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Evaluation of BMPs to Reduce NPS Pollution at the Farm Level

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Arroyo Colorado Agricultural Nonpoint Source Assessment
FY 06 CWA 319(h)
TSSWCB Agreement No. 06-10-07-05
Task 7 Report

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Table of Contents

INTRODUCTION

The Arroyo Colorado flows through Hidalgo, Cameron and Willacy Counties in the Lower Rio Grande Valley of Texas into the Laguna Madre and is the major source of fresh water to the lower Laguna Madre. The Arroyo Colorado is an economically and ecologically important resource to the region, having water exchange with the Gulf of Mexico. One third of the stream is also used for shipping from the Gulf Intracoastal Waterway to the Port of Harlingen. Most of the flow water in the Arroyo Colorado is also sustained by wastewater discharges, agricultural irrigation return flows, urban runoff, and base flows from shallow groundwater (Webster et al. 2000; Filteau 1995; Charbonnet et al. 2006; Rosenthal and Garza 2006). The Arroyo Colorado watershed has been on the state's list of impaired water bodies for low dissolved oxygen since the state began assessing water bodies in 1974. Moreover, the Laguna Atascosa National Wildlife Refuge and several county and city parks are located within the Arroyo watershed; its mild climate, semi-tropical plants and animals, and many recreational opportunities draw large numbers of people.

The Arroyo Colorado contributes significant amounts of agricultural, municipal, and industrial contaminants to the Laguna Madre (Custer and Mitchell 1991). Some efforts to implement best management practices (BMPs) have been taken to reduce nonpoint source (NPS) pollution in the region (Rosenthal and Garza 2007). In 1998, the Texas Commission on Environmental Quality (TCEQ) initiated an effort to develop total maximum daily load (TMDL) to address low dissolved oxygen (DO) levels in the tidal segment of the Arroyo (Rosenthal, et al. 2001, Matlock et al. 2003).

The TCEQ presented water quality data that indicated high levels of nutrients in the tidal segment (2201) and the above tidal segment (2202) (Figure 1), which exceeded the state's screening criteria, resulting in high chlorophyll-a and low levels of DO (TCEQ 2003). These high levels of nutrients are results of runoff from agricultural farms and urban areas. The impact of BMPs could be assessed indirectly with water savings between the water applied and the water used for beneficial purposes such as crop evapo-transpiration and salinity leaching. Excess water is lost through deep percolation, which eventually may carry nutrient loadings to the aquifer and runoff to the drainage, carrying loadings to ditches and to the Arroyo Colorado (TCEQ 2006).

Segments 2201 and 2202 have not met water quality standards in several years because of the presence of *E. coli* bacteria and low levels of DO. To meet the DO criteria (24-hour average of 4.0 mg/L and minimum of 3.0 mg/L) at least 90% of the time between the critical period of March through October, TCEQ (2003) estimated that a 90% reduction in nitrogen, phosphorous, oxygen demanding substances, and sediment would be necessary. The adoption of agricultural BMPs would help contribute to the reduction coming from agricultural areas.

This project monitored the water quality of irrigation, runoff, and percolation water of six irrigated farms that have adopted different combinations of BMPs. The main objective of this study was to assess the impact of these BMPs on water quality at these selected agricultural fields located in the Arroyo Colorado watershed during two irrigation events in 2009 and 2010.

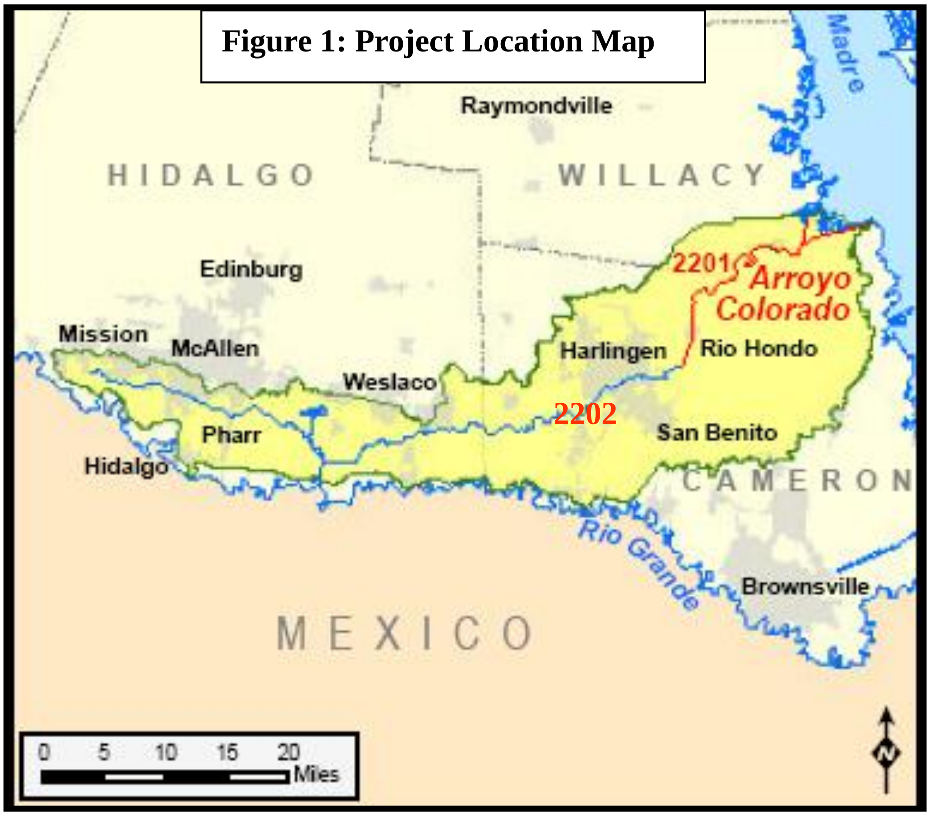


Figure 1. Location map of the Arroyo Colorado

MATERIAL AND METHODS

In addition to providing loading reductions resulting from BMPs, this project also provided result demonstrations to landowners in the Arroyo Colorado watershed. This data collection effort involves monitoring irrigation water inflow and outflow (via either tile drains or shallow groundwater) from agricultural fields to aid in evaluating BMP effectiveness and assessing agricultural loadings. Monitoring was conducted to represent both tiled and non-tiled irrigated cropland fields that drain to both drainage ditches and directly into the Arroyo. General guidelines followed in selection of the six fields are as follows:

- Sites are irrigated;
- Sites represent the primary production crops raised in the Lower Rio Grande Valley (LRGV), i.e., grain/sorghum, cotton, corn, and sugar cane;
- Sites represent both conventional and innovative irrigation BMPs in the LRGV;
- Sites are farmed by willing participants in the study; and
- Sites are within the Arroyo Colorado Watershed.

Texas AgriLife Extension Service (Extension), Texas AgriLife Research -Weslaco (AgriLife Research-Weslaco), and Texas A&M University-Kingsville (TAMUK) selected six suitable demonstration sites to assess loadings from agricultural runoff and leachate produced by different BMPs and to compare them with traditional practices. Six sites were selected by Texas State Soil and Water Conservation Board (TSSWCB), Texas Sea Grant, AgriLife Research and Extension, Harlingen Irrigation District, and Texas A&M Kingsville. The BMPs for the three most representative crops of the watershed were selected on March 30, 2007. Six representative sites were characterized and physical characteristics such as topography (slopes, coordinates and distances), soil texture, salinity and fertility levels, water quality and crops were obtained and evaluated. The six fields that were selected for the evaluation of agricultural BMPs are shown in Table 1 and Figure 2. Cultural practices such as irrigation timing, crop fertilization, and pest management used by the cooperating farmers in the recent past were documented. The layout and slopes of the sites with sampling points are shown in Figures 3 through 7. The BMPs for each site are shown in Table 2. Information regarding the type of BMPs adopted by the farmers were provided by the farmers and then corroborated with the Harlingen office of the TSSWCB.

Table 1. Site identification and description for BMP demonstration/evaluation.

Site ID	Location	Management Practices
FA	Rangerville: FM 800	Land leveled, IPM, poly-pipe, furrow irrigation
FB	Rangerville: FM 800	Land leveled, poly-pipe, furrow irrigation
FC	Simmons Rd/ FM 1479	Reduced till, poly-pipe, furrow irrigation, irrigation scheduling, Doppler meter
FD	South of San Juan. Hwy 281	Poly-pipe, furrow irrigation, drain tile
FE	South of Weslaco (FM 1015)	Poly-pipe, furrow irrigation
FF	N. of Harlingen (FM 508 & FM 507 N)	Poly-pipe, furrow irrigation, tile drained

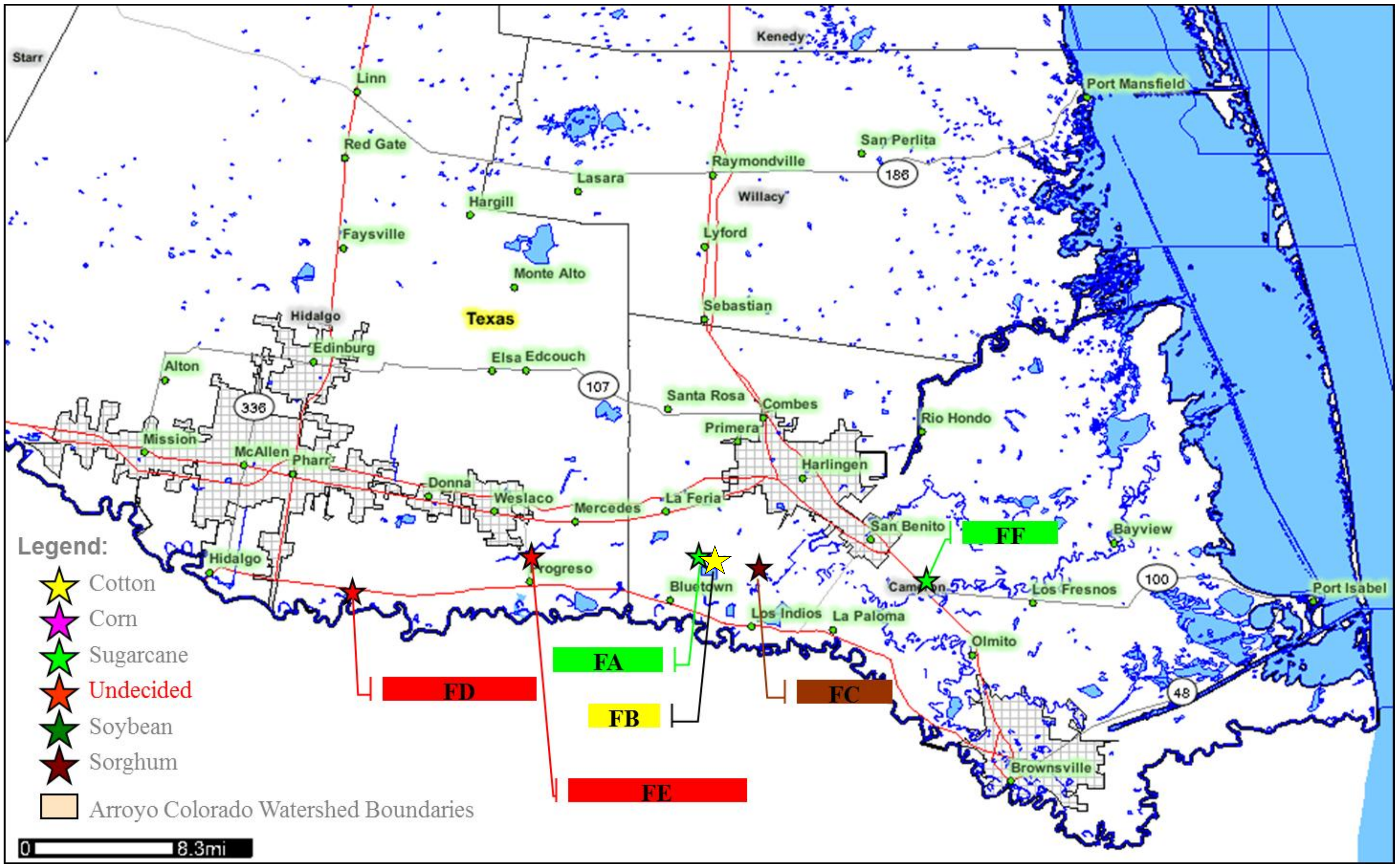


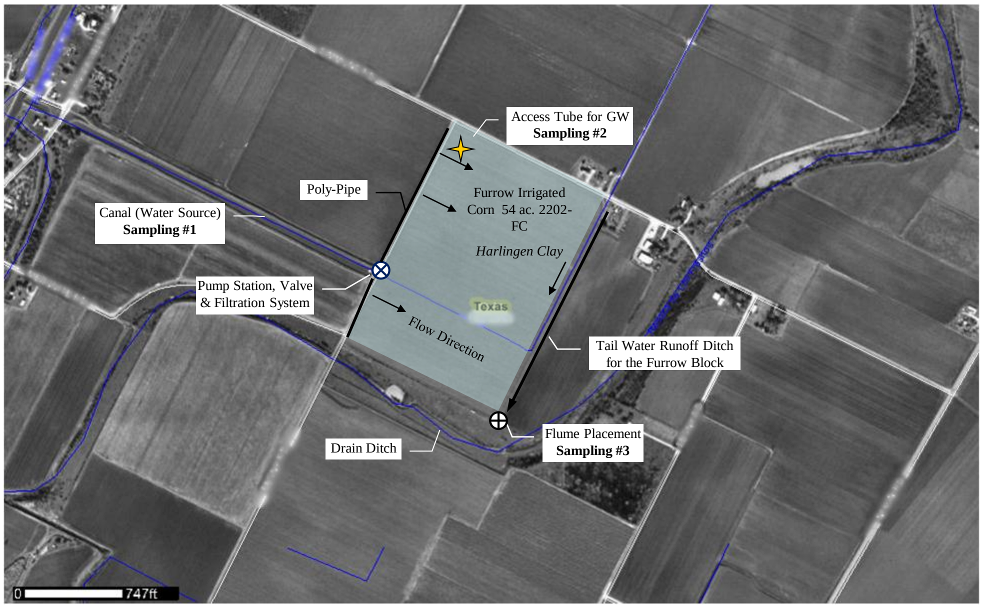
Figure 2. Cooperators sites in the Arroyo Colorado located in the Lower Rio Grande Valley, TX.

Table 2. Survey of BMPs practices at the six demonstration sites during 2009 and 2010.

BMPs in place	**FA**	**FB**	**FC**	**FD**	**FE**	**FF**
	2009					
Conservation Crop Rotation	X	X	X	X	X	X
Residue Management		X	X			X
Nutrient Management			X	X		X
Pest Management	X	X	X	X		
Irrigation Land Leveling	X	X	X	X	X	X
Irrigation Water Management	X	X				
Irrigation with Poly-pipe	X	X	X		X	X
Subsurface Drain				X		X
Filter Strip			X			
	2010					
Conservation Crop Rotation	X	X	X	X	X	X
Residue Management		X	X			X
Nutrient Management	X	X	X	X	X	X
Pest Management	X	X	X	X	X	X
Irrigation Land Leveling	X	X	X	X	X	X
Irrigation Water Management	X	X	X	X	X	X
Irrigation with Poly-pipe	X	X	X		X	X
Subsurface Drain				X		X
Filter Strip			X			

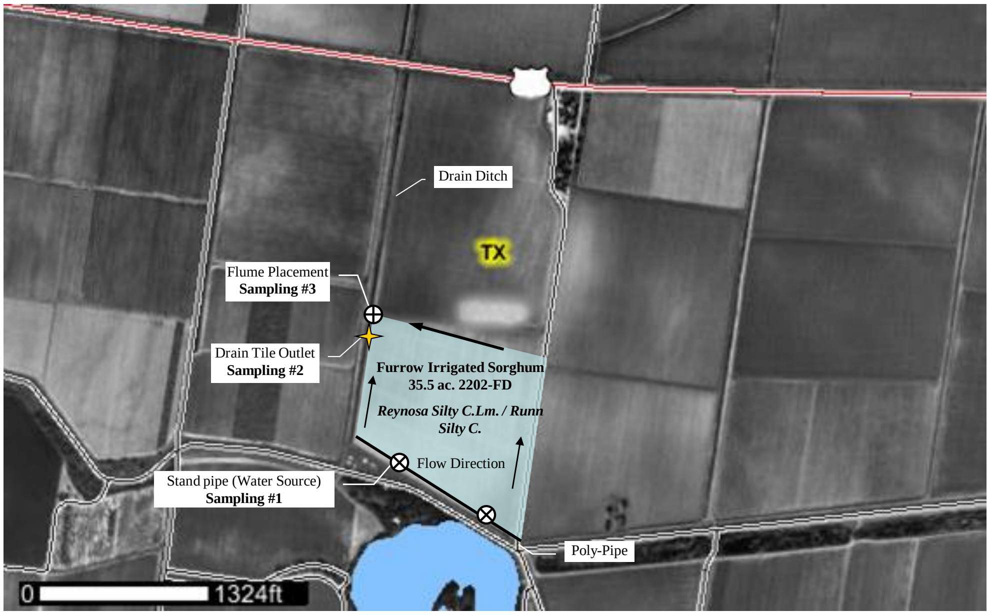
2202-FA	⊕ Location N.W. corner, by drop structure N 26°07.806' / W 097°44.403' / Elev. 38 ft.	⊗ Location S.E. corner stand pipe (1/3) N 26°07.611' / W 097°44.144' / Elev. 38 ft.	✦ Location N.W. corner, 50' from drop-off N 26°07.716' / W 097°44.162' / Elev. 34 ft.
2202-FB	⊕ Location S.W. corner, by drop structure N 26°07.306' / W 097°44.538' / Elev. 38 ft.	⊗ Location N.E. corner stand pipe (1/2) N 26°07.588' / W 097°44.389' / Elev. 35 ft.	✦ Location central East, 10th row N 26°07.560' / W 097°44.615' / Elev. 33 ft.

Figure 3. Sites FA and FB selected for the Agricultural Nonpoint Source Assessment Project.



2202-FC	⊕ Location S.E. corner, by drop structure N 26 07.684' / W 097 42.795' / Elev. 44 ft.	⊗ Location gate above canal N 26 07.867' / W 097 42.965' / Elev. 50 ft.	✦ Location 20th row from N.W corner, 20 steps in N 26 08.039' / W 097 42.847' / Elev. 46 ft.

Figure 4. Site FC selected for the Agricultural Nonpoint Source Assessment Project.



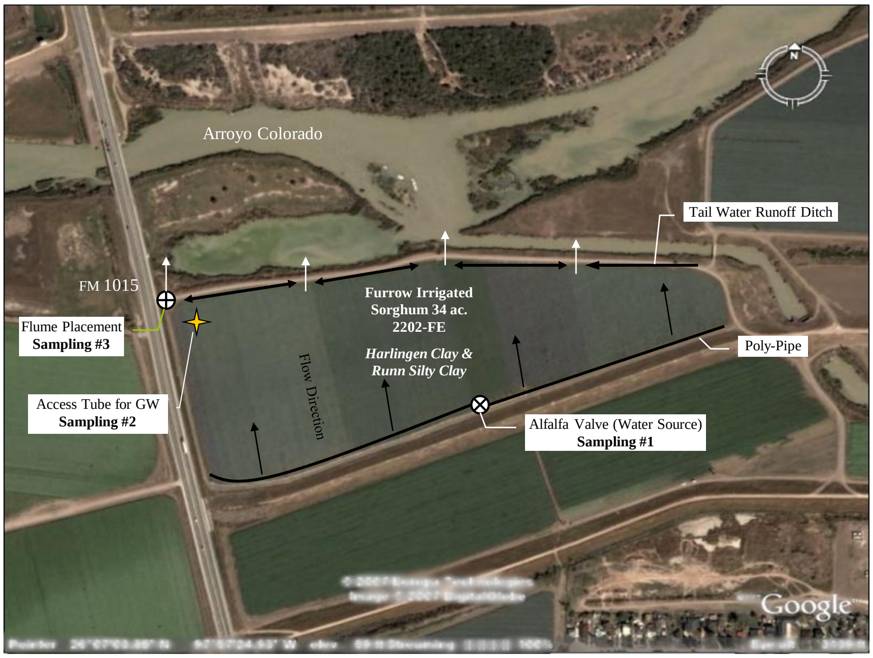
2202-FD

⊕ Location N.W. Corner

⊗ Location: 2 valves on South Side, along canal

✦ Location N.W. Corner

Figure 5. Site FD selected for the Agricultural Nonpoint Source Assessment Project.



2202-FE

⊗ Location S. side
N 26°07.023' / W 097°57.332' / Elev. 40 ft.

✦ Location N. side, by drop structure
N 26°07.123' / W 097°57.430' / Elev. 36 ft.

⊕ Location N.W. corner, by drop structure
N 26°07.084' / W 097°57.605' / Elev. 41 ft.

Figure 6. Sites FE selected for the Agricultural Nonpoint Source Assessment Project.

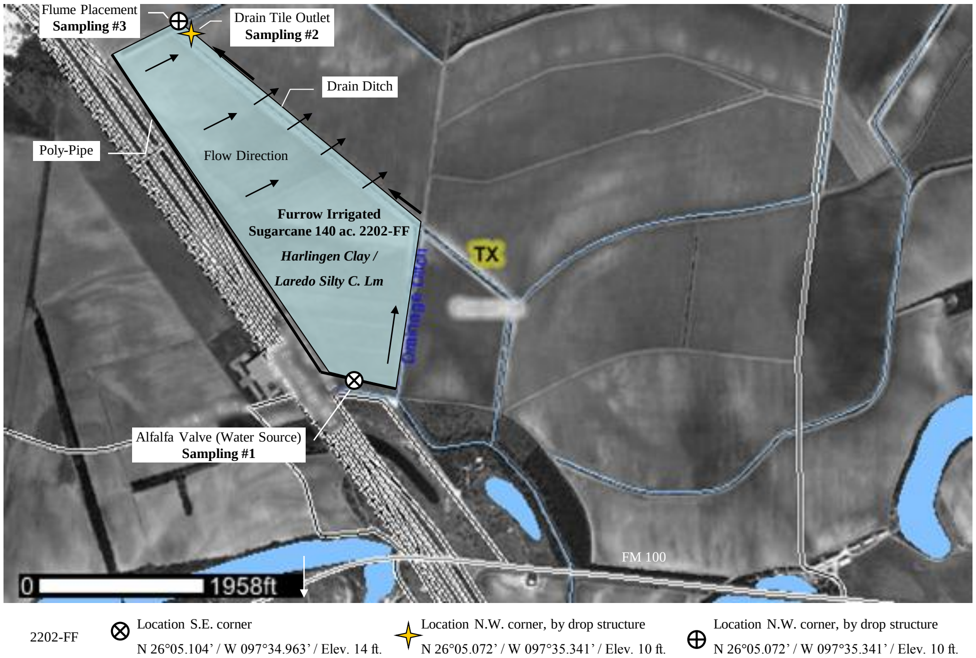


Figure 7. Site FF selected for the Agricultural Nonpoint Source Assessment Project.

Installation of Sensors

Flow meters, rain gauges, piezometers, soil water sensors were installed by Research-Weslaco on the demonstration sites.

Additionally the following actions were conducted:

a. **Site FA** (site with no drain tiles): a 2-inch PVC access tube was installed to a depth of 10 feet to collect samples from the groundwater. Watermark sensors were installed on one location at 6 and 12 inches deep to monitor soil moisture along the season. The topography of the 40-acre site was measured.
b. **Site FB** (site with no drain tiles): a 2-inch PVC access tube was installed to a depth of 10 feet to collect samples from the groundwater. Watermark sensors were already installed on one location at 6 and 12 inches deep to monitor soil moisture along the season.
c. **Site FC** (site with no drain tiles): a 2-inch PVC access tube was installed to a depth of 10 feet to collect samples from the groundwater. Corn was planted and Watermark sensors were installed on one location at 6 and 12 inches deep to monitor soil moisture along the season.
d. **Site FD** (site with no drain tiles): The previous crop was harvested and disked in mid-March. A pre-irrigation occurred afterwards to ensure a good germination of sorghum when it was planted. After planting, a 2-inch PVC access tube was installed to a depth of

10 feet to collect groundwater samples. Watermark sensors were installed on one location at 6 and 12 inches deep to monitor soil moisture along the season.

e. **Site FE** (site with drain tiles). Sorghum was planted and Watermark sensors were installed on one location at 6 and 12 inches deep to monitor soil moisture along the season.
f. **Site FF** (site with drain tiles): The outlet was under water most of the time.
g. AgriLife Research installed signs at all of the participating producer sites (in English and Spanish) to notify the producers to contact AgriLife Research before irrigating (Figure 8).

AgriLIFE EXTENSION
Texas A&M System

This irrigation demonstration site is sponsored by
Texas State Soil & Water Conservation Board

"to evaluate BMP's to reduce NPS pollution at the farm level"

Contact Xavier (772) 538-7334 or Dr. Enciso (956) 969-5635
at least 24 hours before irrigation occurs
Antes de regar por avise 24 hrs antes a las personas y
telefonos indicados arriba

Soil Water TSSWCB

ARROYO COLORADO
Know it. Respect it. Enjoy it.
Conócelo. Respétalo. Disfrútalo.

Figure 8. English Sign used during the result demonstration reports

Collection and Analysis of Data

Irrigation water inflow, surface runoff and outflow from the tile drainage system or through shallow groundwater, were monitored by AgriLife Research-Weslaco on selected irrigation events. The crops were monitored continuously to determine the optimum time for irrigation and for water sampling. The irrigation dates were not previously known because (1) fields have different crops with different water requirements, (2) fields were operated under different water management schemes, and (3) irrigation dates were highly dependent on climate, growth stage, and the operation of the irrigation district. Two irrigation events were selected for sampling each year. Sample numbers and frequency for the BMP demonstration are shown in Table 3.

Table 3. Sample type & frequency for demonstration and evaluation of BMPs.

Sample Type	**Number of Sites**	**Sampling Frequency**	**Total # Samples (2 years)**
Surface water runoff into Drainage Ditch for specific crops	6	2 samples per event, 2 different irrigation events per year	48
Subsurface drainage from different crops (tile drain outlet)	2	2 per year	8
Irrigation water	6	2 per year	24
Shallow groundwater (access tube)	4	2 per year	16

All water samples were analyzed for various nutrient forms (i.e., total phosphorus, dissolved orthophosphate phosphorus [frequently referred to as soluble reactive phosphorus], total Kjeldahl nitrogen, dissolved ammonia, dissolved nitrite plus nitrate), and total suspended sediments (TSS). In addition, monthly grab samples were analyzed for Biochemical Oxygen Demand (BOD), dissolved oxygen, water temperature, specific conductance, and pH. The nitrogen forms were included in the laboratory analyses to provide a more complete indication of macronutrient conditions in the watershed, evaluate whether agricultural BMPs were reducing both nutrients (nitrogen and phosphorus), and ensure that efforts to reduce one nutrient is not inadvertently increasing another.

A water sample was collected in a clean LDPE bottle and rinsed to measure temperature, conductivity, DO, and salinity on the field. Field parameters were measured in-situ using a portable hand-held YSI 85 meter for temperature, conductivity, DO, and salinity; and a YSI 60 meter for pH (Figure 9). Duplicate field measurements were taken and recorded. This is done to monitor potential water and meter variability. Additionally, water samples were collected immediately after recording those measurements and shipped to TAMU-K for analysis of total phosphorus, dissolved orthophosphate phosphorus, total Kjeldahl nitrogen, dissolved ammonia, dissolved nitrite plus nitrate, TSS and BOD5 (Table 4).

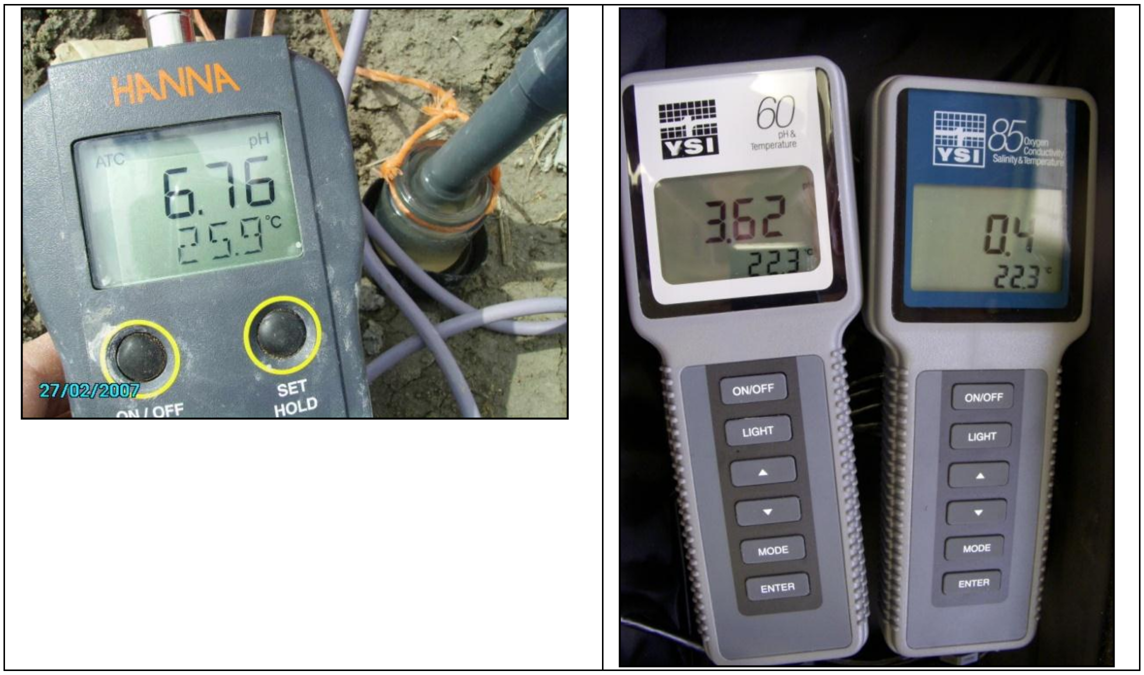


Figure 9. Left: Apparatus used to measure electrical conductivity of the water table. Right: apparatus used to monitor pH and BOD.

Table 4. Monitoring frequency for BMP demonstration/evaluation.

Station ID	Nutrients	Sediment	Flow Measurement
FA-I	2 per year	2 per year	Continuous 2 per year
FA-S	4 per year	4 per year	Continuous 2 per year
FA-GW	2 per year	2 per year	NA (well sample)
FB-I	2 per year	2 per year	Continuous 2 per year
FB-S	4 per year	4 per year	Continuous 2 per year
FB-GW	2 per year	2 per year	NA (well sample)
FC-I	2 per year	2 per year	Continuous 2 per year
FC-S	4 per year	4 per year	Continuous 2 per year
FC-GW	2 per year	2 per year	NA (well sample)
FD-I	2 per year	2 per year	Continuous 2 per year
FD-S	4 per year	4 per year	Continuous 2 per year
FD-TD	2 per year	2 per year	NA (well sample)
FE-I	2 per year	2 per year	Continuous 2 per year
FE-S	4 per year	4 per year	Continuous 2 per year

Station ID	Nutrients	Sediment	Flow Measurement
FE-GW	2 per year	2 per year	Instantaneous 2 per year depending on conditions (submerged or not)
FF-I	2 per year	2 per year	Continuous 2 per year
FF-S	4 per year	4 per year	Continuous 2 per year
FF-TD	2 per year	2 per year	Instantaneous 2 per year depending on conditions (submerged or not)

Nutrients = NO_2+NO_3*, TKN,* NH_3*,* PO_4*, TP*
Sediment = TSS
Field = dissolved oxygen, pH, conductivity, temperature, turbidity

Irrigation Water

The volume of water used during each irrigation event was measured using propeller flow meters (McCrometer) such as the ones shown in Figure 10. The volumes were then converted to irrigation depth. The quality of irrigation water was measured directly from the irrigation pipe (Figure 11). In case the farmer was applying fertilizer with the irrigation water, the sample was taken before it was mixed with fertilizer.

Figure 10. Propeller flow meters used to measure irrigation depth.

Figure 11. Collection of a water sample from irrigation.

Surface Runoff

Runoff was collected at the end of the surface drain before flow reached the Arroyo Colorado. A PVC mobile circular flume placed at the drainage ditch was used to measure runoff flow-rate using a data logger and a pressure transducer. This flume presented a discharge-head relationship for critical flow conditions by reducing the flow cross section (Hager 1988; Samani et al. 1991). Samani et al. 1991 described the construction and testing of these devices for different nominal sizes with different column pipes of external diameters. The flume measured water depth passing through and the water depth readings were recorded and directly related with the runoff flow rate. Two water samples were collected per irrigation event: a first sample collected during the early stage of the runoff event and a second sample at the peak runoff flow. Only the peak runoff was reported in this study. Peak runoff was taken from the drainage stream ditch where furrow discharge was in excess of irrigation water. See Figure 12 for schematic of the flume that was used to measure irrigation return flows. To assure that the circular flume measured accurately and with less than 10% error, the flow meter was calibrated in the Harlingen Irrigation District (Figure 13). The runoff depth was recorded with a data logger that was installed on the flume (Figure 14). The runoff volume was calculated from the hydrograph. Two water samples were collected per irrigation event: the first sample collected during the early stage of the runoff event and the second sample at the peak runoff flow (Figure 13). This is done because of the variability in runoff due to changing soil moisture conditions.

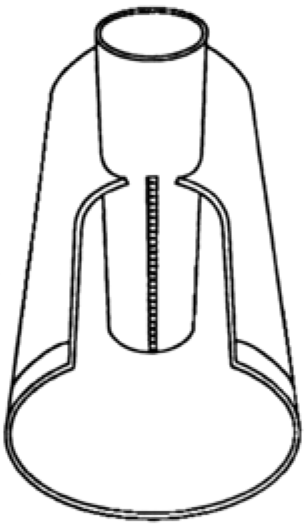
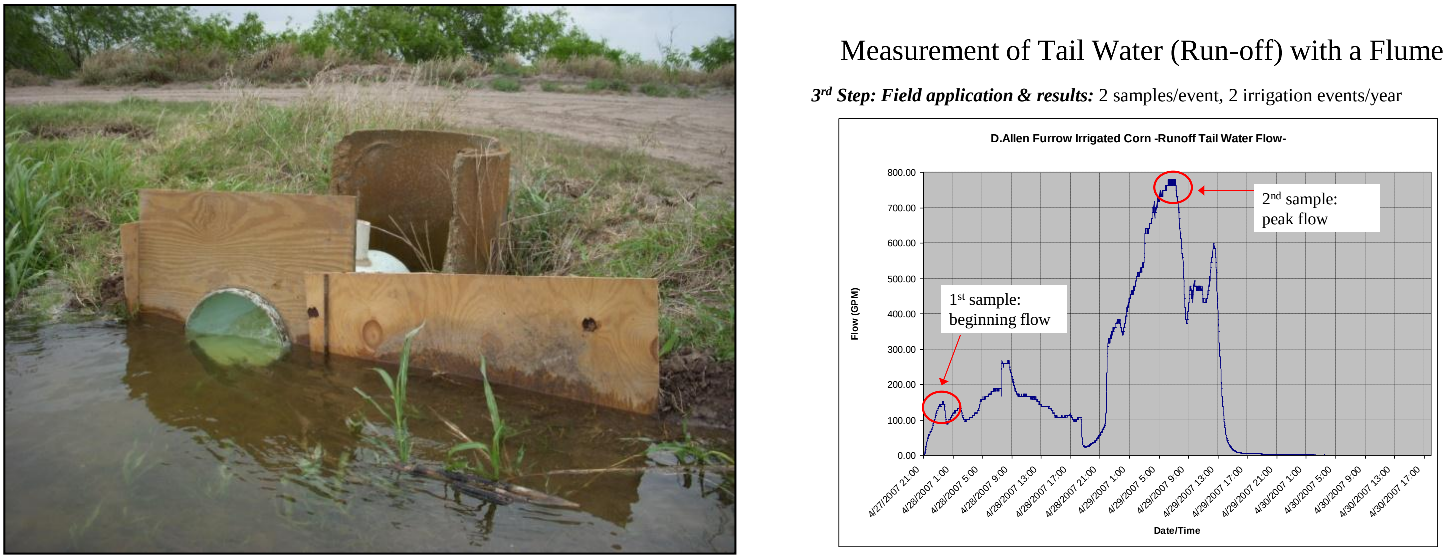


Figure 12. Circular Flume used to measure runoff.

Figure 13. Calibration of the circular flow meter in the Harlingen Irrigation District.



Measurement of Tail Water (Run-off) with a Flume

3rd Step: Field application & results: 2 samples/event, 2 irrigation events/year

Figure 14. Left: Circular flume measuring runoff with a data logger. Right: Hydrograph obtained during the irrigation event.

Water samples were collected during initial runoff from one furrow. It was generally the faster row to reach the lower end of the field first (Figure 15). The peak runoff was taken from the earthen ditch that collected the runoff from all the rows that were being irrigated at the approximate time when the peak runoff was achieved (Figure 16).

Figure 15. Collecting a water sample from initial runoff with a syringe at the end of the furrow.

Figure 16. Collecting a water sample to determine peak runoff.

Subsurface Drainage

Field sites with tile drains installed were sampled during selected irrigation events at the main outlet of the tile drains (Figure 17). In the fields that did not have tile drains, groundwater samples were collected from a 2-inch well that was dug in the field to a depth of 6 feet. The well was cased with a perforated PVC access tube. The groundwater sampling and monitoring method was done using the method described by Harter (2003). The installation of the piezometer to monitor the shallow ground is shown in Figure 18. Shallow groundwater was sampled from the project fields with no tile drains using EPA standard methods (Figure 19).


20/02/2007

Figure 17. Outlet that received the water drain from the field during the irrigation event.


09/10/2006

27/02/2007

Figure 18. Left: Installing a piezometer to obtain groundwater samples. Right: Probe to measure the depth of the water table.


Figure 19. Collecting a groundwater sample with a variable flow pump from a 2-inch well.

RESULTS

The irrigation dates and the crops grown in the six sites during the 2009 and 2010 growing seasons are shown in Table 5. Some pictures taken during the evaluations of the six sites are shown in Figures 20 to 26.

Table 5. Timing of irrigation and crops irrigated for each BPM demonstration site.

Site	First irrigation	Second irrigation	Crop 2009	Fertilizer	First irrigation	Second irrigation	Crop 2010	Fertilizer
FA/ 39.5 acres Clay texture	01/13/09	04/16/09	Corn		3/27/10 Post germination	6/03/10 1st bloom	Cotton	Injection of N32 during the second irrigation (8 gallons/acre equivalent to 29 lbs of nitrogen/acre)
FB/ 43 acres Clay texture	03/15/09	04/29/09	Sugarcane		7/26/10	8/17/10	Sugarcane	
FC/54 acres Clay soil	01/13/09	03/18/09	Sorghum		04/05/10 Post-plant	5/06/10	Corn	
FD/35 acre Silty clay loam soil	10/27/09		Onions		3/24/10		Onions	
FE/34 acres Clay soil	01/09/09	04/09/09	Collar green		5/02/10 Post-planted	5/31/10 bloom	Sorghum	
FF/ 140 acres Clay soil	02/04/09	03/23/09	Sugarcane	N32 was knifed prior to first irrigation 50 gal/ac (Feb 2009)	8/06/10 2nd irrigation	6/15/10 Post harvest	Sugarcane	N32 - 60 gal/ac (May 2010)

Figure 20. Site FA fertigating during the first irrigation. Right: Shows the flume to measure runoff volume at the corner of the field.

Figure 21. Upper Left: Site FB Irrigating with poly-pipe; Upper Right: Showing how water is pumped from the groundwater to collect samples for analysis. Lower Left: The lower left picture shows the installation of a flume to measure runoff volume. Lower Right: The lower right shows a vegetation strip where runoff is discharged.

Figure 22. Upper Left: Site FC irrigation with poly-pipe; Upper Right: Showing the downstream end of the field where runoff was collected.

Figure 23. Upper Left and Right: Site FD Irrigation with earth ditches and siphon tubes. Bottom Left: The bottom left shows an irrigation starting a siphon tube; Bottom Right: The right picture shows a pressure transducer used to measure drainage water from an outlet of a drain tile.

Figure 24. Site FE irrigated with poly-pipe and right picture showing the runoff from the field.

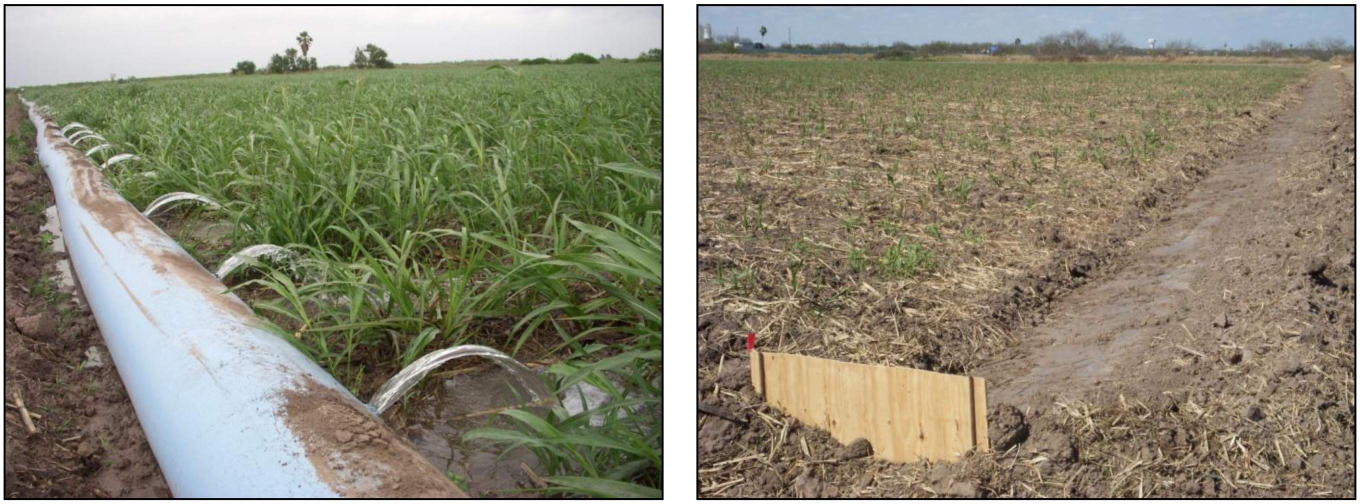
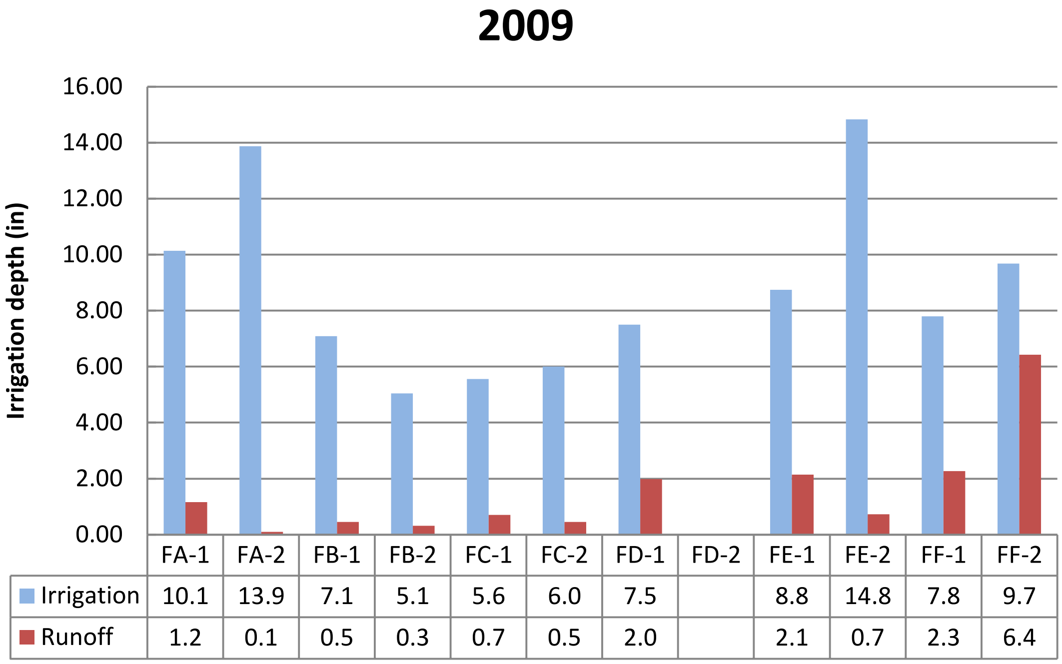


Figure 25. Site FF irrigated with poly-pipe and right picture showing the place where runoff was going to be measured.

Irrigation and Runoff Water Amounts

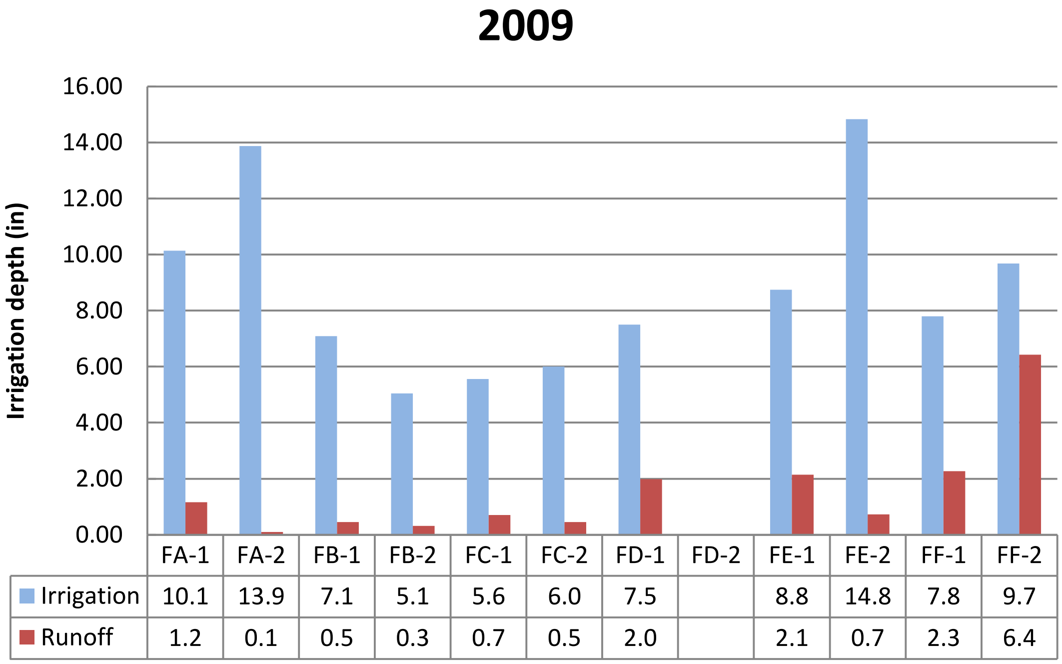
The highest irrigation depths were observed in site FA during the first and second irrigations and in site FE during the second irrigation in 2009 (Figure 26). Irrigation depths higher than 10 inches were observed in these two sites. Site FA has a clay texture that has a potential capacity of about 2.2 inch per foot depth. If we consider a root depth of 3 feet, this soil can hold up to 6.6 inches of water. Site FE also has a clay soil and it can also hold up to 6.6 inches of water in the 3 feet root zone. Therefore, the irrigation application of over 10 inches of water is excessive considering that the runoff amounts of sites FA and FE were very small. Most of the water at these sites was probably lost through deep percolation. In site FA, the rows were 1,305 feet long (Table 6) and it took 15 hours and 15 minutes for the water to reach the lower end of the row. The long irrigation time produced deeper water percolation. In 2009, it was also observed that the runoff amount was higher for site FF-2 during the second irrigation (Figure 27). The reason for this higher volume of runoff could be that the irrigator applied more water per row (25 gpm in one site and 16.7 gpm at another site) and the length of the rows were much less. The irrigator also left this site unattended, thus impacting the amount of runoff.

Most of the farmers applied small irrigation depths and the runoff amounts were also small in 2010 (Figure 27). This improved management was likely influenced as farmers received written reports regarding the amount of water that needs to be applied from AgriLife Research-Weslaco during the 2009 growing season. The data is not reported for sites FB during first and second irrigation and site FF during the second irrigation because the water meters and water level sensors did not work properly.



2009

	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
🟦 Irrigation	10.1	13.9	7.1	5.1	5.6	6.0	7.5		8.8	14.8	7.8	9.7
🟥 Runoff	1.2	0.1	0.5	0.3	0.7	0.5	2.0		2.1	0.7	2.3	6.4



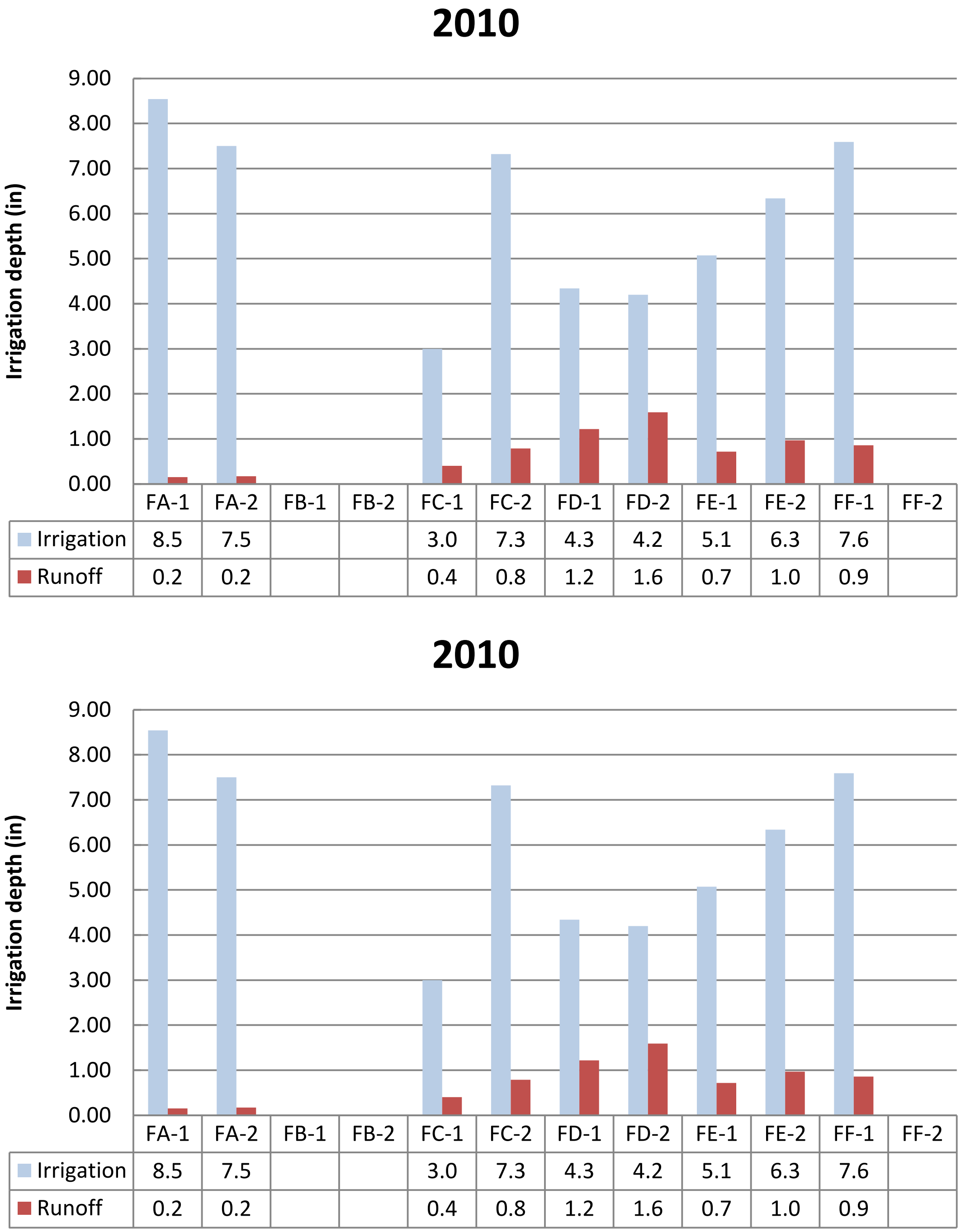
2009

	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
🟦 Irrigation	10.1	13.9	7.1	5.1	5.6	6.0	7.5		8.8	14.8	7.8	9.7
🟥 Runoff	1.2	0.1	0.5	0.3	0.7	0.5	2.0		2.1	0.7	2.3	6.4

Figure 26. Irrigation depth versus surface runoff recorded on the six demonstration sites during two irrigation events in 2009.

Table 6. Flow-rates applied per row and run lengths for the furrows for 2009. Some fields are not square and the lengths of both sides are reported.

Site	Flow (gpm)	Rows	Flow-rate per row (gpm)	Maximum length (ft)	Minimum length (ft)
FA-1	1100	60	18.3	1305	1305
FA-2	1000-1200	54-63	20.4-17.5		
FB-1	N/A	77	----------	1589	1396
FB-2	N/A	N/A			
FC-1	1100	63	17.4	1290	1290
FC-2	1100	74-80-97	14.9		
FD-1	2100	160-270	13.1-7.7	1426	1305
FD-2	No irrigation	No irrigation	No irrigation		
FE-1	1200	101	11.8	817	210
FE-2	1600-1900	151	11.6		
FF-1	600 to 1000	66-122	12.1-6.5	755	743
FF-2	1300 to 2000	66-102	25-16.7		



	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
Irrigation	8.5	7.5			3.0	7.3	4.3	4.2	5.1	6.3	7.6	
Runoff	0.2	0.2			0.4	0.8	1.2	1.6	0.7	1.0	0.9	

2010

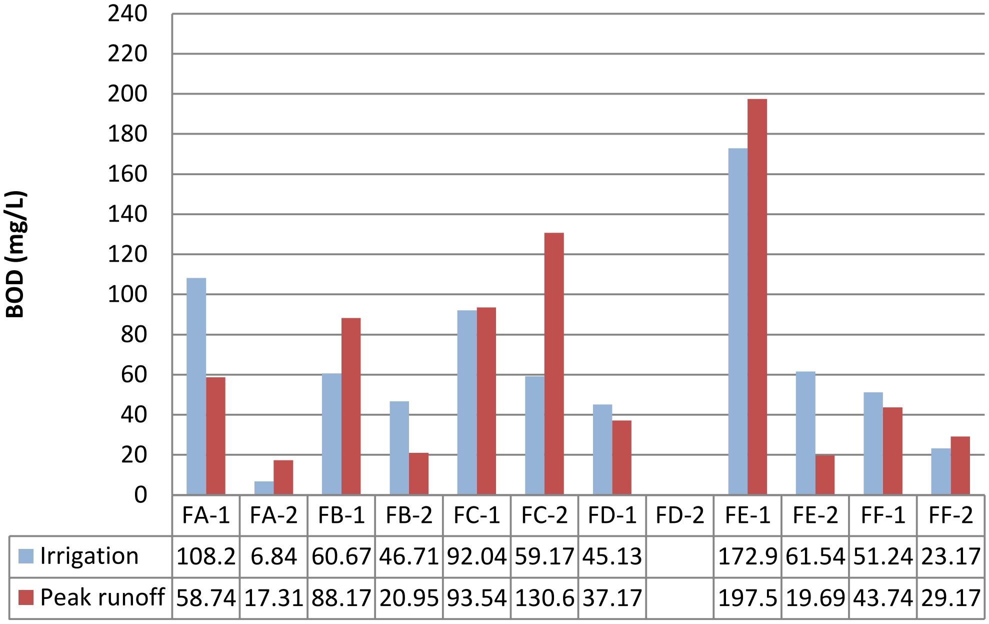
	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
Irrigation	8.5	7.5			3.0	7.3	4.3	4.2	5.1	6.3	7.6	
Runoff	0.2	0.2			0.4	0.8	1.2	1.6	0.7	1.0	0.9	

Figure 27. Irrigation depth versus surface runoff recorded on the six demonstration sites during two irrigation events in 2010.

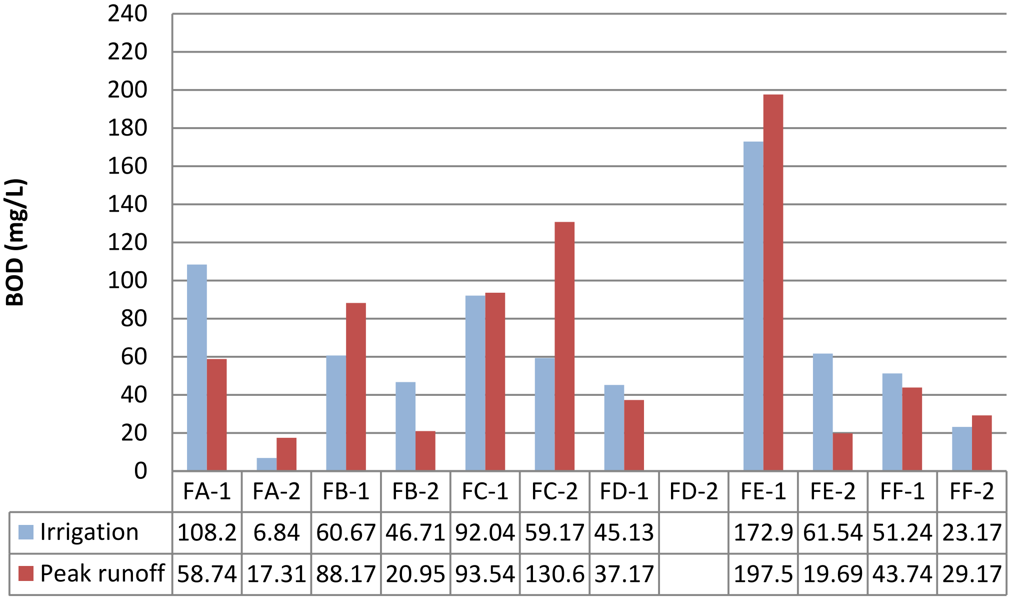
Irrigation and Runoff Water Quality Parameters

Biochemical Oxygen Demand

Biochemical oxygen demand is a chemical procedure for determining the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period. This parameter is used as an indication of the organic quality of water. It is commonly expressed in milligrams of oxygen consumed per liter of sample during 5 days of incubation at 20 °C and is often used to determine the degree of organic pollution in water. The BOD of all the sites was less than 100 mg/l in 2009. Few exceptions were sites FA for irrigation water during the first irrigation, site FC for runoff water during the second irrigation, and site FE for irrigation and runoff during the first irrigation due to already high levels in water supplied for irrigation. When the irrigation water entered the field, the BOD only increased in sites FB during the second irrigation, site FC during the second irrigation and site FE during the first irrigation. In the rest of the sites, BOD was almost the same or decreased with runoff. Most rivers with good water quality will have a BOD below 1 mg/L. Moderately polluted rivers may have a BOD value in the range of 2 to 8 mg/L. Untreated sewage can have BOD that varies around 600 mg/L in Europe and as low as 200 mg/L in the U.S. (Sawyer et al., 2003). The water used for irrigation in this study comes from the Rio Grande where it is pumped and then distributed through a network of canals. It is possible that the Rio Grande had already high levels of BOD or it increased within the irrigation canals. Mostly it can be said that the BOD decreased in the sites during 2009 (Figure 28); however, BOD increased in most of the sites in 2010 (Figure 29). The most noticeable were sites FB and FE.

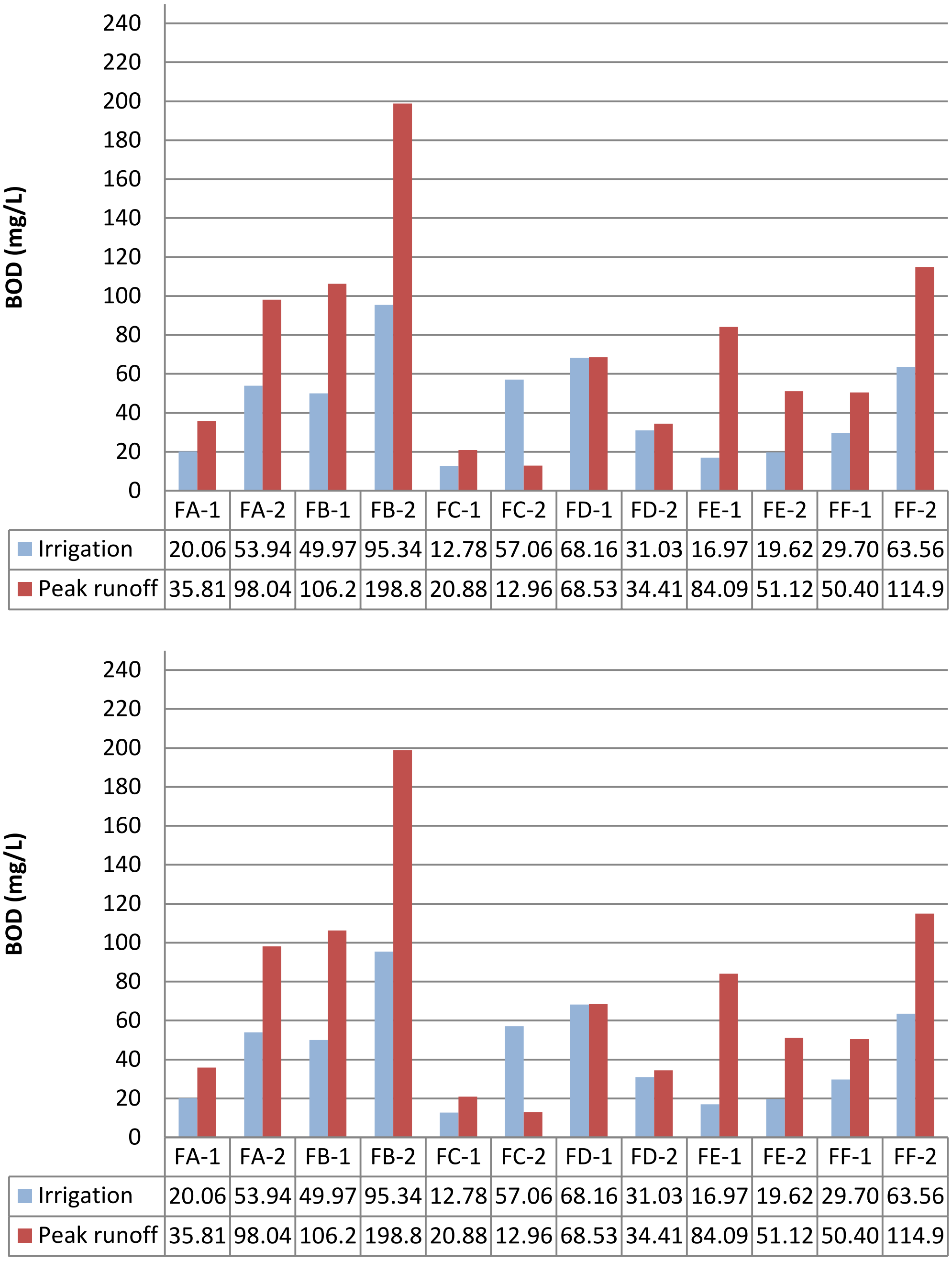


	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
🟦 Irrigation	108.2	6.84	60.67	46.71	92.04	59.17	45.13		172.9	61.54	51.24	23.17
🟥 Peak runoff	58.74	17.31	88.17	20.95	93.54	130.6	37.17		197.5	19.69	43.74	29.17



	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
🟦 Irrigation	108.2	6.84	60.67	46.71	92.04	59.17	45.13		172.9	61.54	51.24	23.17
🟥 Peak runoff	58.74	17.31	88.17	20.95	93.54	130.6	37.17		197.5	19.69	43.74	29.17

Figure 28. Biochemical oxygen demand of irrigation water and of peak runoff for six sites and two irrigation events in 2009.



	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
🟦 Irrigation	20.06	53.94	49.97	95.34	12.78	57.06	68.16	31.03	16.97	19.62	29.70	63.56
🟥 Peak runoff	35.81	98.04	106.2	198.8	20.88	12.96	68.53	34.41	84.09	51.12	50.40	114.9

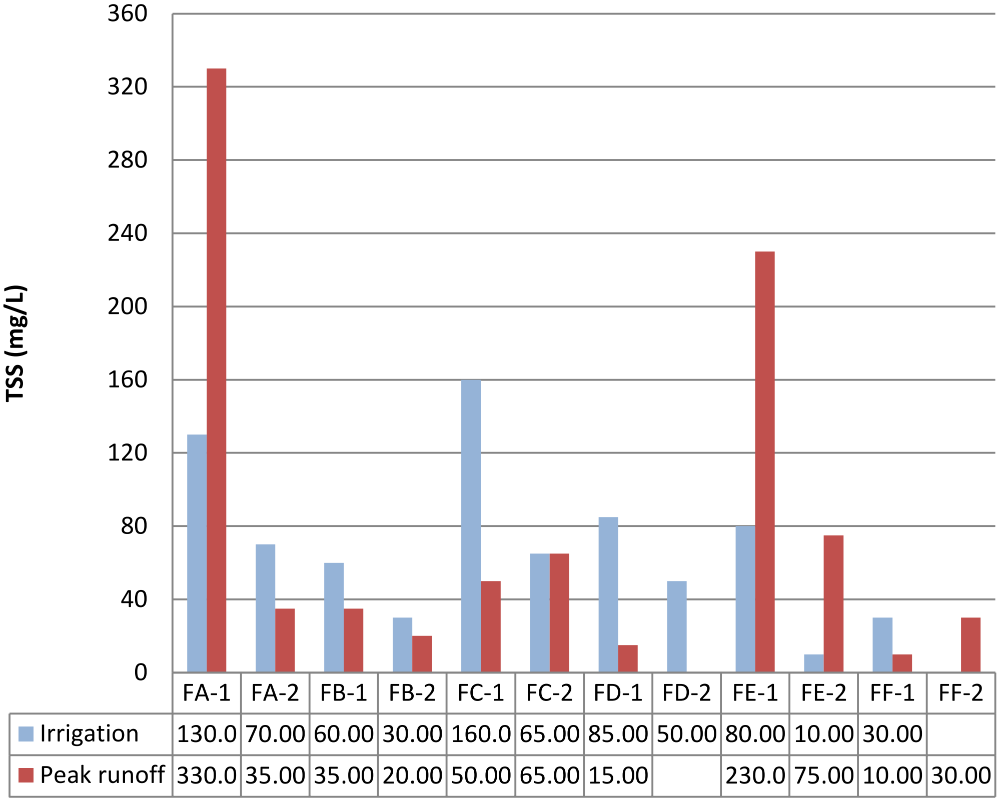
	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
🟦 Irrigation	20.06	53.94	49.97	95.34	12.78	57.06	68.16	31.03	16.97	19.62	29.70	63.56
🟥 Peak runoff	35.81	98.04	106.2	198.8	20.88	12.96	68.53	34.41	84.09	51.12	50.40	114.9

Figure 29. Biochemical oxygen demand of irrigation water and of peak runoff for six sites and two irrigation events in 2009.

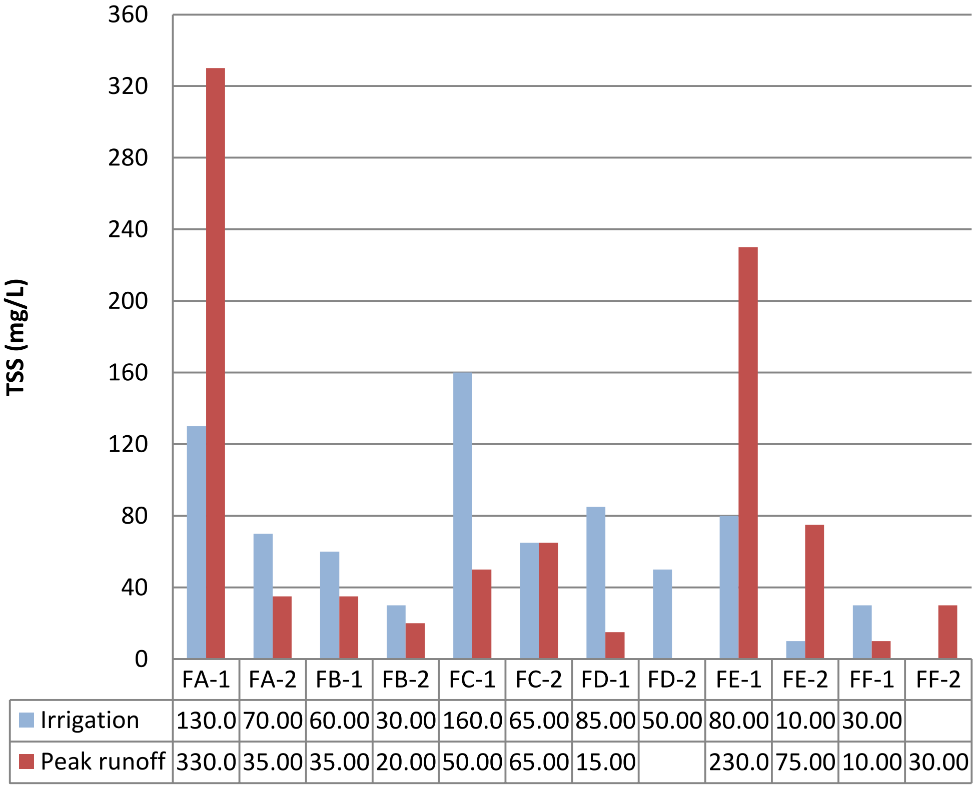
Total Suspended Solids (TSS)

Total suspended solid is a parameter used to measure water quality and includes all the particles suspended in water retained by a filter per unit volume of water. In surface irrigation, water flow detaches particles of soil, which are transported downstream changing the cross section area of the furrow. This process is called erosion. One of the main contributors to erosion in surface irrigated systems is the stream size; treatment typically consists of settling prior to discharge the water through runoff (Strelkoff and Bjorneberg, 1999).

Water, as it advances down the furrows, detaches soil particles from sides causing the particles to settle in the bottom of the row or be transported elsewhere. This happens because the rapid wetting of the soil, as irrigation water travels down the furrow, traps air inside the clods making them explode (especially during the first irrigation). The transport process is called erosion. One of the main contributors to erosion in surface irrigated systems is the stream size. Farming practices such as no-till, minimize soil erosion and practices such as improved irrigation management using non-erosive stream sizes (smaller stream sizes), could reduce TSS and protect water quality. Most people consider water with a TSS concentration less than 20 mg/l to be clear. Water with TSS levels between 40 and 80 mg/l tends to appear cloudy, while water with concentrations over 150 mg/l usually appears dirty. The nature of the particles that comprise the suspended solids may cause these numbers to vary. In general, the TSS numbers of the runoff water were smaller than the ones of the supply water in 2009 (Figure 30). However there were some exceptions; most notably were sites FA for the first irrigation event and site FE for the second irrigation event, which increased from 130 to 330 mg/l and from 80 to 230 mg/l, respectively. In 2010, only two sites appeared to have high TSS in runoff; these were sites FA for the first irrigation and site FC during the second irrigation (Figure 31). The reason could be that the first and second irrigation of the season generally produce more erosion. Site FD also added some TSS in the runoff water. It is likely that this site increased its TSS value in runoff water compared to the supply water. This can be attributed to using earth ditches and siphon tubes instead of the poly-pipe and erosion at the upstream side increased.

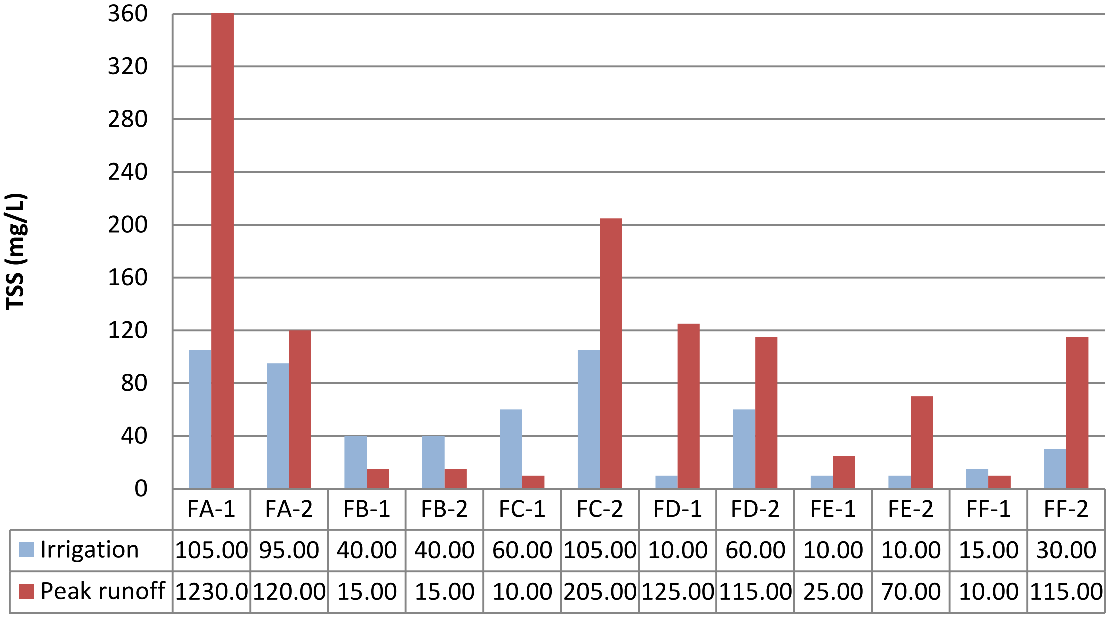


	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
🟦 Irrigation	130.0	70.00	60.00	30.00	160.0	65.00	85.00	50.00	80.00	10.00	30.00	
🟥 Peak runoff	330.0	35.00	35.00	20.00	50.00	65.00	15.00		230.0	75.00	10.00	30.00

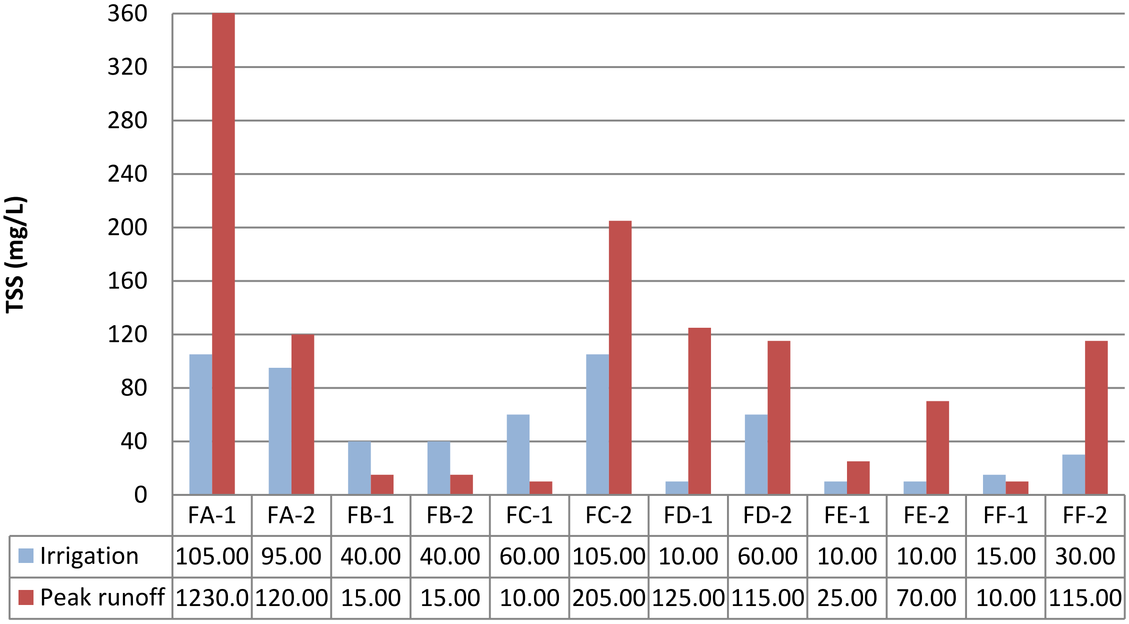


	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
🟦 Irrigation	130.0	70.00	60.00	30.00	160.0	65.00	85.00	50.00	80.00	10.00	30.00	
🟥 Peak runoff	330.0	35.00	35.00	20.00	50.00	65.00	15.00		230.0	75.00	10.00	30.00

Figure 30. Total suspended solids of irrigation water and of peak runoff for six sites and two irrigation events in 2009.



	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
🟦 Irrigation	105.00	95.00	40.00	40.00	60.00	105.00	10.00	60.00	10.00	10.00	15.00	30.00
🟥 Peak runoff	1230.0	120.00	15.00	15.00	10.00	205.00	125.00	115.00	25.00	70.00	10.00	115.00



	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
🟦 Irrigation	105.00	95.00	40.00	40.00	60.00	105.00	10.00	60.00	10.00	10.00	15.00	30.00
🟥 Peak runoff	1230.0	120.00	15.00	15.00	10.00	205.00	125.00	115.00	25.00	70.00	10.00	115.00

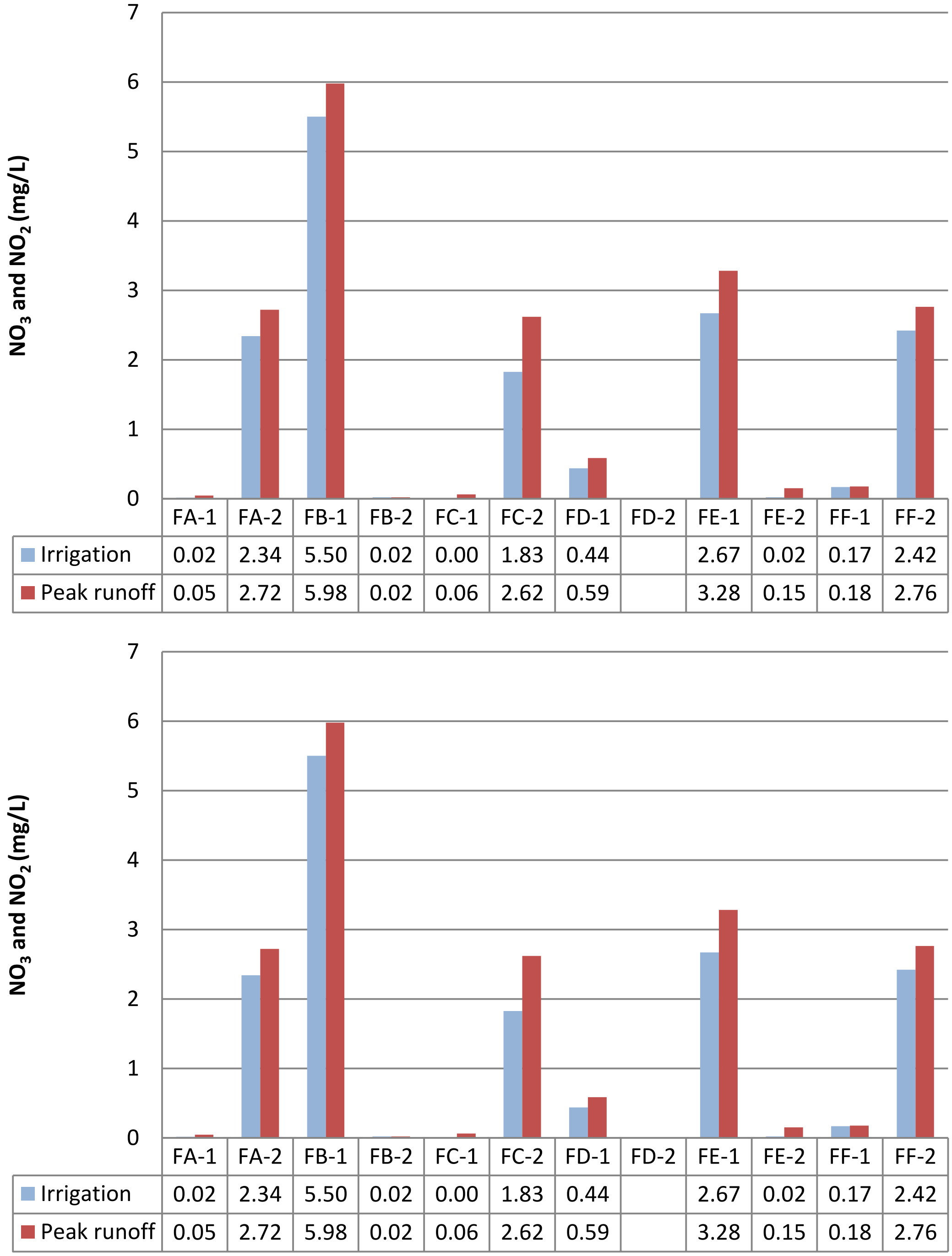
Figure 31. Total suspended solids of irrigation water and of peak runoff for six sites and two irrigation events in 2010.

Nitrates and Nitrites

Nitrate (NO3-) and nitrite (NO2-) are naturally occurring inorganic ions that are part of the nitrogen cycle. Microbial action in soil or water decomposes waste containing organic nitrogen into ammonia, which is then oxidized to nitrite and nitrate. Because nitrite is easily oxidized to nitrate, nitrate is the compound predominantly found in groundwater and surface waters.
The U.S. Environmental Protection Agency (EPA) drinking water standard for nitrates is 10 parts per million (ppm). The concentration of nitrate in the water can be increased by contamination with nitrogen-containing fertilizers, human organic wastes, organic animal wastes and contamination from septic sewer systems. Nitrate containing compounds in the soil are generally soluble and readily leach with infiltration.

For 2009, the sum of nitrates and nitrites for all the sites were lower than 6 mg/l (Figure 32). The highest was in site FB in which the irrigation and peak runoff water collected was 5.5 and 6.0 mg/l respectively. The nitrates and nitrites of the supply water and peak runoff were about the same for most sites. Even if nitrates and nitrites were high for site FB-1, the impact on nutrient loadings were low (0.6 lbs/ac), because the runoff volume was low (0.5 in). The highest nitrate and nitrite loadings were observed for site FE for the second irrigation with a loading of 4 lbs/acre due to high volumes of runoff (6.43 in). It is important to mention that the nitrates and nitrites of the irrigation water were already high and little loadings were added on the farm during irrigation. The net additions at site FE were just 1.3 lbs/ac of nitrates and nitrites. The second highest nitrates loading was site FE-1 with 1.6 lbs/ac in the runoff water; however, the nitrates and nitrites of the irrigation water were 5.3 lbs/ac. The rest of the sites presented nitrate and nitrite loadings of the runoff water of less than 0.3 lbs/ac.

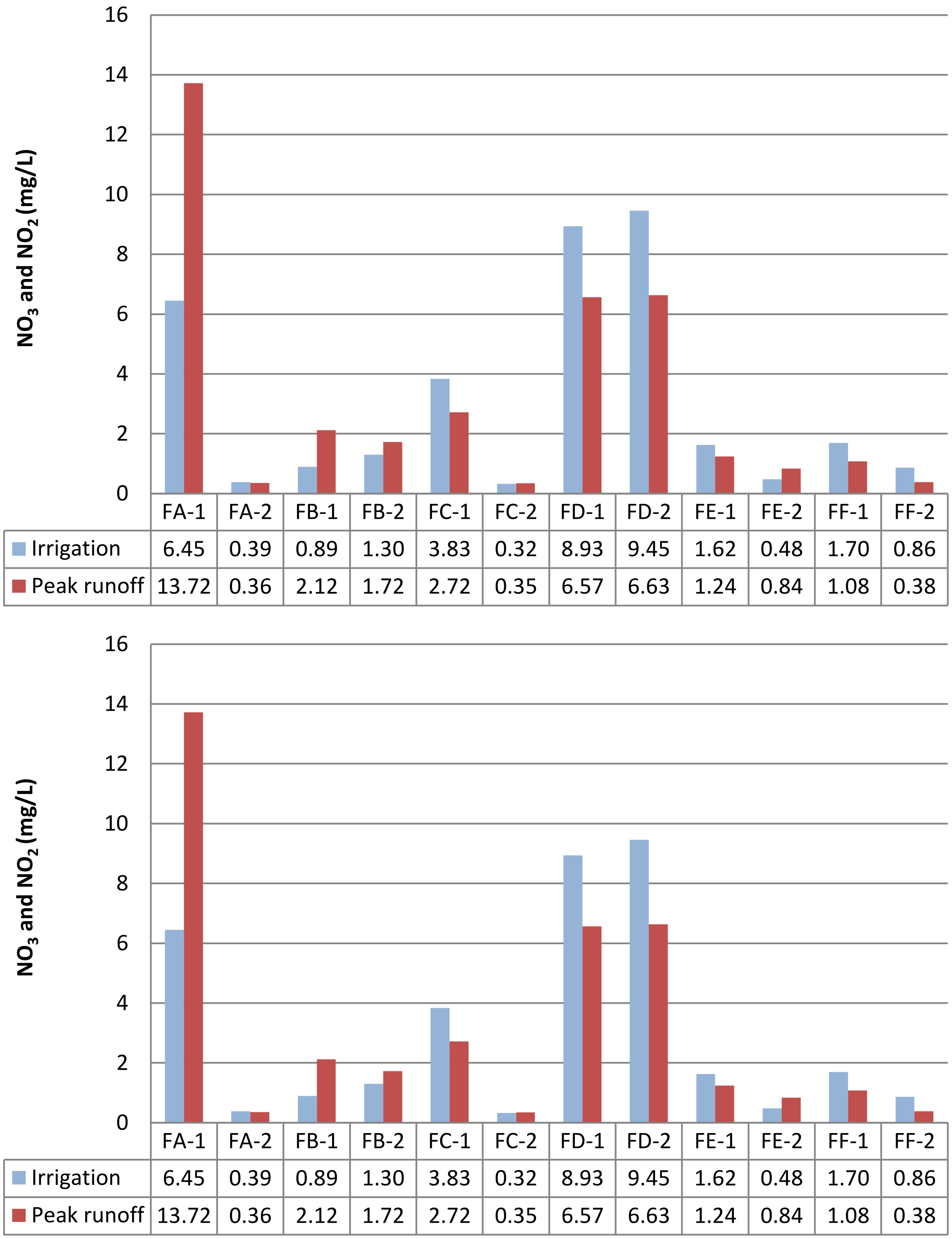
The same trend was observed in 2010 (Figure 33) with the exception of site FA for the first irrigation event. At this site, the nitrates and nitrites increased from 6.45 mg/l for the irrigation water to 13.72 mg/l in the runoff water. However, at site the nutrient loadings were low (0.5 lbs of nitrates and nitrites per acre) because of the low runoff produced (0.15 in). At site FD, the nitrate and nitrite loadings were 1.8 and 2.4 lbs/acre for the runoff water of the first and second irrigation respectively due to high volumes of runoff produced (1.2 and 1.6 inches). Nutrients were previously high on the irrigation water and the field helped to filter some of these high contents of nitrates and nitrites. The results indicate that the irrigation water already had high contents of nitrates and nitrites and this was variable from irrigation to irrigation. The gains of nitrates and nitrites loadings on the farm were small and the management practice that could impact nutrient loadings the most is the volume of runoff reduced. If irrigation is well attended, runoff can be reduced considerably.



	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
🟦 Irrigation	0.02	2.34	5.50	0.02	0.00	1.83	0.44		2.67	0.02	0.17	2.42
🟥 Peak runoff	0.05	2.72	5.98	0.02	0.06	2.62	0.59		3.28	0.15	0.18	2.76

	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
🟦 Irrigation	0.02	2.34	5.50	0.02	0.00	1.83	0.44		2.67	0.02	0.17	2.42
🟥 Peak runoff	0.05	2.72	5.98	0.02	0.06	2.62	0.59		3.28	0.15	0.18	2.76

Figure 32. Nitrates and nitrites of irrigation water and of peak runoff for six sites and two irrigation events in 2009.



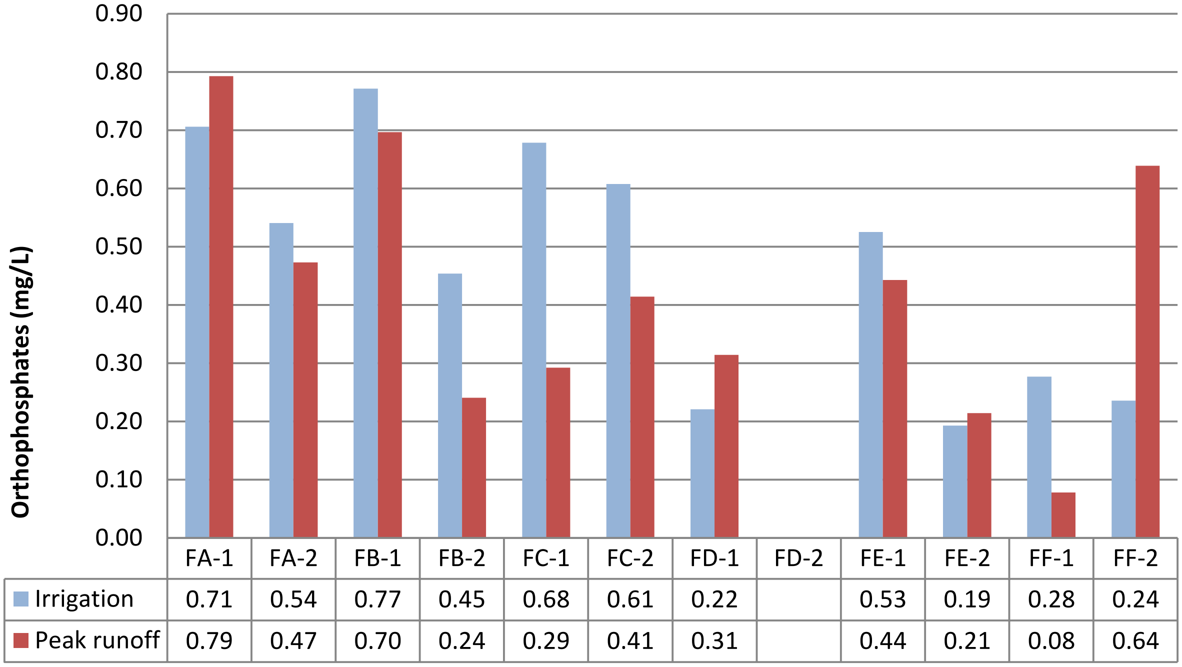
	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
🟦 Irrigation	6.45	0.39	0.89	1.30	3.83	0.32	8.93	9.45	1.62	0.48	1.70	0.86
🟥 Peak runoff	13.72	0.36	2.12	1.72	2.72	0.35	6.57	6.63	1.24	0.84	1.08	0.38

	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
🟦 Irrigation	6.45	0.39	0.89	1.30	3.83	0.32	8.93	9.45	1.62	0.48	1.70	0.86
🟥 Peak runoff	13.72	0.36	2.12	1.72	2.72	0.35	6.57	6.63	1.24	0.84	1.08	0.38

Figure 33. Nitrates and nitrites of irrigation water and of peak runoff for six sites and two irrigation events in 2010.

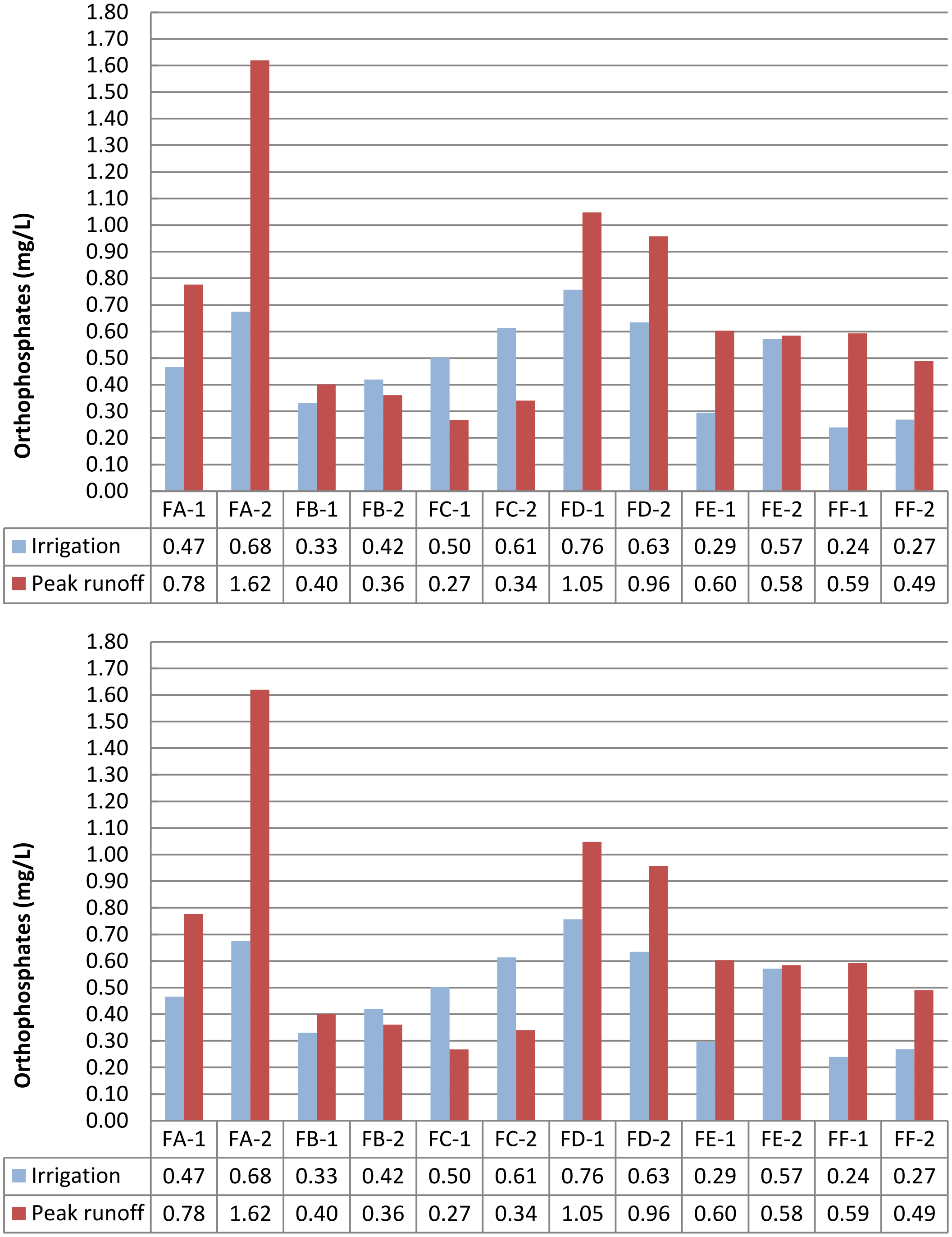
Orthophosphate

Orthophosphate ion $(PO_4)^{-3}$ is the simplest of a series of phosphates. In 2009, the orthophosphates were less than 0.8 mg/l and peak runoff contained almost the same or less orthophosphates than the irrigation water (Figure 34). The only exceptions were sites FA for the first irrigation event, and site FF for the second irrigation event in which orthophosphates increased from 0.71 to 0.79 mg/l and from 0.24 to 0.64 mg/l, respectively. The nutrient loadings due to orthophosphates were extremely low for all sites. The highest concentration was 1.2 lbs/ac for site FF during the second irrigation, which was impacted by the highest runoff volume collected at this site. However, if the orthophosphates that irrigation water had already contained were subtracted, the orthophosphates loadings were just 0.4 lbs/ac. Similar to 2009, the nutrient loadings due to orthophosphates were extremely low in 2010. The orthophosphates increased in the peak runoff in sites FA and FD in 2010 (Figure 35). Excluding these two sites, the orthophosphates were also lower than 0.8 mg/l. Site FA produced more erosion and TSS, probably because of higher furrow stream size, which resulted in higher orthophosphates carried by sediments. Site FD also produced the highest runoff of all sites in 2010. This impacted the orthophosphate loadings, which were highest of all sites at 0.2 and 0.3 lbs/ac for the first and second irrigation. Like the nitrate and nitrites loadings, the orthophosphates loading is highly influenced by the amount of runoff.



	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
🟦 Irrigation	0.71	0.54	0.77	0.45	0.68	0.61	0.22		0.53	0.19	0.28	0.24
🟥 Peak runoff	0.79	0.47	0.70	0.24	0.29	0.41	0.31		0.44	0.21	0.08	0.64

Figure 34. Orthophosphates of irrigation water and of peak runoff for six sites and two irrigation events in 2009.



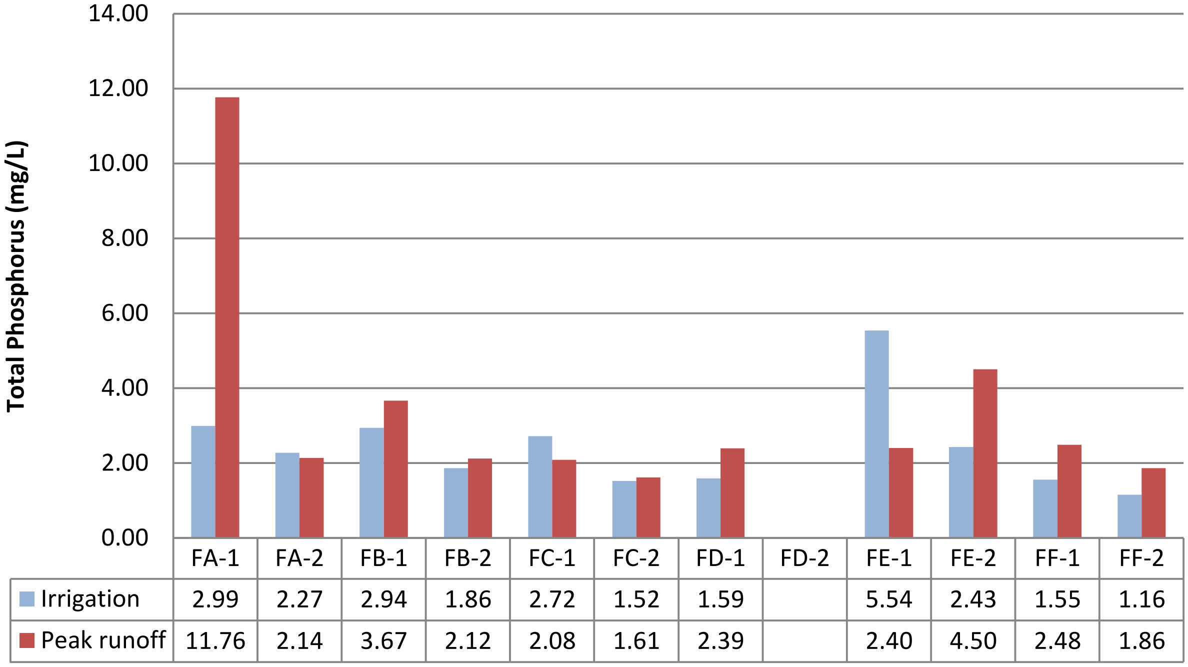
	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
🟦 Irrigation	0.47	0.68	0.33	0.42	0.50	0.61	0.76	0.63	0.29	0.57	0.24	0.27
🟥 Peak runoff	0.78	1.62	0.40	0.36	0.27	0.34	1.05	0.96	0.60	0.58	0.59	0.49

	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
🟦 Irrigation	0.47	0.68	0.33	0.42	0.50	0.61	0.76	0.63	0.29	0.57	0.24	0.27
🟥 Peak runoff	0.78	1.62	0.40	0.36	0.27	0.34	1.05	0.96	0.60	0.58	0.59	0.49

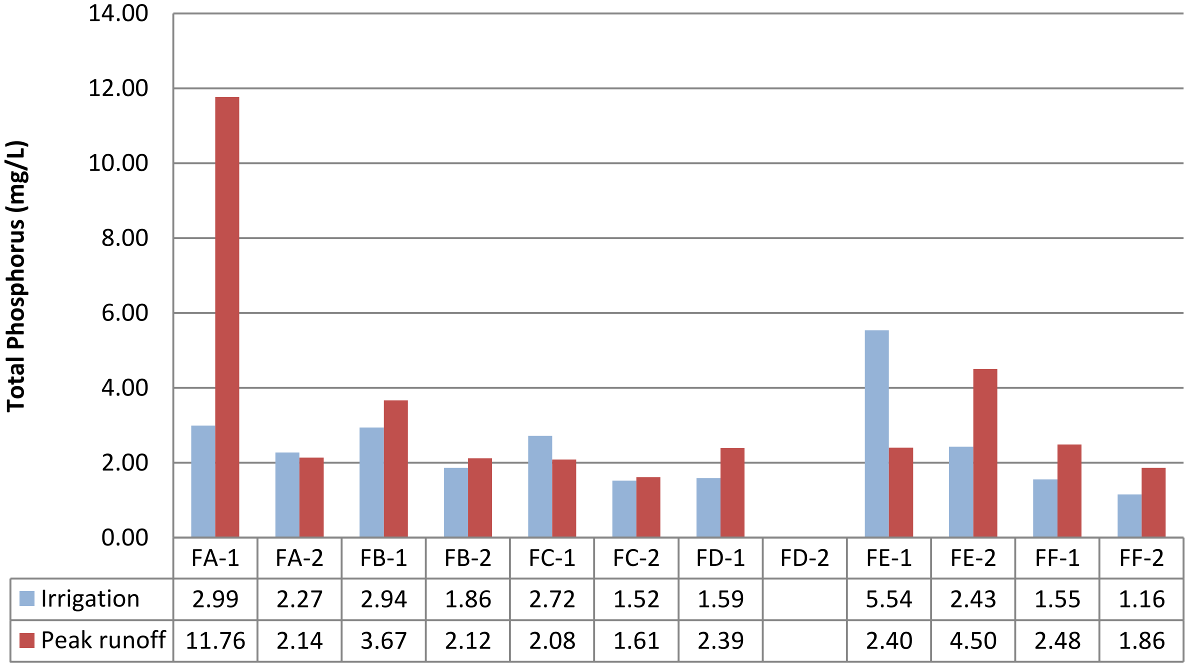
Figure 35. Orthophosphates of irrigation water and of peak runoff for six sites and two irrigation events in 2010.

Total Phosphorus

The total phosphorus in water was less than 6 mg/l in 2009 and less than 4 mg/l in 2010 (Figures 36 and 37). The highest increases from peak runoff occurred at site FA for the first irrigation event and at site FE for the second irrigation event in 2009. At most of the sites, the total phosphorus of the irrigation water and runoff were very similar. The total phosphorus of the peak runoff only increased significantly at sites FA-1 and FE-2. There is a relation between total suspended solids and total phosphorus. It may be possible to reduce the total phosphorus by decreasing the stream size in rows, especially during the first two irrigations. The highest nutrient loadings were observed at Site FA during the first irrigation, followed by site FF during the first and second irrigation and FE-1 with 3.1, 2.7, 1.3 and 1.16 lbs of total phosphorus per acre, respectively. This site also produced the highest runoff (1.2, 6.4, 2.3, 2.1 inches). In 2010, the sites that produced the higher total phosphorus levels were sites FA and FD. However, the highest total phosphorus loadings were for site FD during the first and second irrigation with 0.3 and 0.6 lbs/ac and this site also produced the largest runoff volumes. A similar trend was observed with orthophosphates and TSS.

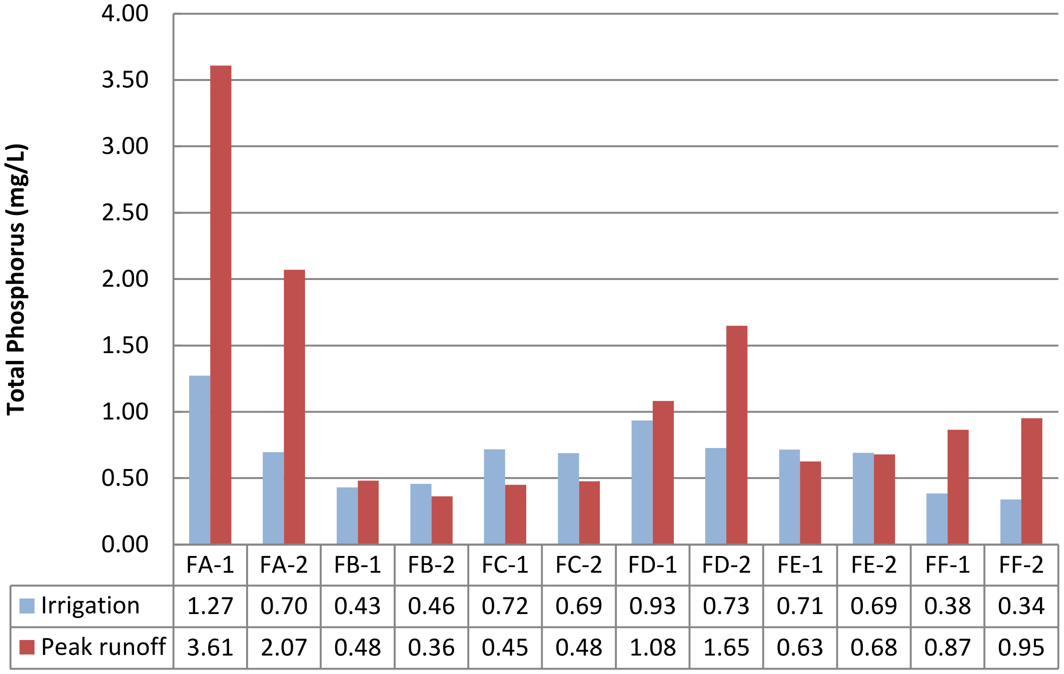


	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
🟦 Irrigation	2.99	2.27	2.94	1.86	2.72	1.52	1.59		5.54	2.43	1.55	1.16
🟥 Peak runoff	11.76	2.14	3.67	2.12	2.08	1.61	2.39		2.40	4.50	2.48	1.86

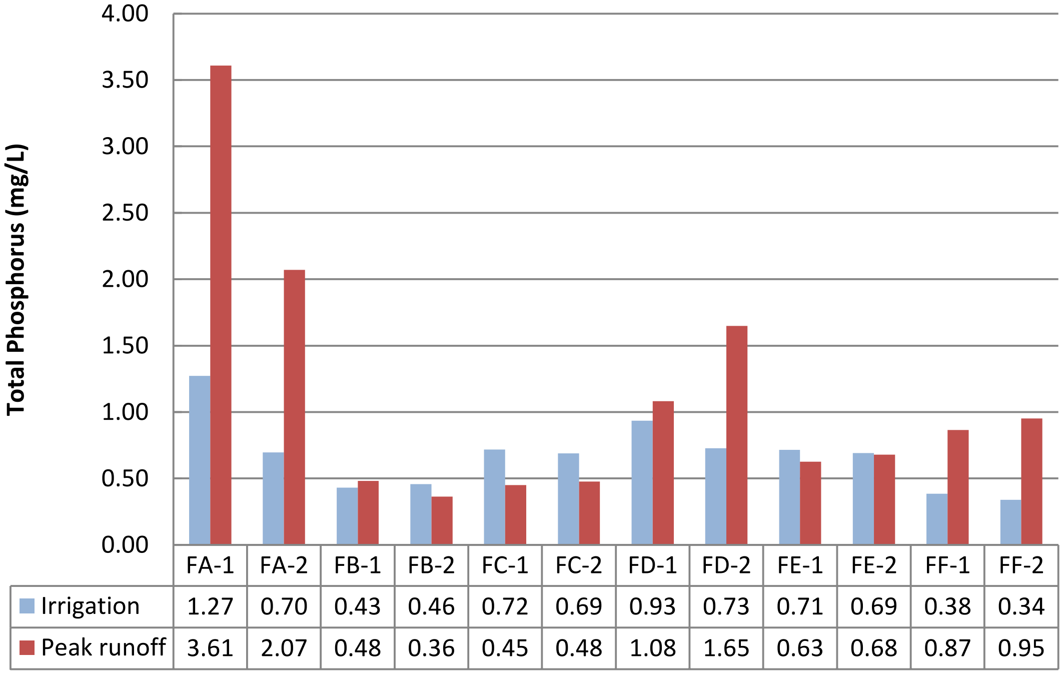

Total Phosphorus (mg/L)
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00

	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
🟦 Irrigation	2.99	2.27	2.94	1.86	2.72	1.52	1.59		5.54	2.43	1.55	1.16
🟥 Peak runoff	11.76	2.14	3.67	2.12	2.08	1.61	2.39		2.40	4.50	2.48	1.86

Figure 36. Total phosphorus of irrigation water and of peak runoff for six sites and two irrigation events in 2009.



	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
🟦 Irrigation	1.27	0.70	0.43	0.46	0.72	0.69	0.93	0.73	0.71	0.69	0.38	0.34
🟥 Peak runoff	3.61	2.07	0.48	0.36	0.45	0.48	1.08	1.65	0.63	0.68	0.87	0.95

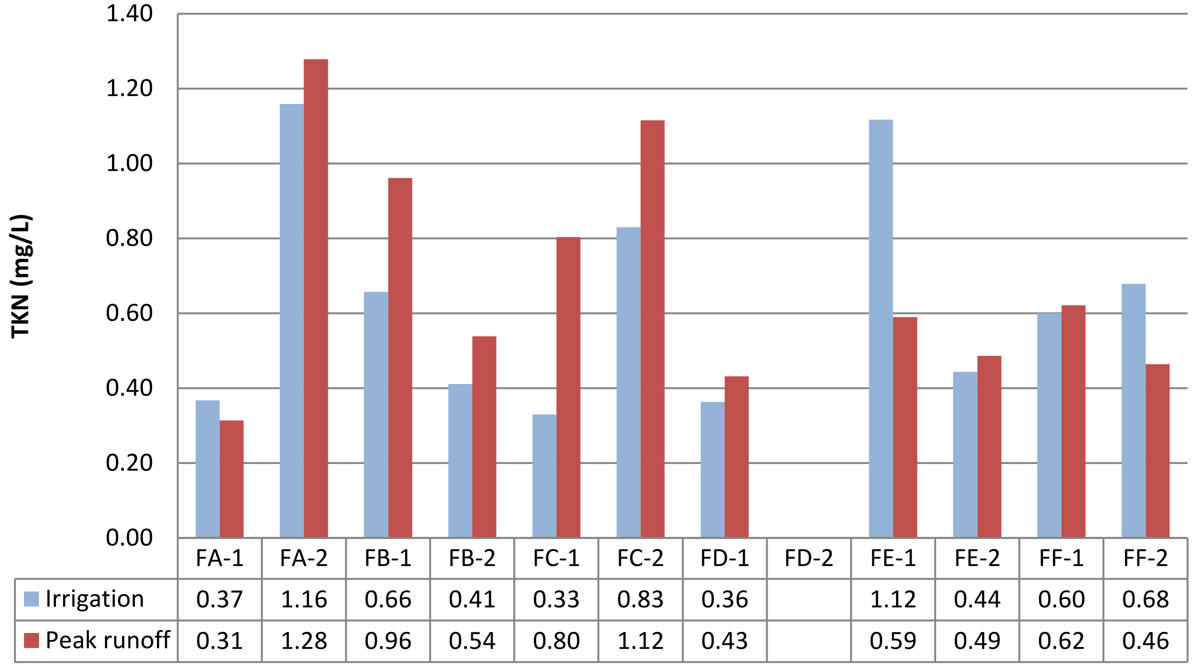

Total Phosphorus (mg/L)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00

	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
🟦 Irrigation	1.27	0.70	0.43	0.46	0.72	0.69	0.93	0.73	0.71	0.69	0.38	0.34
🟥 Peak runoff	3.61	2.07	0.48	0.36	0.45	0.48	1.08	1.65	0.63	0.68	0.87	0.95

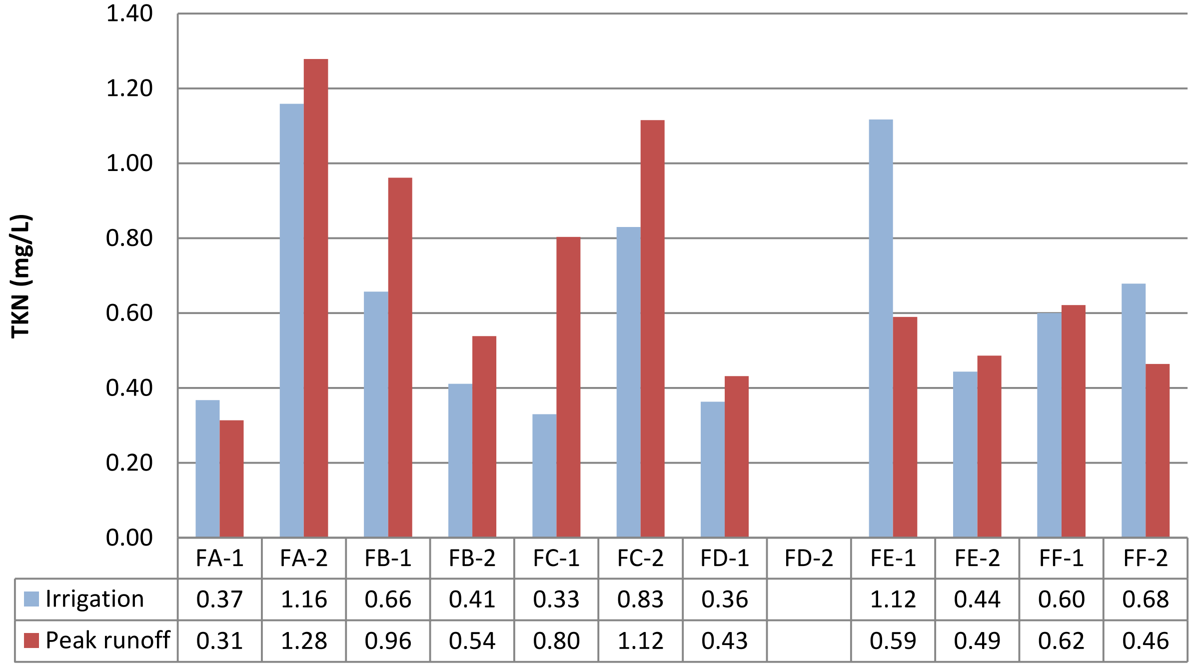
Figure 37. Total phosphorus of irrigation water and of peak runoff for six sites and two irrigation events in 2010.

Total Kjeldahl Nitrogen

Total Kjeldahl Nitrogen (TKN) analysis is the total of the organic nitrogen plus any ammonia-nitrogen in a sample. The ammonia-nitrogen samples were practically zero for all the sites and the values are not shown. Therefore, very small TKN values were observed during 2009 and 2010 (Figures 38 and 39). The values were less than 1.4 mg/l in 2009 and less than 0.6 mg/l in 2010. The TKN nutrient loadings of runoff water in 2009 were highest for site FF during the second irrigation with 0.7 lbs/ac. In 2010, the TKN nutrient loadings of the runoff water were less than 0.6 kg/ac for all sites and were influenced by low runoff amounts due to improved irrigation management. Most of the irrigation and runoff values were almost similar or the irrigation had higher TKN values than the runoff water with a few exceptions.

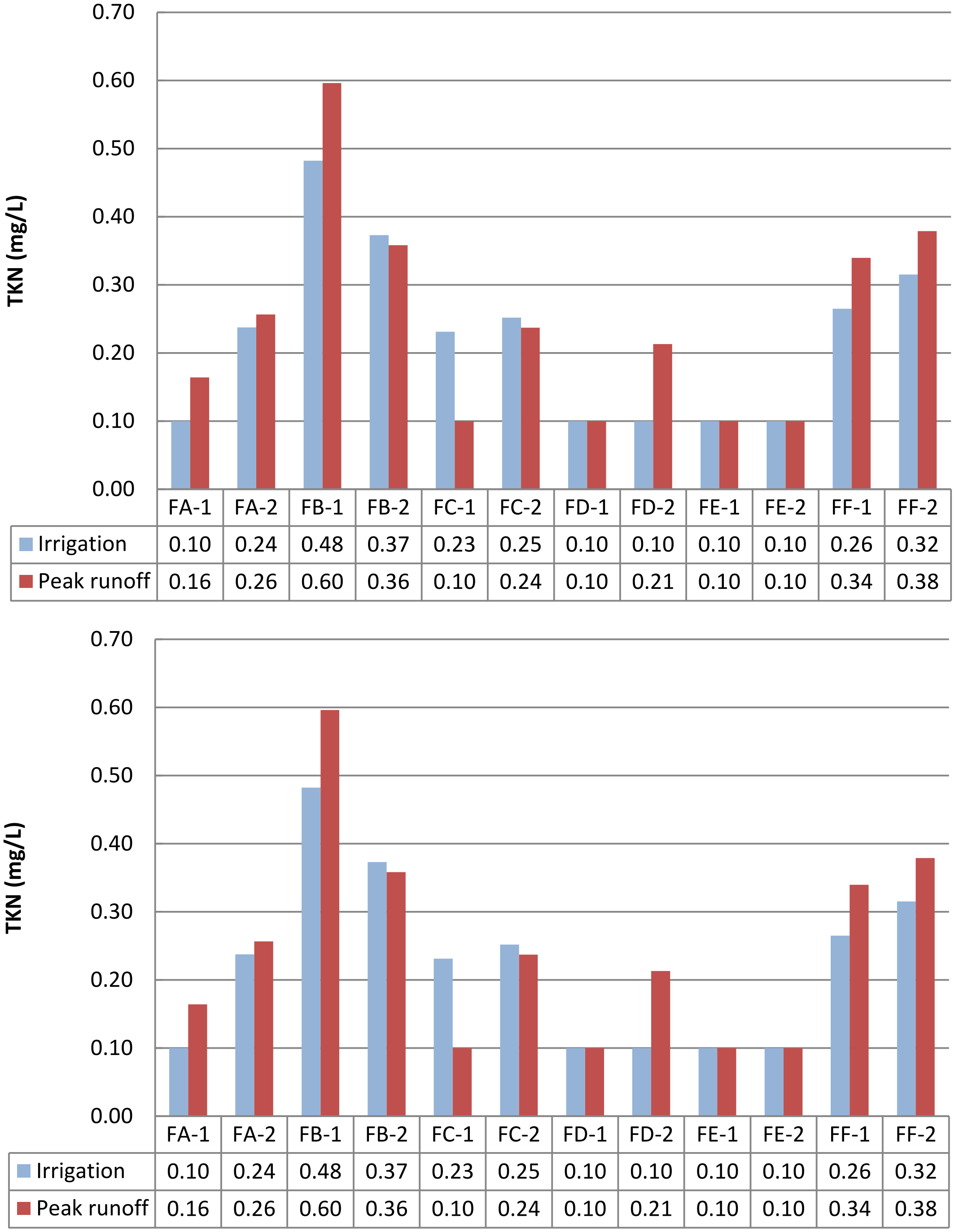


	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
🟦 Irrigation	0.37	1.16	0.66	0.41	0.33	0.83	0.36		1.12	0.44	0.60	0.68
🟥 Peak runoff	0.31	1.28	0.96	0.54	0.80	1.12	0.43		0.59	0.49	0.62	0.46



	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
🟦 Irrigation	0.37	1.16	0.66	0.41	0.33	0.83	0.36		1.12	0.44	0.60	0.68
🟥 Peak runoff	0.31	1.28	0.96	0.54	0.80	1.12	0.43		0.59	0.49	0.62	0.46

Figure 38. Total Kjeldahl nitrogen of irrigation water and of peak runoff for six sites and two irrigation events in 2009.



	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
🟦 Irrigation	0.10	0.24	0.48	0.37	0.23	0.25	0.10	0.10	0.10	0.10	0.26	0.32
🟥 Peak runoff	0.16	0.26	0.60	0.36	0.10	0.24	0.10	0.21	0.10	0.10	0.34	0.38

	FA-1	FA-2	FB-1	FB-2	FC-1	FC-2	FD-1	FD-2	FE-1	FE-2	FF-1	FF-2
🟦 Irrigation	0.10	0.24	0.48	0.37	0.23	0.25	0.10	0.10	0.10	0.10	0.26	0.32
🟥 Peak runoff	0.16	0.26	0.60	0.36	0.10	0.24	0.10	0.21	0.10	0.10	0.34	0.38

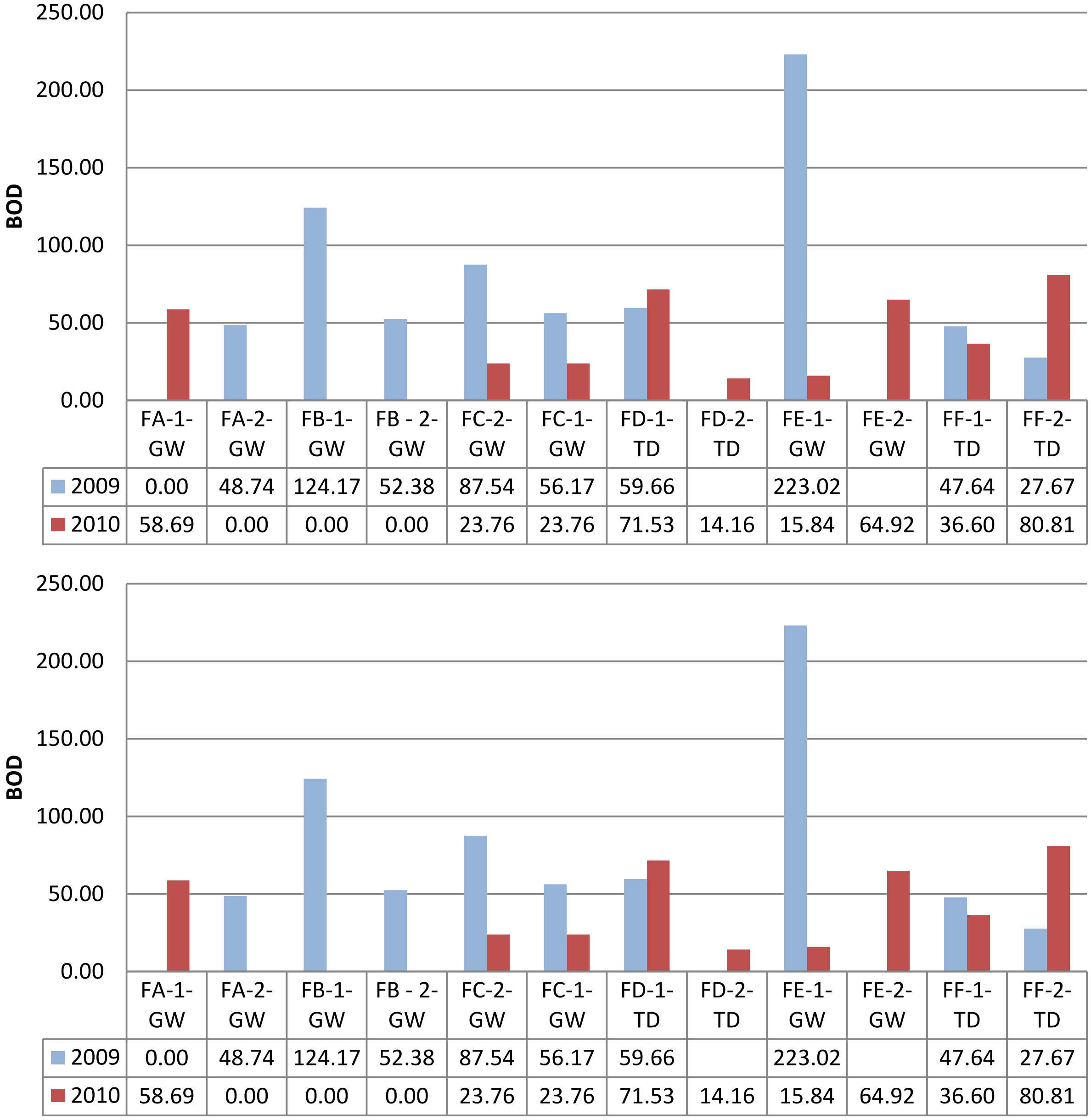
Figure 39. Total Kjedahl nitrogen of irrigation water and of peak runoff for six sites and two irrigation events in 2010.

Groundwater Quality (Water table and tile drains)

Water that percolates from the irrigation system reaches the water table. Groundwater samples were collected from the groundwater table in sites FA, FB, FC and FE. An observation well was drilled in these sites and the water samples were taken from the groundwater table by pumping. Sites FD and FF had drain tiles and the water sample was taken from the drain outlet that discharged to the drainage ditches.

Biochemical Oxygen Demand in Groundwater

The laboratory could not determine the values for all the samples. This is the reason that some values are not shown on the following figures. It can be observed that the values fluctuate year to year (Figure 40). The highest values were observed in 2009 for site FB with 124 mg/l and site FE with 223 mg/l.



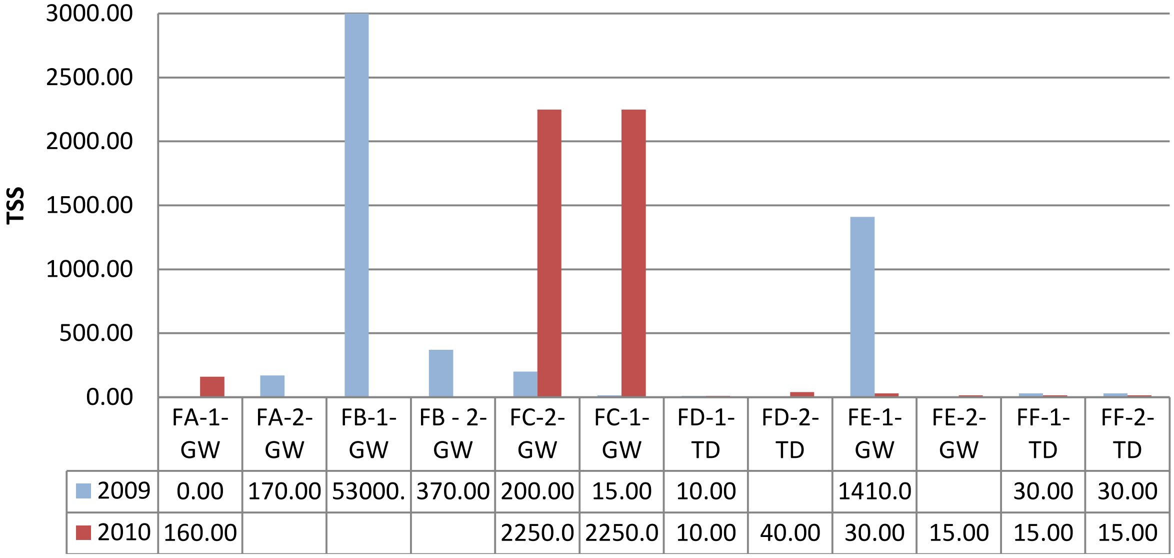
	FA-1-GW	FA-2-GW	FB-1-GW	FB - 2-GW	FC-2-GW	FC-1-GW	FD-1-TD	FD-2-TD	FE-1-GW	FE-2-GW	FF-1-TD	FF-2-TD
🟦 2009	0.00	48.74	124.17	52.38	87.54	56.17	59.66		223.02		47.64	27.67
🟥 2010	58.69	0.00	0.00	0.00	23.76	23.76	71.53	14.16	15.84	64.92	36.60	80.81

	FA-1-GW	FA-2-GW	FB-1-GW	FB - 2-GW	FC-2-GW	FC-1-GW	FD-1-TD	FD-2-TD	FE-1-GW	FE-2-GW	FF-1-TD	FF-2-TD
🟦 2009	0.00	48.74	124.17	52.38	87.54	56.17	59.66		223.02		47.64	27.67
🟥 2010	58.69	0.00	0.00	0.00	23.76	23.76	71.53	14.16	15.84	64.92	36.60	80.81

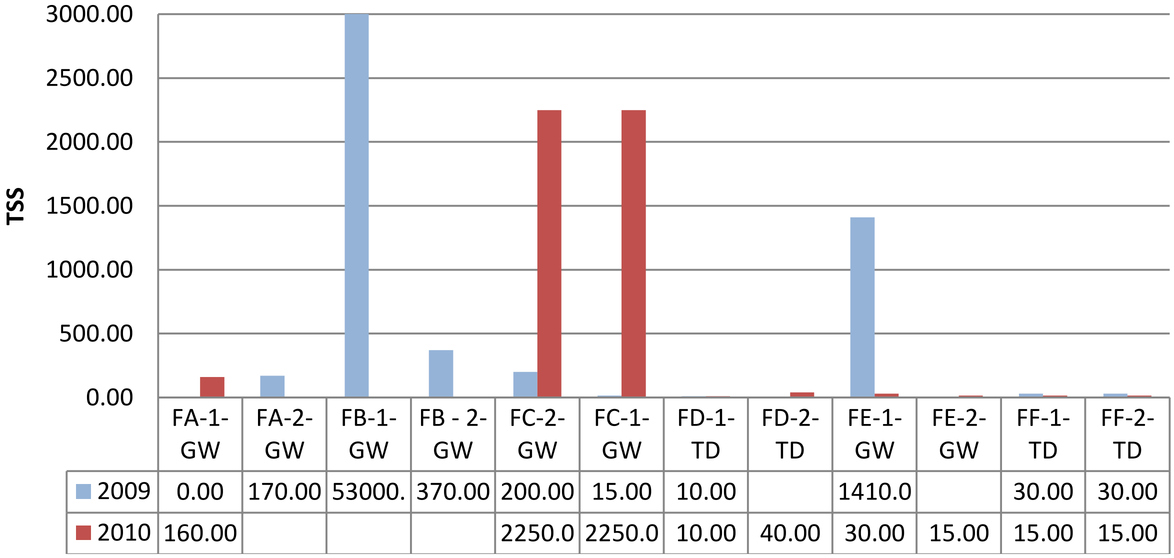
Figure 40. Biochemical oxygen demand of groundwater for six sites and two irrigation events during 2009 and 2010. GW samples were taken from the water table and the TD samples from the tile drain.

Total Suspended Solids in Groundwater

The total suspended solids of groundwater were relatively small for all the sites (Figure 41). A few exceptions were sites FE and FE in 2009 and site FC in 2010.



	FA-1-GW	FA-2-GW	FB-1-GW	FB - 2-GW	FC-2-GW	FC-1-GW	FD-1-TD	FD-2-TD	FE-1-GW	FE-2-GW	FF-1-TD	FF-2-TD
🟦 2009	0.00	170.00	53000.	370.00	200.00	15.00	10.00		1410.0		30.00	30.00
🟥 2010	160.00				2250.0	2250.0	10.00	40.00	30.00	15.00	15.00	15.00

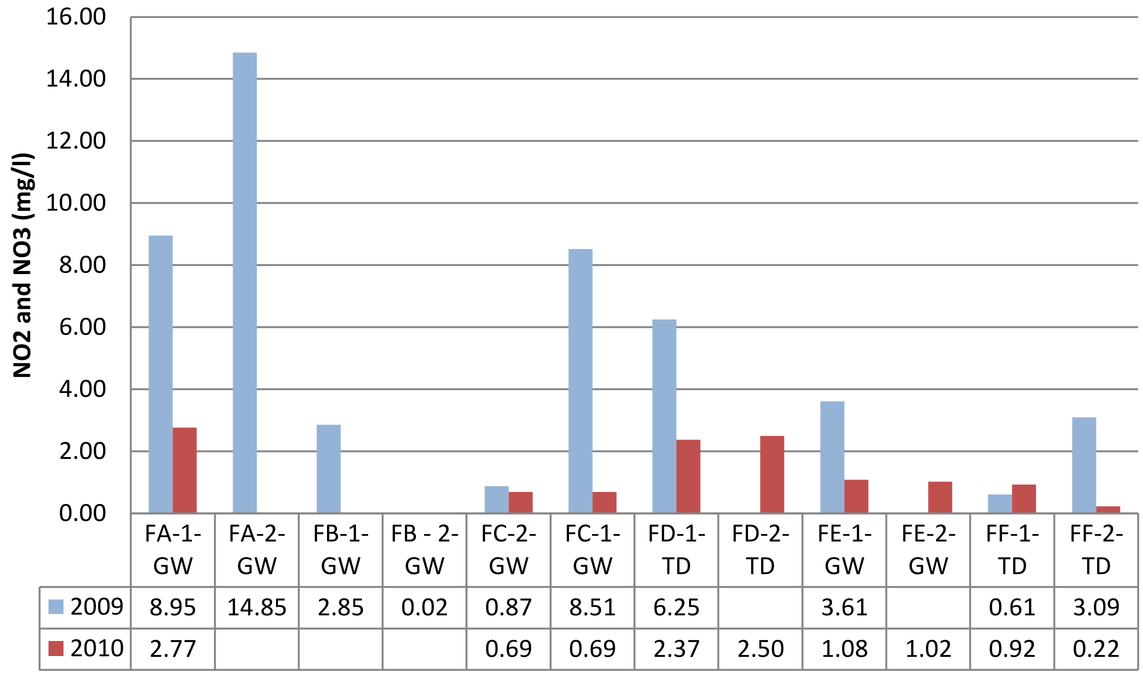


	FA-1-GW	FA-2-GW	FB-1-GW	FB - 2-GW	FC-2-GW	FC-1-GW	FD-1-TD	FD-2-TD	FE-1-GW	FE-2-GW	FF-1-TD	FF-2-TD
🟦 2009	0.00	170.00	53000.	370.00	200.00	15.00	10.00		1410.0		30.00	30.00
🟥 2010	160.00				2250.0	2250.0	10.00	40.00	30.00	15.00	15.00	15.00

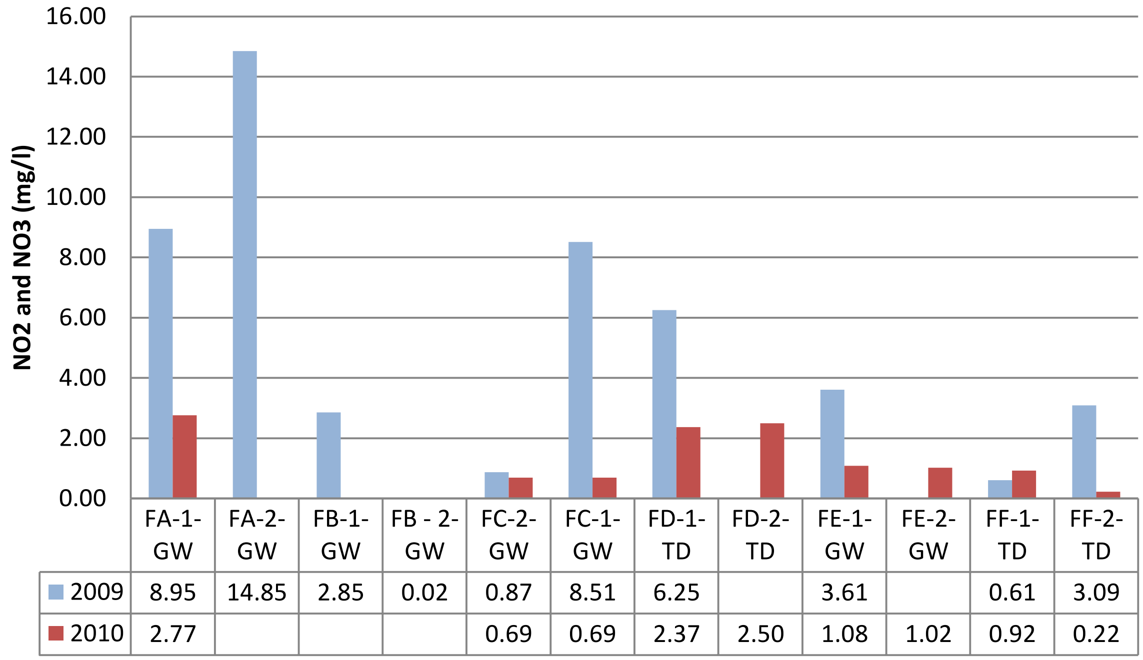
Figure 41. Total suspended solids of groundwater for six sites and two irrigation events during 2009 and 2010. Some values are not shown because the samples could not be analyzed. GW samples were taken from the water table and the TD samples from the tile drain.

Nitrates and Nitrites in Groundwater

The nitrates and nitrites of groundwater were less than 9 mg/l for most of the sites (Figure 42). The exception was site FA during the second irrigation in 2009. The increase in nitrates could be that this field may be over-fertilized over several years.



	FA-1-GW	FA-2-GW	FB-1-GW	FB - 2-GW	FC-2-GW	FC-1-GW	FD-1-TD	FD-2-TD	FE-1-GW	FE-2-GW	FF-1-TD	FF-2-TD
🟦 2009	8.95	14.85	2.85	0.02	0.87	8.51	6.25		3.61		0.61	3.09
🟥 2010	2.77				0.69	0.69	2.37	2.50	1.08	1.02	0.92	0.22

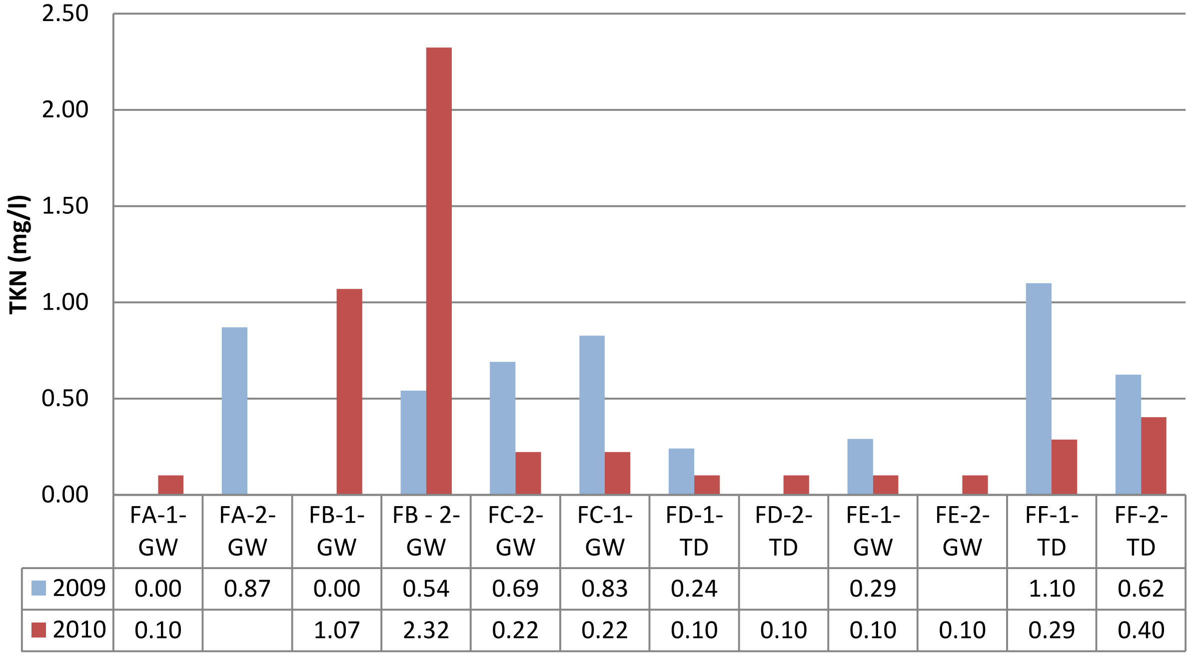

NO2 and NO3 (mg/l)

	FA-1-GW	FA-2-GW	FB-1-GW	FB - 2-GW	FC-2-GW	FC-1-GW	FD-1-TD	FD-2-TD	FE-1-GW	FE-2-GW	FF-1-TD	FF-2-TD
🟦 2009	8.95	14.85	2.85	0.02	0.87	8.51	6.25		3.61		0.61	3.09
🟥 2010	2.77				0.69	0.69	2.37	2.50	1.08	1.02	0.92	0.22

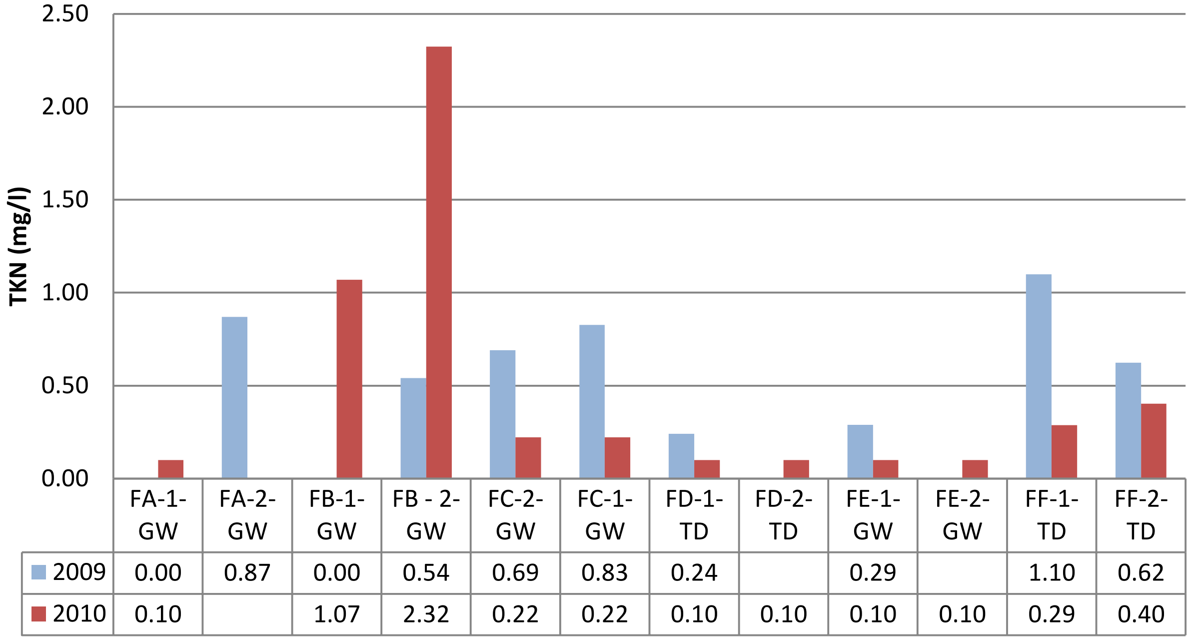
Figure 42. Nitrates and nitrites of groundwater for six sites and two irrigation events during 2009 and 2010. Some values are not shown because the samples could not be analyzed. GW samples were taken from the water table and the TD samples from the tile drain.

Total Kjedahl Nitrogen in Groundwater

Total Kjedahl nitrogen values were low and less than 1.1 mg/l for most of the soils (Figure 43). The only exception was site FB, which presented a high value during 2010. During this year, the TKN value of irrigation water was 0.37 mg/l during the first irrigation.



	FA-1-GW	FA-2-GW	FB-1-GW	FB - 2-GW	FC-2-GW	FC-1-GW	FD-1-TD	FD-2-TD	FE-1-GW	FE-2-GW	FF-1-TD	FF-2-TD
🟦 2009	0.00	0.87	0.00	0.54	0.69	0.83	0.24		0.29		1.10	0.62
🟥 2010	0.10		1.07	2.32	0.22	0.22	0.10	0.10	0.10	0.10	0.29	0.40

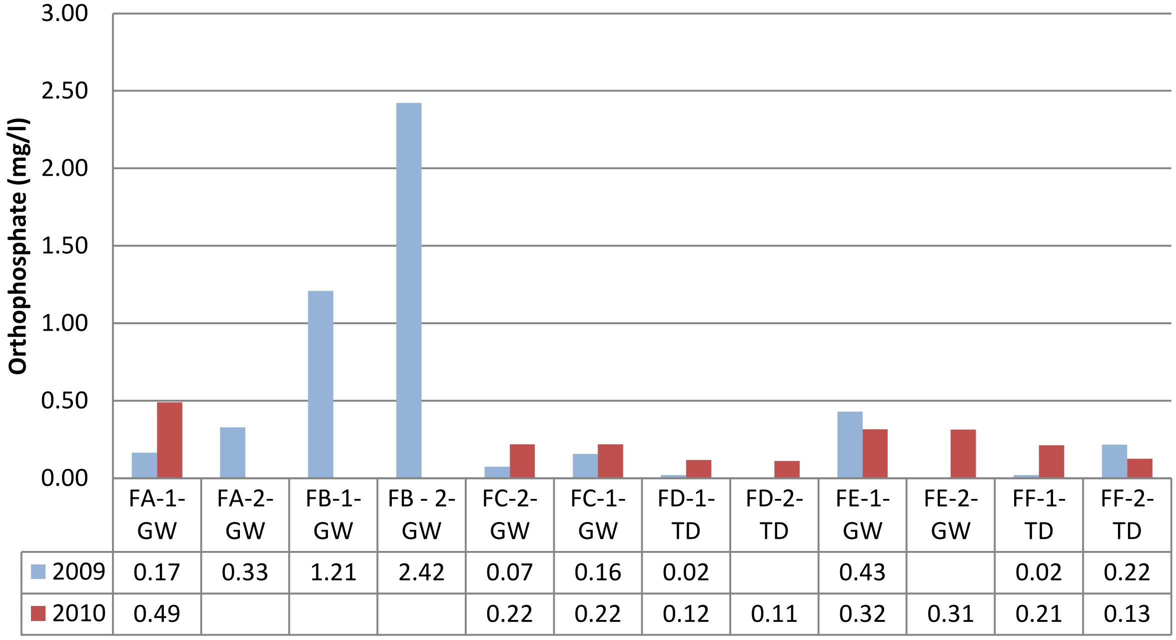


	FA-1-GW	FA-2-GW	FB-1-GW	FB - 2-GW	FC-2-GW	FC-1-GW	FD-1-TD	FD-2-TD	FE-1-GW	FE-2-GW	FF-1-TD	FF-2-TD
🟦 2009	0.00	0.87	0.00	0.54	0.69	0.83	0.24		0.29		1.10	0.62
🟥 2010	0.10		1.07	2.32	0.22	0.22	0.10	0.10	0.10	0.10	0.29	0.40

Figure 43. Total Kjedahl nitrogen of groundwater for six sites and two irrigation events during 2009 and 2010. Some values are not shown because the samples could not be analyzed. GW samples were taken from the water table and the TD samples from the tile drain.

Orthophosphate in Groundwater

The total orthophosphates values were low and less than 0.43 mg/l for most of the soils. The only exception was site FB, which presented a high value during 2009 (Figure 44). During this year, the TKN value of irrigation water was 1.21 and 2.42 mg/l during the first and second irrigation. In the rest of the sites, orthophosphates in groundwater were lower than levels of irrigation and peak runoff.



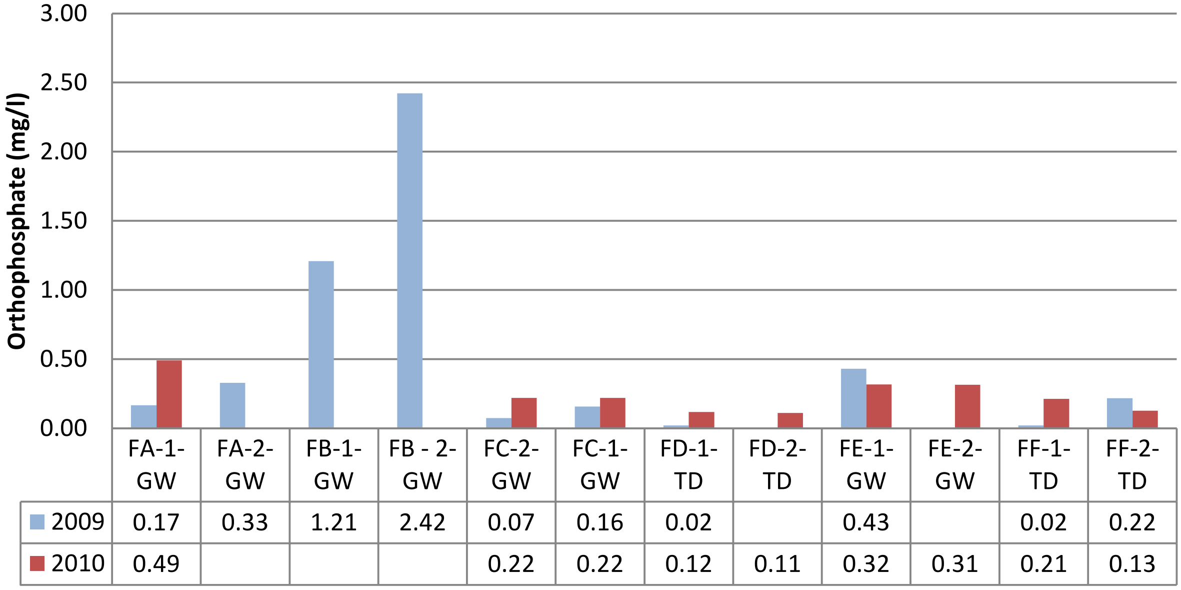
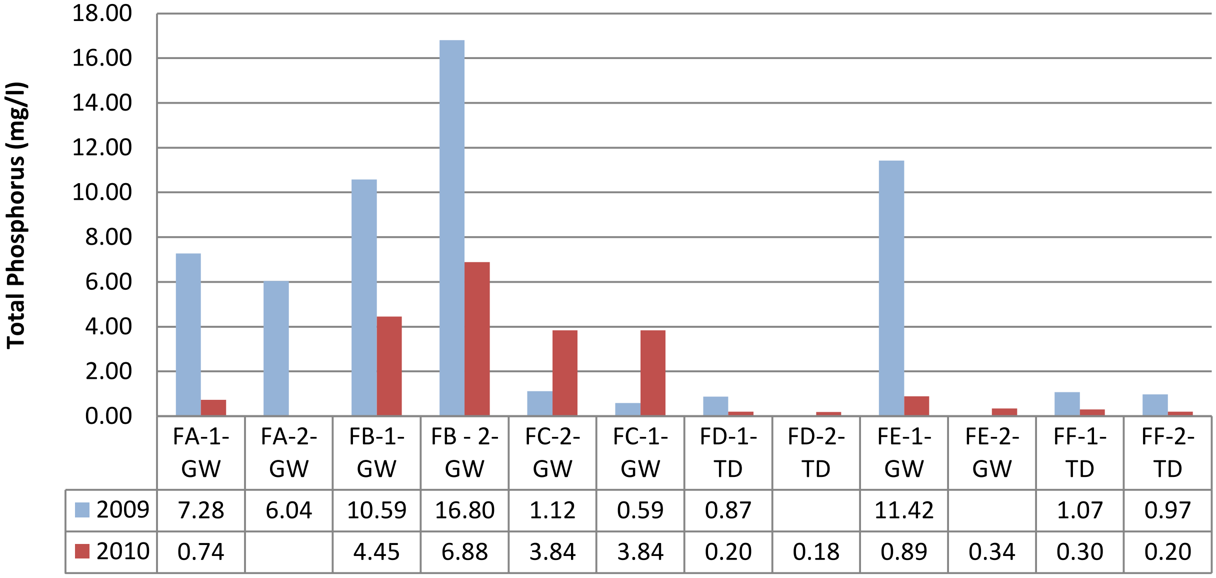


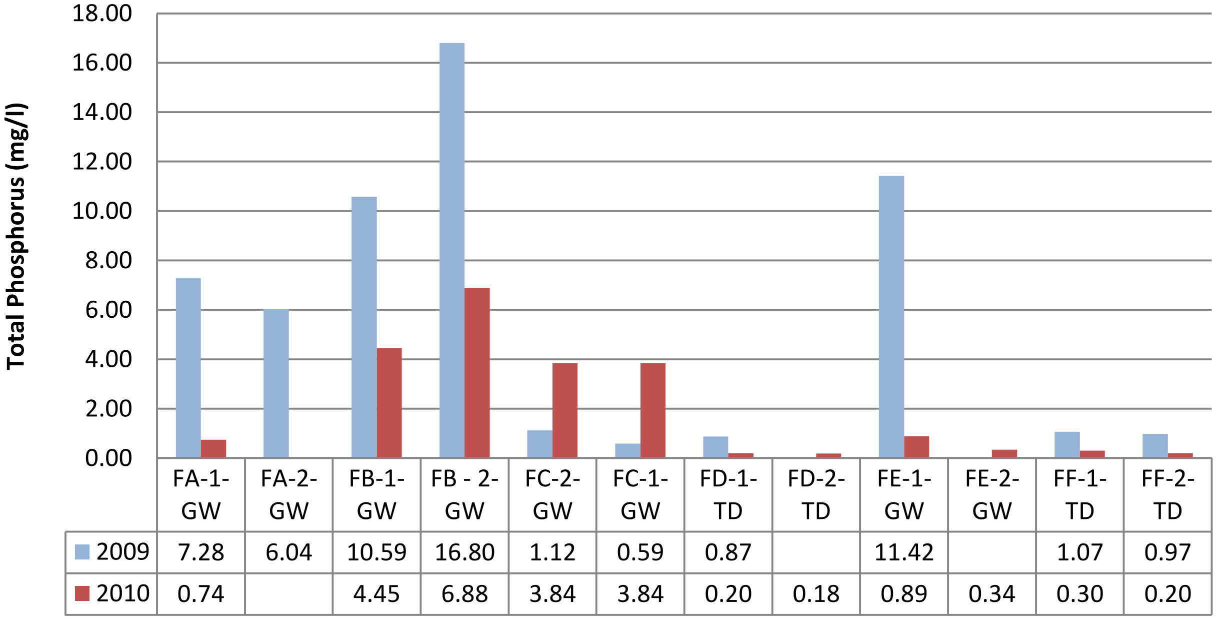
Figure 44. Orthophosphates of groundwater for six sites and two irrigation events during 2009 and 2010. Some values are not shown because the samples could not be analyzed. GW samples were taken from the water table and the TD samples from the tile drain.

Total Phosphorus in Groundwater.

Higher total phosphorus values were observed in 2009 (Figure 45). The highest values were observed in sites FA, FB, and FE. Site FB has sugarcane and also presented high values of orthophosphates and TSS.



	FA-1-GW	FA-2-GW	FB-1-GW	FB - 2-GW	FC-2-GW	FC-1-GW	FD-1-TD	FD-2-TD	FE-1-GW	FE-2-GW	FF-1-TD	FF-2-TD
🟦 2009	7.28	6.04	10.59	16.80	1.12	0.59	0.87		11.42		1.07	0.97
🟥 2010	0.74		4.45	6.88	3.84	3.84	0.20	0.18	0.89	0.34	0.30	0.20


Total Phosphorus (mg/l)

	FA-1-GW	FA-2-GW	FB-1-GW	FB - 2-GW	FC-2-GW	FC-1-GW	FD-1-TD	FD-2-TD	FE-1-GW	FE-2-GW	FF-1-TD	FF-2-TD
🟦 2009	7.28	6.04	10.59	16.80	1.12	0.59	0.87		11.42		1.07	0.97
🟥 2010	0.74		4.45	6.88	3.84	3.84	0.20	0.18	0.89	0.34	0.30	0.20

Figure 45. Total phosphorus of groundwater for six sites and two irrigation events during 2009

and 2010. Some values are not shown because the samples could not be analyzed. GW samples were taken from the water table and the TD samples from the tile drain.

Field Days and Result Demonstrations

The following actions were completed:

A 30-minute presentation was conducted on irrigation management and best management practices for sugarcane at the Sugarcane Field Day in Weslaco, Texas on September 24, 2010. Seventy people attended the conference.

Dr. Juan Enciso presented a 30-minute presentation on best management practices and irrigation management during the Irrigation Expo on October 20-22, 2010. About 70 people attended the conference. Dr. Enciso provided an update on the progress of the project and discussed the impact of best irrigation management practices on water conservation and on the reduction of nutrient loadings to the Arroyo Colorado. He also explained how to improve surface irrigation management to reduce deep percolation and runoff water losses. A field day was also conducted at the Irrigation Expo to demonstrate best irrigation management practices. Thirty-five people attended this field day. Among the practices were the use of poly-pipe compared to earth ditches and siphon tubes, the use of metering devices, drip and sprinkler irrigation. Dr. Enciso also provided a demonstration on how to manage fertilizers with irrigation to avoid leaching and transport of fertilizer with runoff water. The tour lasted three hours.

DISCUSSION AND CONCLUSIONS

The predominant irrigation system in the Lower Rio Grande Valley is surface irrigation. The main BMPs adopted by the farmers in the Arroyo Colorado with this irrigation method are conservation crop rotation, irrigation land leveling, the use of poly-pipe and nutrient management. Only one farmer had filter strips at the lower end of the rows, which received irrigation runoff, and the same farmer had residue management including all the BMPs mentioned before. The main conclusions of this study are:

1. Of the six sites, only one farm had excessive runoff (site FF), and this site practically impacted the nutrients loadings of all the nutrients measured in the runoff water. The amount of runoff for this site was (6.4 inches) during the second irrigation in 2009. The same site also had high runoff during the first irrigation (2.4 inches) of the same year.
2. Four out of ten irrigation events evaluated in 2009 applied a depth greater than 9 inches. Considering that those soils cannot hold more than 6.6 inches of water for a soil depth of 3 feet, water only could leave the soil storage capacity through either deep percolation or runoff. Farmer's reports were given to producers in 2009, and this could have influenced the results of the 2010 growing season. All of the irrigation depths applied in 2010 were lower than 8.5 inches and the runoff amounts were lower than 1.6 inches. The highest runoff amount in 2010 was from one of the sites in which irrigation was monitored only for one irrigation event during 2009.
3. The results indicated that the irrigation water had already high contents of nitrates and nitrites, and this was variable from irrigation to irrigation. The gains of nitrates and nitrites loadings on the farm were small and the management practice that could have the highest impact on nutrient loadings is the amount of runoff. If irrigation is well attended, runoff can be reduced considerably. The total concentration of NO3- and NO2- in the irrigation and runoff water for all sites were lower than 6 mg/l in 2009 and lower than 10 mg/l in 2010 (with the exception of site FA in which the runoff concentration during the first irrigation was 13.7 mg/l). In 2009, the runoff water with the highest NO3- and NO2- loadings was site FF during the second irrigation with a concentration of 4.0 lbs/ac because of the large volume of runoff. In 2010, the sites that produced the highest NO3- and NO2- loadings was site FD with 1.8 and 2.4 lbs/ac during the first and second irrigation, and this site produced the largest runoff volume.
4. Most of the TKN values of irrigation and runoff were either similar, or irrigation had slightly higher TKN values than the runoff water, with a few exceptions. The TKN values were less than 1.4 mg/l in 2009 and less than 0.6 mg/l in 2010, and they were primarily influenced by the amount of runoff produced on the farms. The TKN loadings were lower than 0.3 lbs/ac for all sites during both years, with exception of site FF's second irrigation, which produced 0.7 lbs/ac.
5. TSS was higher for sites FA and FD during 2009 and 2010. At site FA, the high stream sizes per furrow (17.5 to 20.4 gpm/row) could have produced erosion and higher TSS that could also resulted in higher orthophosphates and total phosphorus in the runoff water than most other sites. In site FD, the high TSS could be caused by erosion on the upstream side of the farm because it was the only site that did not use poly-pipe, making it difficult to control irrigation and producing the highest runoff in 2010. The water flow detached some of the soil particles from the earth ditches.

6. In general, the nutrient loadings due to orthophosphates were extremely low for all sites during both years. The highest concentration was 1.2 lbs/ac of orthophosphates for site FF during the second irrigation of 2009, and it was impacted by the high runoff on this site (6.4 in). Site FF also produced the highest amount of total phosphorus loadings (2.7 lbs/ac) during the second irrigation.
7. The nutrient values of groundwater fluctuated from year to year and from irrigation to irrigation, but they were generally low. Groundwater had values of less than 9 mg/l of nitrates and nitrites (with the exception of site FA-second irrigation), lower than 1.1 mg/l of TKN (with exception of site FB-second irrigation-2010), lower than 0.49 mg/l of orthophosphates (with exception of site FB-first and second irrigation-2009), and lower than 7.28 mg/l of total phosphorus (with exception of site FB-first and second irrigation and site FE-first irrigation on 2009). The only sites that had nutrient management as BMPs were sites FC and FD, and these sites had one of the lowest nutrient values on the groundwater.
8. All of the evaluated sites had irrigation land leveling and crop rotation as best management practices. Future recommendation for best management practices should include nutrient management programs, which means to apply the fertilizer according to a soil analysis, and the improvement of irrigation management, which implies reducing runoff and using nonerosive stream sizes.

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