after application. Water content of cores taken after herbicide application where increased down to a depth 36 inches, which was the lowest depth, indicating that water was available for deep percolation. But even after two irrigations, herbicide residues were restricted within the alfalfa field to the upper layers of soil. Residues were detected only above the 8-inch soil depth.

Movement through the Pond

Residues were detected in runoff water that entered the pond and that rapidly infiltrated into the subsurface soil. Rapid pond water infiltration resulted in a rapid elevation increase in shallow ground water located near the pond, which was also shown to contain herbicide residues. It was concluded that the pond was the predominant source for movement of residues to ground water and that mitigation should focus on either reducing residues in runoff water or on mitigating infiltration of water from the pond.

Figure 2 shows the concentration of diuron and hexazinone in the shallow ground water as a function of distance from a holding pond that did not recycle tail water. Diuron concentrations declined with distance from the pond but hexazinone concentrations did not. It can be speculated that diuron moved less distance due to its higher Koc of 480 versus that of hexazinone at 54.

Figure 2. Concentration of Herbicides in Ground Water as a Function of Distance from the Pond



Good Management Practices which can Reduce Offsite Movement of Chemical Residues or Movement to Ground Water

A practical mitigation measure in this and other similar situations is to manage the runoff water that contains herbicide residues. Pumping the water out of the pond for reuse in the same or adjacent field would reduce the volume of water available for infiltration, reduce the infiltration rate, and decrease the time for infiltration to take place.

Other options include cutting off the onflow at a time to prevent runoff. This strategy causes poor uniformity of infiltrated water towards the end of the check resulting in plant water deficits. The result is less alfalfa production, a loss of stand leading to weed infestations and reduced alfalfa quality. Sprinkler irrigation is also an option which if managed properly results in no runoff. However, the costs of both system installation and operational costs are high when compared to surface irrigation.

Another option is to substitute with alternative chemicals that do not move as readily in the water or soil. An example would be to switch from diuron and hexazinone to trifluralin and paraquat. Table 2 indicates little potential movement due to the high Koc of paraquat and trifluralin. Sometimes a simple substitution is a workable strategy however the performance of the products should be comparable since poor weed control can decrease crop value.

Table 2. Estimates for pesticide active ingredient physical-chemical properties.
Data obtained from Oregon State University Extension website (Vogue et.al., 1994)

Active Ingredient	Soil ½-life (days)	Water Solubility (mg/L)	Koc (L/kg)	Movement Rating
Diuron	90	42	480	moderate
Hexazinone	90	33,000	54	very high
Paraquat	1,000	620,000	1,000,000	extremely low
Trifluralin	60	0.3	8,000	very low

The Effectiveness of a Tail Water Return System

A study conducted in the Tracy area in 2003 evaluated the effectiveness of recycling runoff back to the distribution system in irrigation sets after the runoff is collected. Diuron and hexazinone were applied to the field in December and residues of both were found in the runoff waters in similar concentrations as the 2002 study. Under the management conditions dictated by the grower over 6 irrigations, 45 percent of the runoff was recycled (Table 3). This translates to an equal reduction of herbicide residues moving to the ground water.

Table 3. Recycled Water Efficiency

	Gallons
Recycled Water Volume	257,962
Infiltrated Water	
Pump off to transducer	85,000
Residual pond water	67,639
Infiltrated water during irrigation	139,500
Total infiltrated water (above – evaporation)	268,739
Total runoff captured	573,501
	Percent
Percent of runoff returned	45
Percent of runoff returned using BMP	71

Improving Recycling Efficiency

The volume of water remaining in the pond after the last recycling event and the volume of runoff captured have a significant influence on the recycling efficiency. In the case study pond, 85,000 gallons remained in the pond, which could have been recycled. An additional 67,639 gallons were not recyclable due to the pond silt removal below the pumping inlet before the irrigations began. If these two volumes were recycled in each of the six irrigations, the recycling efficiency would increase to a seasonal average of 72 percent. The practice of pumping down the pond after each irrigation set would also minimize the infiltrated water by reducing the pond wetted area. A generalized estimate of recycling efficiency (if all these practices were implemented) is 85 - 90%. An increase in recycling efficiency is directly related to a decrease in herbicide residues infiltrating to ground water.

Tail Water Return Systems.

The most obvious advantage of a tail water recovery and recycling system is the reduced water use due to increased uniformity of infiltrated water. However, the effective control of applied chemical residuals in the runoff waters by returning them to the field has become an equally important issue. The effective mitigation of these residues can allow use of materials designated as having the potential to pollute ground water. The following chemicals have been detected in ground water or soil pursuant to Section 13149 of the Food and Agricultural Code and are listed in Section 6800(a) of the California Code of Regulations, Title 3 as the Ground Water Protection List (Table 4).

Table 4. 6800 Ground Water Protection List

Atrazine
Simazine
Bromacil
Diuron
Prometon
Bentazon (Basagran ®)
Norflurazon

The primary disadvantages of a tail water return system (other than costs) include the loss of area required for the reuse pond and periodic maintenance required for the pump and storage pond. Pond maintenance includes the removal and distribution of accumulated silt and controlling weeds.

Costs of Constructing and Operating a Tailwater Recycling Pond

Requirements

Tail water return systems consists of water ditches to collect runoff, drainage ways to convey water to the collection pond, sump pump and power unit, and a pipeline to conduct water to the point of redistribution. The point of redistribution is usually the top of the field being irrigated but can be an adjacent field.

Design Criteria

Proper design for the pump/driver is dependent on both the irrigation system and pond. Irrigation system applied volume, field slope, infiltration rate combined with irrigation management determine the amount of water available for runoff. Every field and soil type will accept water at varying rates. The actual rate that works best giving the best uniformity of infiltrated water is established by experience. The storage pond is typically determined by the quantity of runoff for an irrigation set. In the Tracy area, cracking clay soils are typical requiring about 15% runoff to maximize uniformity. A 2200 gpm water supply operated for 12 hours results in 240,000-gallon pond volume. The pump criterion is generally 1/3 of the supply, which is equal to 733 gallons; however, other considerations such as set length and pond volume can influence the decision. Pond management, defined as the timing and volume of pump back, also can help establish the pond size. Driver size is determined by the pumping rate (gpm) and the total dynamic head. Most growers prefer to discharge from the pond during the day set so different possibilities exist.

Operation Criteria

- **System 1** allows one set's runoff (240,000 gal) to be collected as a result of the night set, and then discharged during the next day set.
- **System 2** allows for collection of runoff (460,000 gal) from 2 sets, and then discharged during the third set. This provides for the first set being a day set.
- **System 3** allows for pond fill to the maximum (600,000 gal), and then discharged over a single set.

Costs

Each one of these scenarios requires different pump/driver and piping size.
Initial costs include pond excavation, concrete sump, electric driver/pump, pvc pipe, valving, and electrical hookup and controls. Installation of each is also included in the initial costs. Annualized costs include the hardware costs annualized over the useful life of each component minus salvage value, energy costs, tax and insurance. The study assumed a three- phase energy Ag 1A cost rate including the price per kilowatt-hour and all current charges via P G & E service area, which equaled $0.19/kWh. Off peak power use was not considered.

Alfalfa Tail Water System Criteria

Field size	80 acres, 1320 ft wide x 2640 long
Irrigated field	Two 1320 x 1320 each with a drain at bottom of field
Water Source Location	Top/North side of field
Pond Size	220 ft long , 50 ft wide, wetted depth of 8 ft. 2:1 slope sides
Pond volume at max	1.8 ac ft or about 600,000 gallons
	2.5 sets required to fill pond @ 15% of onflow as runoff
Pond Location	Bottom/South Side of Field
Distance from source to pond:	2900 ft on the straight line shortest distance
Irrigation system	Open Ditch / Siphons
	One set: 12 checks, (Width: 27 ft Length: 1320 ft)
	Set flow: 2220 gpm
	Gross irrigation: 6.0 in
Pond size	2000 cubic yards moved soil
	Trash removal screen on concrete sectional sump
	Pvc cl 100 IPS gasketed shortest distance
	Electric motor three- phase driver
	Pump single stage turbine
	Electric probe type on/off sensors
	Butterfly throttle valve
	Check valve

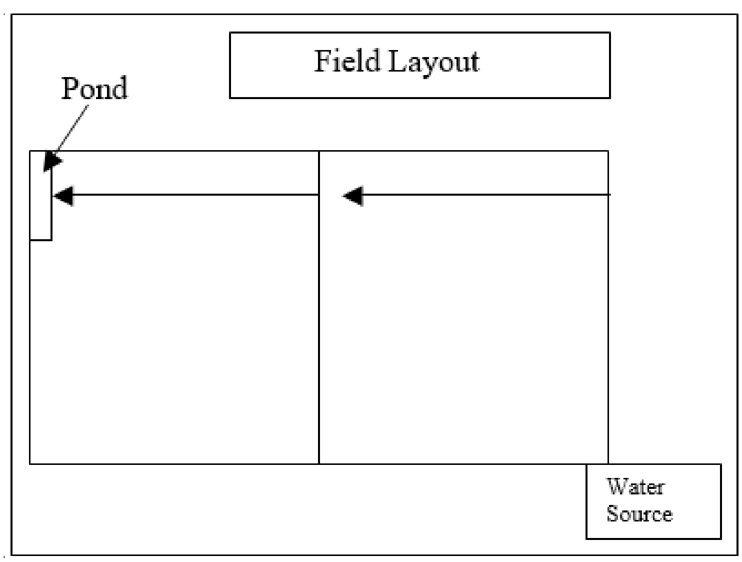


Table 5. Costs to install and operate a tail water return pond

			System 1	System 2	System 3	System 1 Dollars	System 2 Dollars	System 3 Dollars
Pond								
	Cubic Yards 2999	Gallons 605662				4500	4500	4500
Flow Rate	GPM		290	500	850			
Pipeline								
	Pipe	2900 ft	8"	8"	10"	8033	12441	12441
	Installation					14500	14500	14500
Concrete Sump						3000	3000	3000
	Installation							
Driver						5982	6726	7054
	Pump							
	Motor hp		5	10	15			
	Check Valve							
	Butterfly Valve							
	Installation							
Power Supply and Hookup						2500	2500	2500
	Pole							
	Service Panel							
	Mag Starter/ Panel							
	Auto on/off sensor/control							
	Installation							
Total Capital Costs						$38515	$43667	$43995
Annualized Costs								
	Annual Repairs/Maintenance					354	414	430
	Energy					444	515	454
	Weed control					200	200	200
	Silt Removal					200	200	200
Total Yearly Operational Costs						$1198	$1328	$1284

- Apply pesticides in a manner consistent with IPM practices. Utilize established pest management thresholds as outlined in UC IPM guidelines. Web site URL http://www.ipm.ucdavis.edu/

- Consider alternative weed management practices such as tillage, alternate herbicides when possible and cultural practices that discourage weeds.

- Minimize irrigation runoff from individual fields.

- Develop tail water return or neighbor-field recycling systems

- The use of alternative pesticides having less impact on water quality. Pesticides having low water solubility and high sorptivity have less likelihood of offsite movement.

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