Proceedings of the Fourth Annual Four Corners Irrigation Workshop

July 10-11, 2003
Shiprock Chapter House
Shiprock, New Mexico

Agricultural Solutions for a semi-arid environment

Sponsored by:

Colorado State University
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US Department of the Interior, Bureau of Reclamation, Upper Colorado Region

Cover Photograph: **Center pivot irrigation system located at the Navajo Agricultural Products Industry farm.**

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Acknowledgements

The organizing committee would like to thank the following individuals and organizations for helping to make the Fourth Annual Four Corners Irrigation Workshop a success:

1. The Shiprock Chapter of the Navajo Nation who allowed us to use their Chapter house facility for our workshop.

2. Mrs. Naomi Deal and her staff for there excellent food preparation and service during the two days.

3. The staff at the NMSU Agricultural Science Center who helped to host the luncheon for our field trip day.

4. Our invited speakers: Rudy Garcia from NRSC in Albuquerque; Jeannie Benally, Tri-State Cooperative Extension, Shiprock; Fritz Kramer, International Development Enterprises, Denver; Martin Duncan, Superintendent of the San Juan River/Dineh Water Users Inc.; and Pat Page, Bureau of Reclamation, Durango.

5. Our speakers from the Four Corners Irrigation Workshop Organizing Committee: Ed Martin, Israel Broner, and Abdel Berrada.

6. Pat Page and the Bureau of Reclamation office in Durango, CO, for their support of our program through cooperation and financial assistance.

7. Our field trip hosts including Jeannie Benally, Tracy Raymond, John Wilkins-Wells, Paul Gilon, Mick O'Neill, Dan Smeal and Dan Spare.

Four Corners Irrigation Workshop Program

Day 1 **July 10, 2003 – Shiprock Chapter House**	
7:15	**Departure from Farmington to Shiprock**
8:00 – 9:00	**Registration**
8:30 – 9:00	Welcoming and Introductions – Mick O'Neill, Superintendent, NMSU ASC-Farmington, NM and Abdel Berrada, Research Scientist, CSU-Yellow Jacket, CO
9:00 – 9:30	The Soil Water Reservoir & Simple Ways To Measure It – Rudy Garcia, Soil Conservationist, NRCS, Albuquerque, NM
9:30 – 10:00	Measuring Water In The Ditch And Out Of Gated Pipe – Ed Martin, Extension Irrigation Engineer, UA-MAC, Maricopa, AZ
10:00 – 10:30	**Break**
10:30 – 11:00	Transitioning From Flood To Gated Pipe – Jeannie Benally, Extension Agent, Navajo Dept. of Agriculture, Shiprock, NM
11:00 – 11:30	Using Inexpensive Sprinklers for Small Scale Irrigation – Israel Broner, Extension Irrigation Engineer, CSU, Fort Collins, CO
11:30 – 12:00	Open Discussion and Morning Wrap-up
12:00 – 1:15	**Lunch**
1:30 – 2:00	The IDE Experience with Micro-Irrigation – Fritz Kramer, Director of Operations, International Development Enterprises, Denver, CO
2:00 – 2:30	Options for Water Management During Drought – Abdel Berrada, Research Scientist, CSU-Yellow Jacket, CO
2:30 – 2:45	Open Discussion
2:45 – 3:15	**Break**
3:15 – 3:45	Water Management and Delivery In Shiprock – Martin Duncan, Superintendent, San Juan River Dineh Water Users, Inc., Shiprock, NM
3:45 – 4:15	Sharing the Shortages: the San Juan River in 2003 Pat Page, Water Management Coordinator, BOR, Durango, CO
4:15 – 4:45	Afternoon Wrap-up, Announcements, Vote-of-Thanks
5:00	**Return to Farmington**
Day 2 **July 11, 2003 - Field Trip**	
7:15	**Departure from Farmington to Shiprock**
8:00 – 9:30	Irrigated Farm in Shiprock – Tracy Raymond, Irrigation Engineer, Natural Resources Dept. BIA, Shiprock, NM & Jeannie Benally, Extension Agent, Navajo Dept. of Agriculture, Shiprock, NM
10:00 – 11:15	Diné College Demonstration Farm – John Wilkins-Wells, Sociologist, CSU, Fort Collins, CO & Paul Gilon, Title III Project Director, Diné College, Tsaile, AZ
12:15 – 1:00	**Lunch – NMSU ASC-Farmington**
1:00 – 2:00	NMSU Agricultural Science Center – Mick O'Neill, Superintendent, Rick Arnold, Weed Specialist, and Dan Smeal, Irrigation Specialist, NMSU ASC-Farmington, NM
2:30 – 3:30	Navajo Agricultural Products Industry – Dan Spare, Irrigation Engineer, Keller-Bliesner Engineers, Logan, UT
4:00	**Return to Shiprock and Farmington**

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Fourth Annual Four Corners Irrigation Workshop

Shiprock, New Mexico
July 10-11, 2003

Introduction

Mick O'Neill[1] and Edward C. Martin[2]

Once again, we have found ourselves in the midst of a drought here in the arid Southwest and the need for an irrigation workshop could be no greater. Although the winter of 2002-03 brought some relief to the Four Corners area, we are still faced with a severe water shortage and everyone must do their part to assure that we are using our irrigation water to its fullest potential.

This year we returned to the New Mexico side of the Four Corners and were fortunate enough to get the support of the Shiprock Chapter of the Navajo Nation. With their help, we held our workshop at the Shiprock Chapter house. The facility and food were excellent and we appreciate everyone's help.

Our presentations this year focused on small-scale irrigation systems, looking at ways to efficiently deliver water to the crops. We looked at water measurement in surface systems, small-scale sprinklers and even some micro-irrigation systems. We discussed how to measure the water in the soil and the challenges of changing from traditional flood irrigation to more efficient gated pipe systems. We also discussed options for irrigating during a drought and Pat Page of the Bureau of Reclamation gave an excellent presentation on "Sharing the Shortage."

It is our hope to continue to hold this workshop in the Four-Corners as long as we get support from growers in the area. We believe that the Four Corners area is an important part of agricultural for all the states involved and we hope that our workshop will help growers more efficiently use their water resources. We hope to see you all there next year.

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Irrigation Water Management

Rudy Garcia
Soil Conservationist
USDA Natural Resources Conservation Service

Measuring Soil Moisture

Soil moisture measurement is a major component of Irrigation Water Management (IWM). Therefore, a basic understanding of the plant root zone depth, soil type, volume of irrigation water applied per irrigation, soil moisture sensor used, and evapotranspiration or consumptive use is very important in understanding soil moisture content (i.e., so that you can know when and how much water to apply). However, I have found through my personal field experience in working with many producers that this management practice or concept is probably the least understood or appreciated. Most producers know the importance of laser leveled fields in order to obtain a uniform irrigation application and they also see that a well-maintained concrete-lined ditch (or dirt ditch) allows for efficient conveyance of their water supply.

Lets briefly review the above components of IWM and their relevance to measuring soil moisture for the purpose of scheduling irrigations and knowing the approximate volume to apply on a per acre basis.

Plant Root Zone Depth

In measuring soil moisture content it is important to know the root zone depth and the soil moisture extraction pattern of the plant. Now to stay on practical and applied approach, you will find (e.g., I have found through extensive fieldwork and observation) that most orchards and crops have the majority of their moisture uptake occurring in the 0 – 24” depth of their root zone. Consequently, this is the volume of soil that you want to focus your attention (i.e., where you will monitor soil moisture with sensors such as a tensiometer, gypsum block, or watermark block (a synthetic electrical resistance block) or by the feel and appearance method). At this soil depth the soil moisture will generally be extracted by roots in the following pattern: about 40% of the total soil moisture used by the plant roots will come from the 0 – 6” depth; 30% of the total moisture extracted will come from the 6 –12" root zone (note: approximately 70% of total moisture uptake is coming from the 0 –12” root zone); about 20% of the total uptake is coming from the 12 – 18” root zone and; the 10% of the total uptake is extracted from the 18 – 24” root zone depth. Remember to use this information as a general guideline; site-specific fieldwork and experience will fine-tune this concept.

Soil Type

Since we already established the plant root zone (soil volume) at which we wish to manage our irrigation scheduling (when to irrigate) and water requirement (how much to apply), the next step to evaluate is the soil type (i.e., the % of sand, silt, and clay; e.g., loamy sand, silt loam, clay loam, etc.). Each soil type has an inherent "available water" holding capacity which can very between 1.0"/acre-foot for a loamy sand to 2.5" for a silty clay loam. Consequently, a two foot root zone will typically have an irrigation water requirement that can very between 1.5" (40,500 gallons/acre) for a coarse textured soil to 2.5" (67,500 gallons/acre) for a fine-textured soil; however, since most flood irrigation systems are between 45 – 70% efficient, it is therefore difficult to apply less than 3"/irrigation. Therefore, a well maintained irrigation system is needed so that irrigations approach a 3.0" (81,000 gallons/acre) application. Again, site-specific conditions need to be evaluated in order to properly assess the actual irrigation water requirement.

Volume of Irrigation Water Applied

For a flood irrigation system it is quite easy to determine the volume of water applied: e.g., if I'm irrigating a 5 acre orchard and I'm wanting to apply 3"/acre and I also know that my irrigation ditch averages three CFS (cubic feet per second; one cfs = 450 gallons/minute), then it will take me five hours to irrigate 5 acres, when applying 3"/acre (e.g., inches (3) x acres (5) divided by cfs (3) = 5 hours). Thus, I'm able to irrigate one acre per hour. (Note: I can substitute any values into the given equation and thereby determine the length of time needed to apply a given irrigation). Now that we have a handle on our irrigation requirement, the next parameter that we need to analyze is the amount of time it takes for the irrigation water to infiltrate the soil; this is referred to as the opportunity time. For our example, you will find that it usually takes a clayey soil up to 20+ hours for all the water to infiltrate into the soil (i.e., when applying a 3" application); it will take no more than 2 hours for a sandy soil to infiltrate a 3" application. Again, varying soil properties such as compaction, surfacing sealing, crusting, shallow water tables, etc. can cause substantial changes in the actual amount of time needed to infiltrate a given volume.

Soil Moisture Sensor Used

The soil moisture sensors that I'm most familiar with are tensiometer, watermark (synthetic electrical resistance blocks), and gypsum blocks. As a general-rule-of-thumb, these sensors are typically installed at the 6 – 9" soil root zone depth and at the 18 – 22" root zone depth. The irrigations are scheduled when the soil moisture tension is between 30 to 70 centibars (cb) of soil moisture tension (i.e., for sensors placed in 6 –9" depth); irrigations are generally started at the 30-cb level for sandy soils and at 70 cb on your clay loam soils. The main point to emphasize here, is that monitoring the rate of moisture depletion is just as important as the final reading registered right before commencing an irrigation (e.g., knowing how fast your instrument goes from 10 cb to 30cb or 70cb is critical on predicting when to schedule your next irrigation should). In flood irrigation systems that have long rows, it generally recommended that you install two sets of sensors; one set should be placed at 1/3 of the distance down the tree row and the other set placed at 2/3 of the distance down the tree row. The sensors are typically placed between 5-10' away

from the trunk of the tree; be sure that you place them between trees within a row so that any mowing or disking operation won't be hindered. Finally, when installing your sensors, it is very important that the sensor fit tightly into the hole made for it (a soil probe is usually sufficient for installing your instrument); the sensor must be in intimate contact with the soil in order to function properly. Be sure to follow maintenance and operation instructions that come with your sensors. Record keeping is very important in order to properly analyze and correctly use your sensors.

Evapotranspiration (Consumptive Use)

Finally, all the above should be carefully integrated with the estimated evapotranspiration or consumptive use requirements. As you know, in our arid climate the months of July and August typically have the highest consumptive use requirement. Therefore, it follows that your irrigation interval will be shorter than at any other time of the year (you'll be irrigating more often). As a general rule of thumb, a fully mature tree at peak consumptive use can remove between 0.2 – 0.3"/acre/day, thus, plan your irrigation water requirements accordingly (e.g., at an average consumptive use of 0.25"/day, you would be irrigating on a 10 day interval, when your irrigation water requirement is 2.5"/acre).

In the final analysis, soil moisture measurements are critical to an Irrigation Water Management strategy and does require a basic conceptual understanding of the root zone depth, soil type, irrigation system efficiency, soil moisture sensors used, irrigation water requirement, and consumptive use of the plant throughout the growing season. Thus, when it is all said and done, water management is a science and an art that is developed with plenty of common sense and experience.

Measuring Water Flow in Surface Irrigation Ditches and Gated Pipe

Edward C. Martin
Associate Professor and Irrigation Specialist
Department of Agricultural and Biosystems Engineering
University of Arizona

Measuring water in surface irrigation systems is critical for peak efficiency management. Without knowing the amount of water being applied, it is difficult to make decisions on when to stop irrigating or when to irrigate next. A good irrigation manager should know the flow rate of the irrigation water, the total time of the irrigation event and the acreage irrigated. From this, the total amount of water applied can be determined, which will help determine whether the irrigation was adequate and when the next irrigation should be. Irrigation management decisions should be made based on the amount of water applied and how this relates to the consumptive use demands of the plants and the soil water holding capacity.

Units of Measuring Water

There are many ways to express water volume and flow. The volume of water applied is usually expressed in acre-inches or acre-feet for row crops or gallons per tree in orchards. Flow rate terminology is even more varied. Flow rate is expressed as cfs (cubic feet per second), gpm (gallons per minute) and in some areas, miner's-inches. Below is a description of each.

Acre-inch (ac-in.): An acre-inch is the volume of water required to cover an acre of land with one inch of water. One acre-inch equals about 3,630 cubic feet or 27,154 gallons.

Acre-foot (ac-ft): An acre-foot is the volume of water required to cover an acre of land with 1 foot of water. One acre-foot equals about 43,560 cubic feet, 325,848 gallons or 12 acre-inches.

Cubic feet per second (cfs): One cubic foot per second is equivalent to a stream of water in a ditch 1-foot wide and 1-foot deep flowing at a velocity of 1 foot per second. It is also equal to 454 gallons per minute, or 40 miner's-inches.

Gallons per minute (gpm): Gallons per minute is a measurement of the amount of water being pumped, or flowing within a ditch or coming out of a pipeline in one minute.

Miner's inches: Miner's-inches was a term founded in the old mining days. It is just another way of expressing flow. Some areas in the West still use this measurement unit. Caution needs to be taken because there are Arizona miner's-inches, California miner's-inches and probably some that are locally used. Approximately 40 Arizona miner's- inches equals1 cfs or 454 gpm.

Pressure or Head (H): People often use the phrase "head of water." A foot of head usually implies that the water level is one foot above some measuring point. However, head can also mean pressure. For example, as the level of water rises in a barrel, the pressure at the bottom of the barrel increases. One foot of water exerts 0.43 pounds per square inch (psi) at the bottom of the barrel. Approximately 2.31 feet of water equals 1 psi. Thus, if a tank of water were to be raised 23.1 feet (2.31 x 10) in the air with a hose connected to it, the pressure in the hose at the ground would be about 10 psi.

Area: The cross sectional area of a ditch is often required to calculate flow. Some ditches are trapezoids and others or more like ellipses. To find the area of a trapezoid (Fig. 1a), measure the width of the bottom (b) and the width of the ditch at the water surface (s) and add them together. Divide that number by 2 and then multiply by the height (h) of the water. If the ditch is more elliptical in shape (Fig. 1b), take the depth of the water (h), multiply it by the width of the ditch at the surface (s), divide by 4 and then multiply by PI (3.14). To calculate the cross-sectional area of a pipe, the formula is PI x r^2, where PI is 3.14 and "r" is the radius of the pipe.
NOTE: All measurements should be in feet.

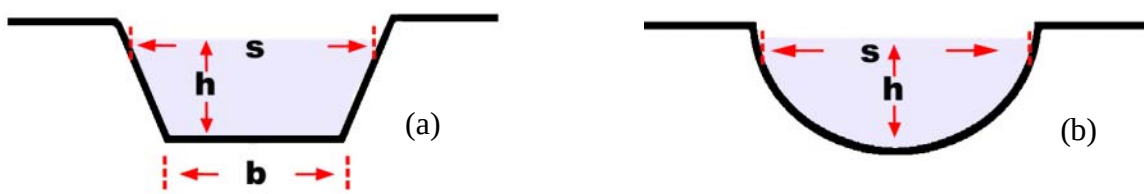

Figure 1. Cross-sectional dimensions for trapezoidal (a) and elliptical (b) ditches. (Diagram by J.S. Jones, 2003)

Measuring Water Flow in Ditches

The Float Method: This method is useful to get a rough estimate of flow. First, choose a 100-foot section of ditch that is fairly uniform in depth and width. Mark the zero point and the 100 ft point with a flag or stick. The 100 ft mark should be downstream from the zero point. For most people, one good, long stride equals three feet. If there is no tape measure available, step off about 33 paces. Next, calculate the ditch cross sectional area (see "**Area**" above for details). Use an average of several measurements along the ditch.

Now, take a float (tennis balls, apples, oranges, etc.) and place it a few feet up stream from the zero point, in the center of ditch. Once the float hits the zero point, mark the time (probably to the nearest second). Then, mark the time the float passes the 100 ft mark. Record the time. Do this several times. Try to place the float in the center of the ditch flow so that it won't bounce off the sides or get caught up in any weeds. After 5-10 tries, average the recorded times.

The flow rate is determined by calculating the velocity of the water and multiplying it by the cross sectional area of the ditch. First, take the length of the ditch (100 ft) and divide it

by the time (in seconds). This will give the *surface velocity* (speed) in feet per second. However, water at the surface flows faster than water in the center of the flow and it is the average flow or center flow that is needed. Therefore, a conversion factor must be used to determine the *mean channel velocity*. The factor by which the surface velocity should be multiplied by is a function of the depth of the water in the ditch. Table 1 gives the coefficients to be used. Find the depth measured on the left and the corresponding coefficient on the right. Then multiply the surface float velocity by the coefficient to obtain the mean channel velocity.

Table 1. Coefficients to correct surface float velocities to mean channel velocities.(from "Water Management Manual, USDI/BOR, 1997).

Average Depth (ft)	Coefficient
1	0.66
2	0.68
3	0.70
4	0.72
5	0.74
6	0.76
9	0.77
12	0.78
15	0.79
≥ 20	0.80

Finally, take the cross sectional area of the ditch (ft^2) and multiply it by the corrected velocity (ft/sec) and this will compute the flow rate in cubic feet per second (cfs). To convert to gallons per minute, multiply the cfs by 454.

Tracer Method: This method is very similar to the float method but with one exception, a colored dye or salt is used instead of a float. Estimates of the ditch area are still required. Pour the dye upstream of the zero point, and record how long it takes the dye to travel from the zero point to the 100 ft mark. Then the calculations are exactly the same as the float method. This method often works well if the float keeps getting caught on the sides of the ditch. However, in many cases the dye is difficult to see because of the color of the water itself. Test the dye first to make sure it can be seen. The correction factors used with the float method (Table 1) are not required for the tracer method.

Velocity Head Rod: The velocity head rod is used to measure the velocity of water in a ditch and is relatively inexpensive and fairly accurate. The rod is in actuality a ruler used to measure the depth of the water. The water height is first measured with the sharp edge of the ruler parallel with the flow and the again with the ruler turned 90 degrees (Fig. 2). The difference in the height of water is the head differential and using Table 2, an estimate of the velocity (feet per second) can be made. From there, follow the same formula as with the float or tracer method, i.e., multiply the velocity by the cross sectional area of the ditch to get cubic feet per second. The velocity head rod method works only for velocities greater than 1.5 ft/sec and less than about 10 ft/sec.

The procedure is:

- Place the rod with the sharp edge upstream. Record the depth of the water (normal depth).
- Place the rod sideways. This will cause some turbulence and the water level will "jump" causing the water level to rise. Record the level again (turbulent depth).
- Subtract the normal depth from the turbulent depth and this will be the jump height.
- Find the corresponding velocity from Table 2.
- Multiply the velocity by the cross sectional area of the ditch to get the flow rate (cfs).

Table 2. Conversion chart for velocity head rod measurements from inches to ft/sec.

Jump (inches)	1/2	1	2	3	4	5	6	7	8	9	10	11	12	15	18
Velocity (ft/sec)	1.6	2.3	3.3	4.0	4.6	5.2	5.7	6.1	6.5	6.9	7.3	7.7	8.0	9.0	9.8

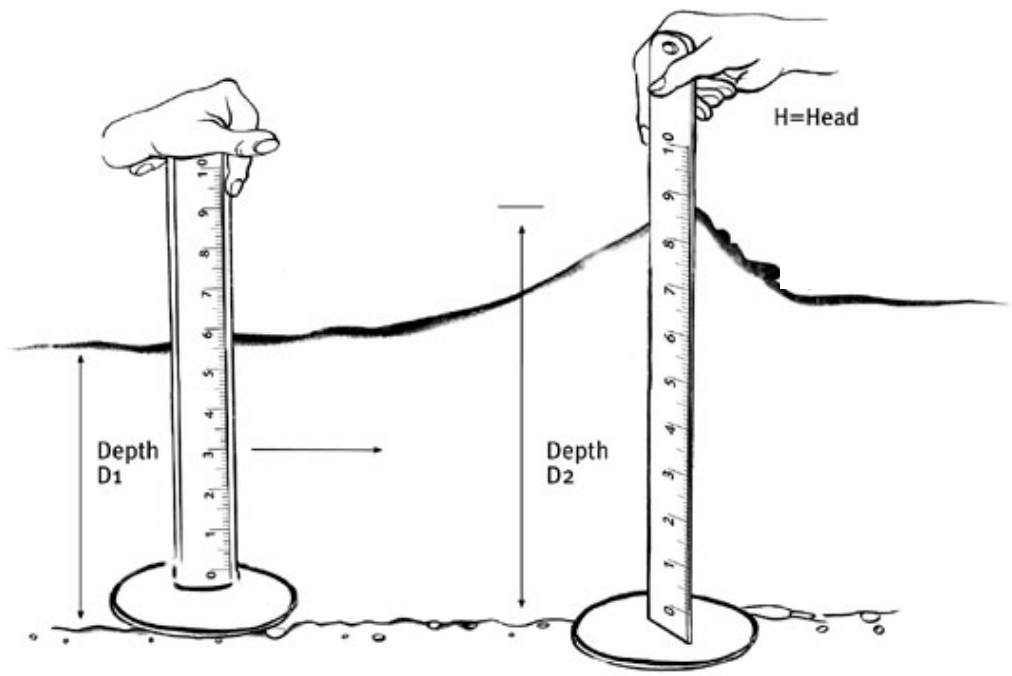

Figure 2. Using a velocity Rod. (Waterwatch, 2002).

Weirs: There are several different types of weirs that can be constructed and used to determine the flow rate in a ditch or stream. The three most common weirs are: (1) V-Notch or Triangular (2) Rectangular and (3) Cipolletti.

The simplest design is to make the weir out of a sheet of plywood or sheet metal. Cut the wood or metal to fit ditch with the particular shape notch cut out of the top. Make sure the weir is sturdy enough to hold up against the flow of the water. Figure 3 shows an example of the three different types. The top two are rectangular weirs. The first is a rectangular contracted weir and is one of the most commonly used. The second is another rectangular weir but since the sides of the weir are actually the sides of the ditch, it is called a suppressed rectangular weir. The third type shown in Figure 3 is the Cipolletti weir. This type of weir has a trapezoidal shaped notch. The last type shown is a triangular or V-notched type. With proper installation, all of these weirs can be accurate.

The dimensions for a contracted rectangular weir are given in Figure 4. An estimate of the actual flow rate must be made before construction of the weir in order to make sure the notch size is correct. For the V-notch, the dimension requirements are the same and for the Cipolletti, the requirements are also the same but with a 25% slope rising outward at the sides of the notch.

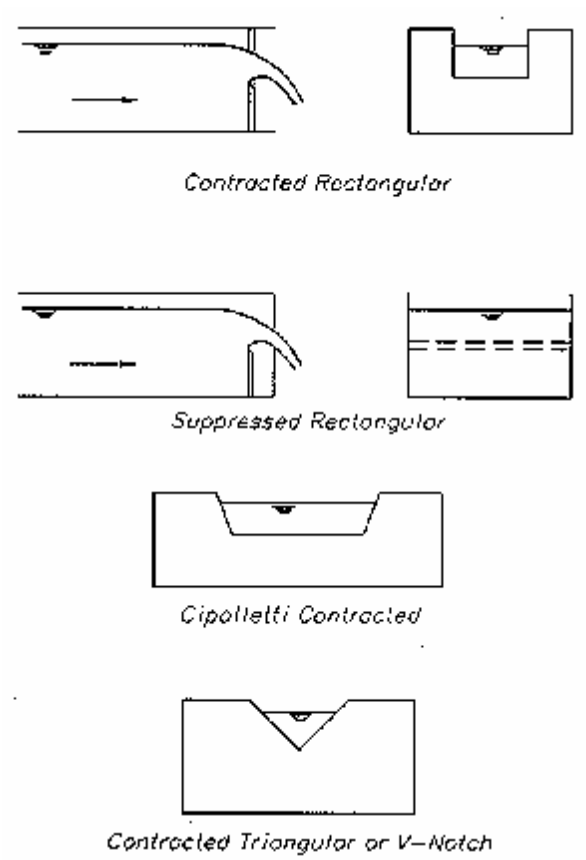

Figure 3. Diagrams of various types of weirs used to measure flow rate in an open ditch. (USDI-BOR, 1997).

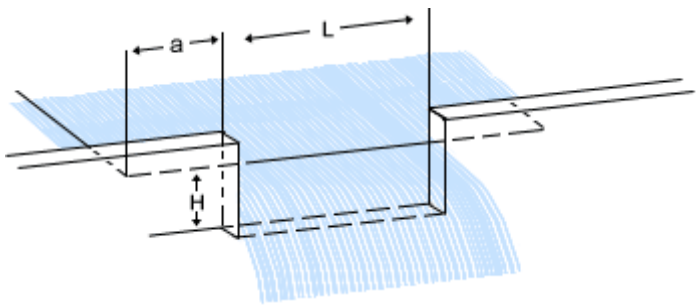

Figure 4. Diagram of a rectangular weir where L = width of weir opening (4 to 8 times H), H = head of weir (measured 6 ft upstream of weir) and a = at least 3*H.

To measure the head or height of the water for these weirs, pound in a stake about 6 feet upstream so that the top of the stake is even with the bottom of the notch in the weir. Once in place, the water will rise behind the weir. Measure the depth of water above the stake. Then, use charts like the ones in Tables 3-5 to estimate the flow rate. The length (L) refers to the width of the opening at the base of the weir notch.

CAUTION: Installing a weir in a ditch will cause the water behind the weir to rise. Make sure there is enough freeboard or the water in the ditch will overflow.

Table 3. Approximate flow over rectangular weirs. (Peterson and Cromwell, 1993).

Head (inches) (H)	Crest length (L)							
	(L): 1 foot		(L): 2 feet		(L): 3 feet		(L): 4 feet	
	GPM	Ac-in/hr	GPM	Ac-in/hr	GPM	Ac-in/hr	GPM	Ac-in/hr
2	98	0.22	198	0.44	298	0.66	398	0.88
3	181	0.40	366	0.81	552	1.22	738	1.63
4	278	0.62	560	1.24	852	1.88	1140	2.52
5	—	—	772	1.70	1164	2.58	1560	3.45
6	—	—	1010	2.22	1535	3.40	2055	4.54
7	—	—	1270	2.80	1980	4.27	2590	5.75
8	—	—	1540	3.40	2330	5.18	3120	6.90

Table 4. Approximate flow over 90-degree triangular weirs. (Peterson and Cromwell, 1993).

Head in inches (H)	Gallons per minute (GPM)	Acre-inches per hour (Ac-in/hr)
3	36	0.08
4	74	0.16
5	126	0.28
6	200	0.44
7	294	0.65
8	405	0.89
9	548	1.21
10	714	1.58
11	895	1.98
12	1118	2.48
13	1365	3.05
13.5	1495	3.34
14	1630	3.63

Table 5. Approximate flow over trapezoidal weirs. The length "L" refers to the length of the bottom of the trapezoid. (Peterson and Cromwell, 1993).

Head (inches) (H)	Crest length (L)							
	(L): 1 foot		(L): 2 feet		(L): 3 feet		(L): 4 feet	
	GPM	Ac-in/hr	GPM	Ac-in/hr	GPM	Ac-in/hr	GPM	Ac-in/hr
2	101	0.22	202	0.45	302	0.67	404	0.89
3	190	0.42	376	0.83	560	1.24	750	1.66
4	296	0.65	580	1.28	864	1.91	1160	2.56
5	—	—	802	1.77	1196	2.66	1500	3.52
6	—	—	1062	2.34	1580	3.50	2100	4.64
7	—	—	1350	2.98	2000	4.42	2660	5.88
8	—	—	1638	3.62	2430	5.38	3220	7.14

Other Methods: There are several other methods available and many devices that can be purchased "off the shelf." One is a current meter, which is a propeller meter that is lowered into the stream of water and records velocity. The flow rate (cfs) is calculated by multiplying the velocity (ft/sec) by the area (ft^2). There are flumes, submerged orifices and even acoustic ultrasonic meters that use ultrasonic pulses to measure the velocity of the flow stream. All of these methods have limits to their use. For more information, refer to the Arizona Cooperative Extension publication "*Measuring Water Flow and Rate on the Farm*", publication AZ1130, Arizona Water Series No. 24 (Martin, 1999).

Counting Tubes: If siphon tubes are used to irrigate out of an open ditch, an estimate of the flow rate can be obtained by counting the number of tubes. The size of the siphon tube and the distance from the water level in the ditch to the water level in the field (the drop) is needed to estimate the flow rate. Figure 5 shows two possible conditions. In Condition I (free flowing) the drop is the distance from the water level in the ditch to the end of the tube on the field side (usually level with the field). In Condition II (submerged), the drop is the distance from the water level in the ditch to the water level in the field. The larger the tube size or the greater the drop, the higher the flow rate. Table 6 shows some typical sizes and drops used for irrigation.

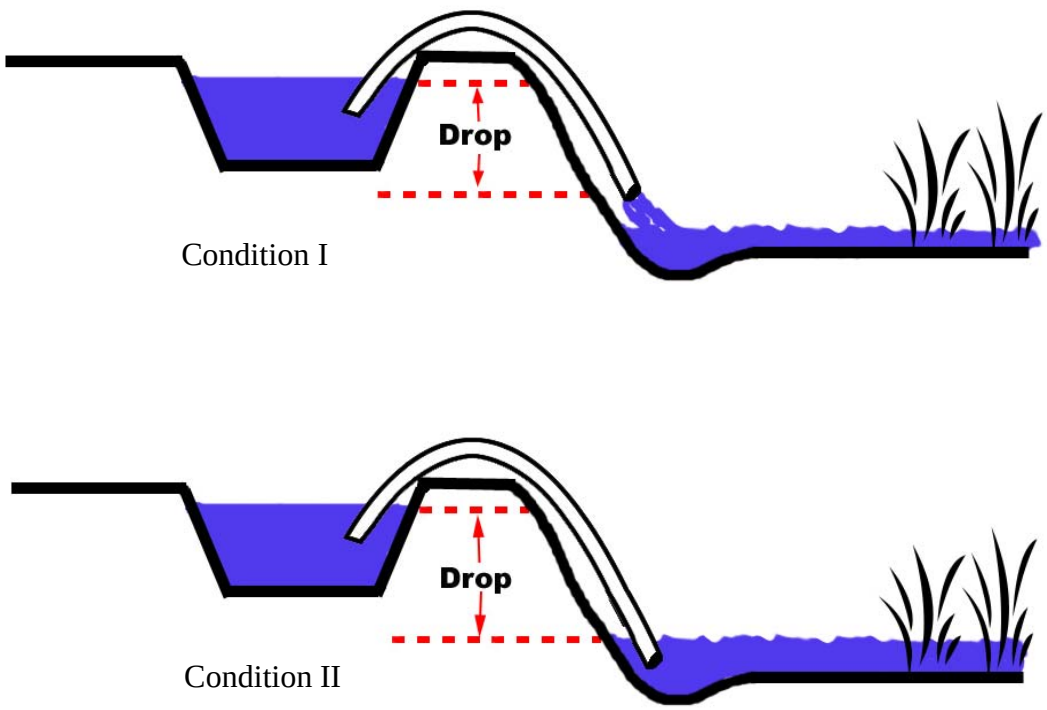

Figure 5. Diagrams where to measure the drop distance for siphon tubes. (Diagram by J.S. Jones, 2003).

Table 6. Approximate flow rate in gallons per minutes for siphon tubes.

Pipe Size (in.)	Flow Rate (gallons per minute)			
Drop (in.)	4”	6”	8”	10”
¾”	3.6	4.4	5.0	5.6
1”	6.4	7.9	9.0	10.0
1 ¼”	10.4	12.7	14.6	16.2
1 ½”	14.3	17.5	20.2	22.5
2”	25.6	31.8	35.9	40.0
3”	57.2	70.0	80.8	90.0

It is often difficult to measure the difference in water levels between the ditch and the field. One easy way is to do this is to get a piece of hose and a tape measure. Put the hose in the ditch and use it to siphon water into the field (Fig. 6a). Next, slowly raise the hose in the field until the water stops coming out (Fig. 6b). Now, use your measuring tape to measure the distance between the end of the hose and the water level in the field or the outlet of an irrigation siphon tube (Fig 6c). Make sure to keep the end up just at the level where the water stops coming out. This distance is your drop!

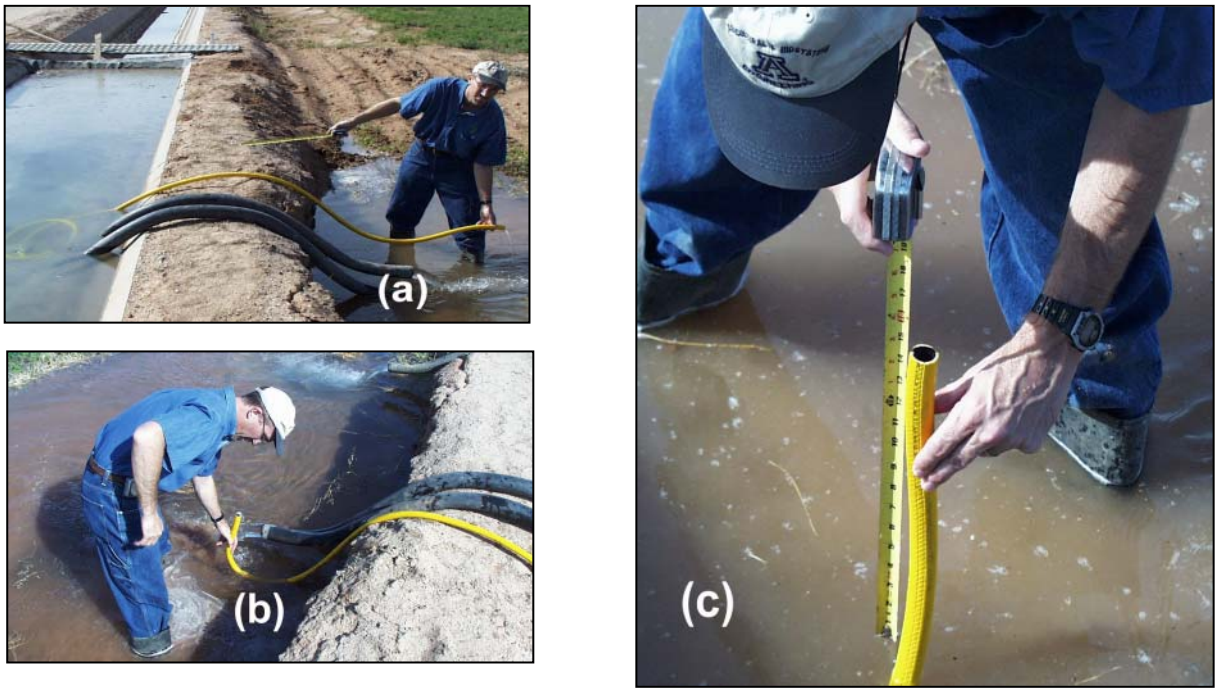

Figure 6. Three photos demonstrating how to measure the “drop” in a surface system. The drop is the distance from the level of the water in the ditch to the water level in the field. (a) Use the hose to siphon water out of the ditch; (b) Raise the hose up until water stops flowing out of the hose end; (c) Measure the distance between the end of the hose and the water level in the field.

Measuring Flow in Gated Pipe

Measuring water flow in gated pipe can be accomplished many different ways. Probably the most commonly used method is the propeller meter. These meters are normally installed inside a section of pipe at the distributor's shop. The buyer then simply buys a meter section for whatever diameter pipe used. There are some other methods that can be used but for convenience and ease of measurement, the propeller is a simple and accurate method.

Propeller meters are permanent pipeline devices that measure and record the volume and flow of water moving through a pipe. The pipe must be running at full flow for the meters to operate properly. Also, there must be a straight length of pipe upstream from the meter at least 10 times the diameter of the pipe. This is to reduce the turbulence in the water it enters the meter section. Thus, a 6-inch pipe would require 60 inches of straight pipe upstream from the meter. Table 7 gives the range of flows for various size meters and Fig. 7 shows a cross-sectional view of a typical meter.

Table 7. Typical range of flows for different size propeller meters.

Meter size	Minimum flow (gpm)	Maximum flow (gpm)
4 inches	50	400
6 inches	90	900
8 inches	100	1200
10 inches	125	1500
12 inches	150	2000

Figure 7. A Mc® Propeller from McCrometer, Inc. This propeller meter is installed inside a pipe section.

The meters are usually placed inside a length of aluminum pipe that is inserted into the gated pipe system. If poly-type plastic pipe is being used, there are connectors that will allow a meter section to be put in place.

If you don't want to pay the expense for the meter, you can use a piece of tubing, similar to the tube method for ditches. Find a piece of tubing (preferably clear) that either fits tight inside a gate or even better, can be attached tightly to the outside of the gate. Raise the tubing into the air until the water stops flowing out. Measure the distance from the water level in the tubing to the center of the gated pipe. If clear tubing is used, then you can raise the tube well above the point when the water stops coming out and it makes for an easier measurement (Fig. 8). Table 8 gives some estimate of flow rates for various manufacturers gates. Most manufacturers should be able to supply this information.

Figure 8. Two photos showing how to measure the head (ft) in a gated pipe system. The head is the distance between the water level in the tube and the center of the pipe. These are Rite-Flow™ gates and there is about 3 ft of head. According to Table 8, the flow is approximately 39 gpm per gate.

Table 8. Approximate flow capacities in gallons per minute (gpm) for some commercially available gates. Gates are wide open. (Burt, 1995).

Head (ft)	Flow Capacities (gpm)			
	Rite-Flow™	Epp™ Snap-Top Boot Gate	Epp™ Fly Gate	Tex-Flow ™ Yellow Top
0.25 (4”)	11	12	15	22
0.50 (6”)	16	17	21	32
1.00	22	24	30	46
2.00	32	35	42	67
3.00	39	42	52	82

Summary

There are many methods that can be used to measure flow rate and only the most common have been covered in this paper. In addition, there are meters that use ultrasound waves to measure flow in pipes, flumes, gates and even a Doppler-type acoustic meter. These are all relatively expensive and are not commonly used by growers. However, measuring flow is the first step in determining how much water is being applied to a field. With the flow rate, the area irrigated and the time of irrigation, you can calculate the amount of water applied. For information on calculating how much water was applied, read the University Arizona Cooperative Extension publication *Determining the Amount of Water Applied to a Field*, Pub. No. AZ1157, Arizona Water Series No. 29 (Martin, 2000).

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Transitioning From Flood to Gated Pipe

Jeannie Benally
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TRANSITIONING FROM FLOOD TO GATED PIPE IRRIGATION

TRANSITIONING FROM FLOOD TO GATED PIPE IRRIGATION

- 4th Annual Four Corners Irrigation Workshop
- July 10 & 11, 2003 – Shiprock Chapter
- San Juan River Farms – Shiprock Agency
- Mini-study via survey questionnaire
- By Jeannie Benally, Extension Agent
- Navajo Nation Department of Agriculture

BACKGROUND AND SETTING

- The San Juan River farm permittees pay $1.50/acre/year for water assessment fees.
- There are 919 land use permits.
- There are 10,906 acreage of farmlands.
- There are three irrigation projects:
  - Fruitland – 530 permits; 6,394 acres
  - Hogback – 341 permits; 3,855 acres
  - Cudei – 48 permits; 657 acres

Traditional Farming

STATEMENT OF THE PROBLEM

- ***What are the perceptions of selected farmers along San Juan River on utilizing gated pipes for irrigation systems?.***
- BOR funded projects within the Area III and Hogback B Line.
- EQIP funded projects within the San Juan River Basin (GPA).

RESEARCH QUESTIONS

- Is it easier to irrigate using gated pipes?
- Do you think by using gated pipes you are conserving water?
- If any, what are the disadvantages to using the gated pipes for irrigation?
- Are there any comparisons between the amount of time it takes to irrigate by gated pipe versus flood irrigation?
- Do you think it was a good investment to install gated pipe?

DEFINITION OF TERMS

- BOR is Bureau of Reclamation.
- EQIP is Environmental Quality Incentive Program.
- GPA is Geographical Priority Area.
- Farm permittee means a person possessing a land use permit.
- Land use permit is a document stating the number of acres a person can farm.

BASIC ASSUMPTIONS

- Mini-study deals with farmers who possess a land use permit.
- Some farmers are EQIP cooperators.
- San Juan River farm permittees are willing to improve their way of life through adoption of relevant technology.

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EQIP COOPERATOR

SIGNIFICANCE OF THE PROBLEM

- Implication: Anyone can use gated pipes for better irrigation efficiency.
- Application: Results of the mini-study can be generalized beyond study to specify what irrigation system makes the most long-term sustainable sense.

LIMITATIONS OF THE STUDY

- This mini-study was limited to BOR and EQIP farmers/cooperators who possess a land-use permit.
- Mini-study was descriptive in nature with a survey questionnaire.

REVIEW OF LITERATURE

- Preferential flow observed for flood irrigation and findings include more spreading of water under flood irrigation. (Jaynes, D.B.; Rice, R.C., 1992)
- Flood irrigation saturates soil surface more. (Meek, B.D.; Rechel E.R.; Carter, L.M.; Detar, W.R., 1992)

RESEARCH DESIGN

- Variables include:
  - Control of irrigation water.
  - Amount of time to irrigate.
  - Conservation of irrigation water.

SUBJECT SELECTION

- Participants in the mini-study are farmers with land-use permits.
- BOR farmers and EQIP cooperators were the appropriate group to study.
- Characteristic of the subjects are that they are water users.
- Size of sample is ten (10).
- Random Accessibility.

INSTRUMENTATION

- Survey questionnaire was developed.
- Interviewer was pre-trained (Reliability)
- BIA Ag. Engineer assist with survey questions. (Validity & Reliability)

DATA COLLECTION PROCEDURES

- Data was collected per telephone interview.
- Everyone contacted participated.
- There was no non-respondents or incomplete data.
- Mini-study was descriptive in nature that opinions were generated.

Transitioning From Flood to Gated Pipe

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DATA ANALYSIS PROCEDURES

- Statistical tool used was a Likert scale.
- Each question addressed was relevant to the affective variables involved.
- This method was chosen because respondents indicated a positive or negative reaction.

Is it easier to irrigate using gate pipe?

- 10 out of 10 indicated a positive reaction of "yes".
- Reasons include
  - Better control of water.
  - Less work.
  - Helps with uneven land topography.
  - Don't have to use a shovel that much.
  - All you do is turn on the valve.
  - Cleaner ditches or no ditches at all.

Do you think by using gated pipes you are conserving water?

- 9 out of 10 responded positively with an "Oh Yeah!".
- Reasons being:
  - Better management; brush and trees are gone.
  - Don't have to irrigate weeds in the ditches.
  - Not too saturating; no seepage loss
  - Gopher problem is not a problem anymore.
  - Only irrigate when I need to.
  - Able to control amount and water flow.

If any, what are the disadvantages to using gated pipes for irrigation?

- 3 out of 10 responded with a "no" or "none" answer.
- Others listed some disadvantages:
  - Brittleness of pipes; cost of pipes and fittings.
  - Pressure sometimes low.
  - Silt built-up and plug ups.
  - On sandy soils with slopes, must irrigate crossways.

Are there any comparisons between the amount of time that it takes to irrigate by gated pipe versus flood irrigation?

- 8 out of 10 responded positively with the following remarks:
  - Cuts down on time by 1/3 and ½.
  - Able to irrigate each row evenly.
  - Able to irrigate by sections
  - Able to watch the drainage portion.
  - A farmer can irrigate within 24 hours while neighbor takes one week on same size of field.

Do you think it was a good investment to install gated pipes?

- 10 out of 10 reacted positively with an answer of "definitely"!

THE END!

Inexpensive Sprinklers for Small Scale Irrigation

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Sprinkler irrigation systems have been available for more than 70 years. The early systems used lightweight steel pipe and non-rotating sprinklers. Rotary impact sprinklers were introduced in the late thirties. However, it was not until after World War II, when aluminum pipe became available, that portable hand-move systems became practical. Most of the early rotary impact sprinklers were low capacity, medium pressure, and constructed of brass. Some companies supplied gun sprinklers, but early models were not very satisfactory, because of the high application rate and potential for runoff. Over the years, the trend has been toward larger sprinklers. Sprinklers are now available with plastic, brass, aluminum, and some stainless steel components. Improvements in bearings contribute to longer life and less maintenance. Quality control has also improved. The major change in aluminum pipe has been a trend toward thinner wall aluminum pipe and stronger alloys. Couplers and gaskets have been improved to reduce leaks at joints. The number of coupler manufacturers has been reduced. Most of these changes have occurred because sprinkler systems evolved during the years from solid sets or portable systems to mechanical move systems were big fields are covered by minimal amount of hardware, such as self-propelled gun travelers, center pivots, and linear move.

The different types of sprinkler systems are:

- Solid Sets Sprinklers
- Portable Systems
  - Hand Move
  - Tractor Tow
  - Traveling Gun
- Mechanical Move Systems
  - Side Roll
  - Center Pivot
- Micro Irrigation

Most of the systems will fit small scale, irrigation. Center Pivot and large traveling guns are designed for larger scale fields.

Solid-Set and Permanent Irrigation Systems

Solid-set system uses aluminum pipe. Enough lateral pipes are purchased so that pipe may be left in place during the irrigation season. Main line for the solid-set system can be aluminum pipe above or underground or buried polyvinyl chloride (PVC) plastic pipe.

The permanent system normally uses buried main and lateral lines. However, some growers use above ground PVC plastic lateral lines. Permanent systems have been used for many years to irrigate turf areas such as golf courses, recreational playing fields, and commercial and residential turf. In more recent years, these systems have been used for agricultural irrigation to include nursery crop production.

Most of the solid-set and permanent systems for agricultural irrigation (including chemigation and fertigation) are used on high value crops such as nursery crops, tree fruits, small fruits, vegetables, and, to a small extent, tobacco. Many of the systems for fruits and vegetables are also used for environmental modification such as frost/freeze protection and crop cooling. These uses require a dependable water supply during the critical environmental period. For crop cooling, it may be possible to cycle the system on and off to reduce the total volume of water pumped.

Spacings of sprinklers may be square, rectangular, or triangular. Spacings are usually about 60 percent of sprinkler wetted diameter, but may need to be adjusted for wind conditions. Single- or double-nozzle sprinklers may be used. The double-nozzle sprinkler generally provides better uniformity, because the second nozzle provides water close to the sprinkler. Smaller sprinklers, because they are less affected by wind, provide better uniformity than gun sprinklers.

However, the labor required for moving pipe when smaller sprinklers are used is increased considerably. (Smaller sprinklers require more lateral lines.)

Figure 1 shows a typical layout for a solid set irrigation system. Sprinkler spacing is 80 feet on the lateral. Spacing of laterals is also 80 feet. Lateral pipe size is 2.5 inch. Main pipe size is 3 inch. One lateral is usually operated at one time. However, more laterals can be operated at the same time depending on the available flow. If higher flows are used than the pipe diameters might need to be changed.

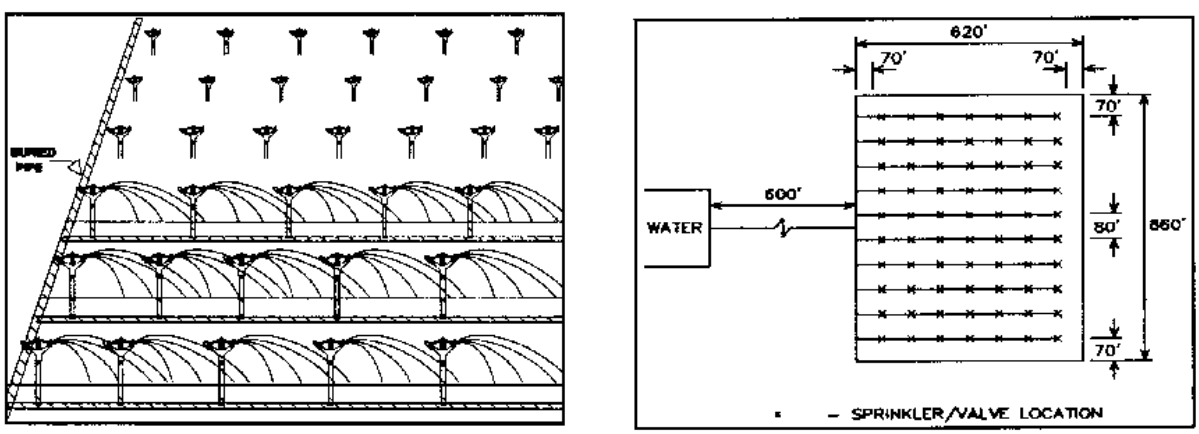


Figure 1. Schematic layout of a solid set irrigation system

Hand-Move Portable Systems

Hand-move systems are normally used to irrigate small fields. Solid-set and permanent sprinkler irrigation systems are used for irrigation, frost/freeze protection, evaporative cooling, and land application of nutrient-rich effluent. Figure 2 shows a typical layout of a portable hand-move aluminum pipe system. Two laterals are operated at one time. Spacing between sprinklers is 60 feet and spacing between laterals is 60 feet. The first and last sprinklers on each lateral are 30 feet from the edge of the field. This is done to provide more uniform water distribution around the edges of the field.

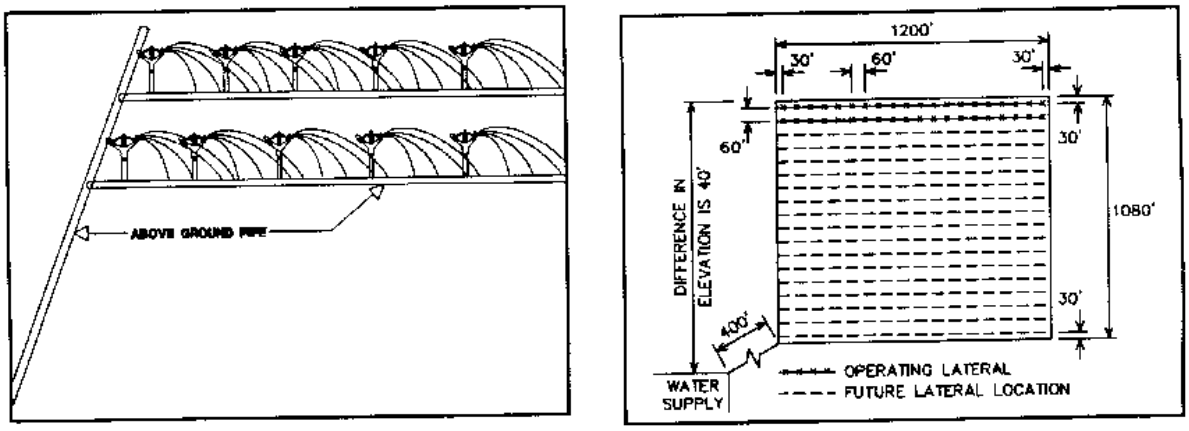


Figure 2**.** Schematic of a portable hand-move aluminum pipe irrigation system.

Laterals and sprinklers are typically moved twice per day, which requires 4.5 days to irrigate the 30-acre field shown in Figure 1. Each setup and movement of the pipe is referred to as a "set". Approximately 22.5 man-hours are required to move pipe each time the field is irrigated. For the field length and shape shown, the lateral pipe size required is 4-inch, and the main line size required is 6-inch. A pump capacity of 425 gallons per minute (GPM) would supply an application rate of 0.28 inches per hour when two laterals are irrigated per set. When operated for four hours (l/2 day per set), the total application to each set is just over one inch of water. The labor required for moving pipe, and the introduction of other types of irrigation systems have diminished the popularity of hand-move potable systems. Instead, growers have shifted to solid-set and permanent systems.

Design Considerations for Solid Sets and Portable Systems

General guidelines ("rules of thumb") have been established and should be followed when designing hand-move, solid-set, and permanent systems. For portable hand-move aluminum pipe systems, friction loss in the main and/or supply pipe should not exceed 2.0 psi for 100 feet of

(fps) pipe or 20% of the initial pressure. For lines that are greater than 1500 feet in length, friction loss should not exceed 1.0 to 1.5 psi per 100 feet. For PVC plastic pipe main and/or supply lines, flow velocity is the limiting factor rather than friction loss. Velocity should not exceed 5 feet per second to prevent pipe failure due to water hammer. Water hammer describes the buildup and sudden release of pressure that occurs when air is trapped in the pipe. The buildup and release of the pressure increases as the velocity of the flowing water increases.

Friction loss in aluminum and plastic lateral lines should not exceed 20 percent of recommended sprinkler operating pressure. Following this rule will assure reasonably uniform water distribution. As sprinkler pressure is reduced, due to friction loss down the lateral line, the volume of water applied by the sprinkler and the diameter of coverage is reduced.

Energy Conservation

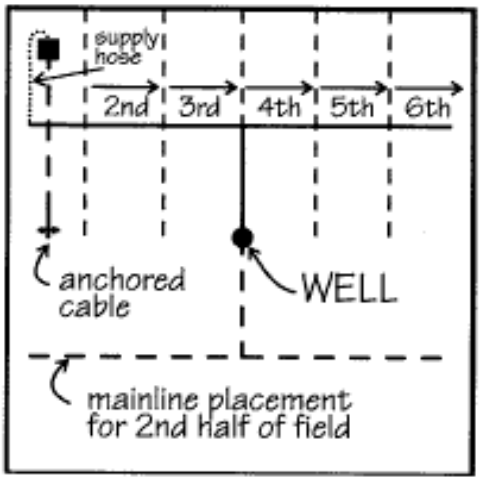
Most portable, solid-set and permanent sprinkler systems are medium in energy consumption. Many of the portable systems use gun sprinklers. Some growers are willing to trade off the higher energy costs for the savings in labor costs. There are some gun sprinklers that will operate satisfactorily at lower pressures and some growers are using these, but they have reduced radius of coverage and, therefore, higher application rates, assuming equal flow rates.
There are some low pressure impact sprinklers that have been marketed for the last several years. They also have reduced radius of coverage and this may increase the application rate.
Fuel cost (and conversely fuel savings) are computed based on the energy required to deliver the required flow rate at the desired operating pressure. To compute horsepower (Hp) requirements, use the formula shown in the box at the top of the next column.

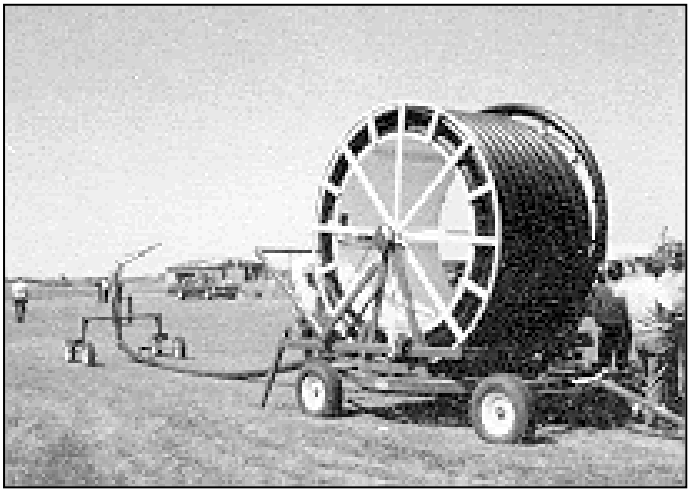
Horsepower = [TDH (feet) x Flow (gpm)]/ [3960 x Pump Efficiency]
Total dynamic head (TDH) or operating pressure at the pump includes the sum of the following:

- sprinkler operating pressure
- friction loss in the main line
- friction loss in the lateral line
- elevation difference between the water supply and the highest point in the field
- height of sprinkler above the ground (riser height)

Flow is the rate water is being delivered to the sprinklers. After computing TDH, a pump efficiency should be assumed so that horsepower can be computed using the above formula. Refer to Extension Publication AG-452-6: Pumping Plant Performance Evaluation, for a discussion of recommended pump efficiencies to select. Once the power requirements have been determined, the fuel cost can be computed (again, refer to AG-452-6 for more information). By comparing costs of several operational and system alternatives (i.e., operating pressure, low pressure sprinklers, etc.) the most energy efficient system can be identified for the given situation.

Traveling Big Gun



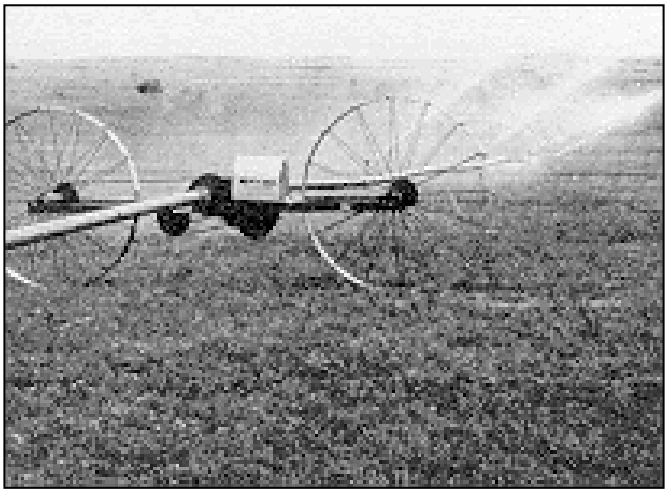


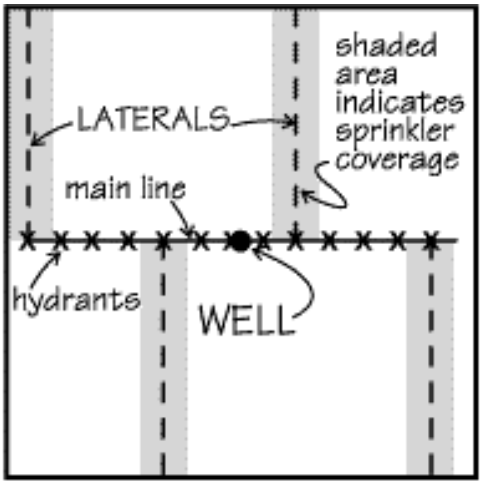
The traveling big gun system uses a large capacity nozzle (3/4 to 1 1/2 inches in diameter) and high pressure (90 to 125 psi) to throw water out over the crop (175 to 350 foot radius) as it is pulled through an alley in the field. Traveling big guns come in two main configurations: hard hose or flexible hose feed. With the hard hose system, a hard polyethylene hose is wrapped on a reel mounted on a trailer. The trailer is anchored at the end or center of the field. The gun is connected to the end of the hose and is pulled to the end of the field. The gun is pulled across the field by the hose wrapping up on the reel.

With the flexible hose system, the gun is mounted on a four-wheel cart. Water is supplied to the gun by a flexible hose from the mainline. A winch cable on the cart pulls the cart through the field. The cable is anchored at the end of the field.

Most traveling big gun systems have their own power unit and cable winch mounted directly on the machine. The power unit may be an internal combustion engine or a water drive. Particularly adaptable to various crop heights, variable travel speeds, odd shaped fields, and rough terrain, the big gun requires a moderate initial investment, more labor and higher operating pressures than center pivots and linears. One 1,320-foot (quarter-mile) long set usually covers 8 to 10 acres, but many variations are available using different water quantities and operating pressures. Irrigated crop land is sacrificed because the alley is generally two rows wide. Most big gun systems are used on a maximum of 80 to 100 acres per gun.

Side Roll





The side roll (sometimes called a wheel roll) system, as shown, consists of a lateral, usually a quarter mile long, mounted on four-to ten-foot diameter wheels with the pipe acting as an axle. Common pipe diameters are 4 and 5 inch. The side roll irrigates an area from 60 to 90 feet wide. When the desired amount has been applied to this set area, a gasoline engine located at the center is used to move the side roll to the next set. The sprinklers are generally mounted on weighted, swiveling connectors so that no matter where the side roll is stopped, the sprinklers will always be right side up. This type of system is not recommended for slopes greater than 5 percent and should be used mainly on flat ground. When not being used, side rolls are subject to damage from high winds.

Other characteristics include: adapted only to low growing crops, medium labor requirements, moderate initial investment, medium operating pressure (50 psi at inlet), generally rectangular field requirements, and each lateral capable of irrigating a maximum of 40 acres. The side roll is better adapted to heavier soils than a continuous moving system. Special wheels must be purchased for moving this system from field to field without disassembly.

The Total Coverage Irrigation Method using NAAN 5022

The total coverage method combines the advantages of the conventional irrigation method (wetting the entire area) with the advantages of low volume irrigation (precipitation rates that are adapted to the rate that water is absorbed by the soil). This irrigation method serves a variety of crops, such as sugar beet, potatoes and leaf vegetables.

System Structure

1. A system of three impulse sprinklers of different sizes with a plastic hammer and one or two nozzles (5022-U sprinklers).
   - An adapter connects the sprinkler to the stand. The adapter also serves as a housing for the flow regulator – an option which enables the use of sprinklers in conditions where flow regulation is required.
   - A 48” long x 8 mm galvanized rod, which is inserted 10” to 20” deep in the soil to stabilize the stand.
   - Flexible 48” long x .455” OD tube as fitting hose. The use of this type of tube prevents it from wrapping around the iron rod during irrigation.
2. The sprinklers are connected to any diameter PE laterals. Low density PE laterals, which enable flexible laying out and winding up of the laterals without tearing, have special importance.
3. Male and female friction fit connectors in the sprinkler and PE laterals enable quick connection. This can hold an operating pressure of up to 70 PSI.
4. Other system components: Water supply line and manifold, operation valves, pressure regulators, head control and more – as required by every pressure irrigation system.

   If the water is dirty (sand, organic matter), filters must be used to ensure the proper operation of the sprinklers, without the need to clean the nozzles during the irrigation cycle.

Principles of the Method

- *Focus on the creation of an irrigation regimen that will create optimum soil-water-air ratio and nutrition*

  The possibility of irrigation with a wide pressure range (25 to 60 PSI), with a variety of nozzles and different sprinkler spacing, enables precise planning of the precipitation rate required according to the soil types, surface slope, required irrigation interval and required operating hours.

  The low precipitation rate, which in many cases is close to the precipitation rate received with a dripline system, enables the absorption of the water by the soil without quick compacting of clay soil, loss of water, air compression from the soil. It enables the creation of a balance between air and water in the capillary spaces and prevention of upper drainage in sloped areas.

- *Achievement of a high irrigation efficiency*

  In conventional irrigation, the accepted values for irrigation efficiency are about 80%. The ratio between the volume of water that reaches the root zone and the volume of irrigation water is always influenced by the distribution uniformity of sprinkler irrigation, loss of water in the accessories, wind, etc.

  In this system of Total Coverage, where the precipitation rates are relatively low, the distribution uniformity of the sprinklers is particularly high about 90%. A high irrigation

efficiency ensures efficient use of water according to the crop requirements – an important factor especially in arid regions.

- *A combination of fertilization and irrigation*

  Creation of a fertigation system, one of the factors for increasing the quality and quantity of the yields in the low volume irrigation system, is also possible with this sprinkler system. Since most of the system's components are made of plastic, in addition to the other aforementioned factors, combining the fertilizer with the irrigation is an especially important factor. Fertilization through the irrigation system also serves as a maintenance operation. For example, injection of phosphoric acid as phosphoric fertilizer also removes sediments of carbonates and increases the pH in the water.

- *Adapting the irrigation system to plots of different sizes*

  This system is suitable for plots of less than one hectare as well as for plots of hundreds and thousands of hectares. The variety of diameters of the sprinkler laterals enables the construction of different size irrigation systems, using one of the three sprinklers in the series.
  For example: A farmer with a narrow vegetable plot of will choose a smaller version as 501-U sprinkler, which can be installed at spacings of 26 x 26 feet. A precipitation rate of 0.125 in/hr can be achieved (57 GPM per Acre).

  A farmer with a larger plot will choose the 502-H sprinkler, with spacings of 30 x 30 feet, to achieve a precipitation rate of 0.153 in/hr.

  A wide-scale project will be irrigated with 5022-U sprinklers, with different nozzle combinations, reaching a precipitation rate of 0.10 to 0.3 in/hr on spacings of up to 40 x 40 feet.

  PE laterals with diameters of 1" and 2" can be used for maximum flexibility. The diameter is adapted precisely to the size of the plot, pressure level and other conditions.

- *Use of flow regulators*

  In order to increase the water distribution efficiency in sloping fields on the one hand, and to enable the use of long laterals with low diameters on the other hand, flow regulators were developed for this system. The flow regulators are installed inside the adapter connecting the sprinkler to the galvanized rod and the tube.

  Flow regulator: 1.5GPM and 2.5GPM. These are suitable for 3/32" nozzle and 3/32" x .071" nozzles accordingly. The regulators operate within a pressure range of 35 to 70 PSI.

- *Mechanized laying out and winding up of the laterals*

  For efficient work at the beginning and end of the irrigation season, before harvest, the irrigation laterals are laid out at the beginning of the season and then wound up at the end of the season by a machine that is connected to a tractor and operated by hydraulic power. The laterals are wound on 2.20 m drums. This enables quick laying out and winding up of the laterals, and storage at the end of the season.

  Another factor that complements the system is the pipe-welding device (thermofusion), which is installed on the tractor, together with the winding machine. This eliminates the need for connection accessories.

Experience over the last three years shows impressive field results for all types of crops. For example: An increase of over 50% in sugar beet yields (in Spain) after changing from flood irrigation to the Total Coverage system.

Sources:

1. The total coverage system. Menachem Cohen, Head design engineer, Naandan Irrigation Systems, Israel.
2. Selection and management of hand move and solid set irrigation systems. Robert Evans. NC State.

Options for Water Management during Drought

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The year 2002 was one of the driest on record in the Four Corners area in general and southwestern Colorado in particular. It followed three years of below average precipitation as shown in the graph titled "Monthly precipitation at Yellow Jacket, Colorado". Precipitation in 2003 was slightly higher than in 2002 (11 in. vs. 8 in.) but still below average. The 30-year average at Yellow Jacket is approximately 16 in. McPhee Reservoir, which holds water for the Dolores Project, was at its lowest level at the end of the irrigation season in 2002 and 2003. Full service irrigators only received approximately one third of their allotment in 2002 and 55 to 60% in 2003. It would take approximately 70 % of average runoff to satisfy 100% of the water demand for the Dolores Project users in 2004.

Droughts occur due to large-scale phenomena's that alter the normal weather patterns in a region and result in less precipitation, and often, higher temperatures than normal. When rain or snow is scarce, there is less water to recharge ground water, feed streams, fill reservoirs and lakes, and grow crops, among other things. The impact of drought on people and all living things can be devastating. Climatic and water data are readily accessible from a variety of sources. There are several indices that are helpful in assessing drought severity and water availability.

Before water from rain or snow touches the ground, some of it may be lost due to wind or evaporation. Some of the water that reaches the ground or comes from melting snow may run off and settle in lower areas of the landscape, some will percolate into the ground, and some will be used directly by the plants or evaporate into the atmosphere. Plants take up available moisture mainly through their roots and use it to process plant material and stay healthy and "cool". Water that evaporates from the soil or is transpired by the plant (Transpiration is the largest portion of ET in a crop) is referred to as evapotranspiration or ET. The relationship between ET and crop growth as measured by dry matter is often linear. The relationship between precipitation amount (irrigation and/or rainfall) is often curvilinear since crop yield levels off at a maximum amount of precipitation. Examples are given using alfalfa and spring wheat. It takes approximately 5 in. of consumptive use (ET) to produce one ton of alfalfa hay in the intermountain region of the southwest. More water will be required to provide 5 in. of water, depending on the irrigation system. For example, approximately 6.7 in. of water (minus effective precipitation and change in soil moisture) will need to be applied with a sideroll that has an irrigation efficiency (total amount applied * 100/amount that enters the soil) of 75%, to produce one ton of alfalfa hay. The example shown in the Table titled "Alfalfa Irrigation Efficiency, Yellow Jacket, 2002" refers to a subsurface drip irrigation system, which, if designed properly, can be highly efficient in delivering water to the crop.

Average water consumptive use (estimated C.U.), growing season precipitation (rain + snow), and effective precipitation for several crops at Yellow Jacket, CO (Elevation: close to 7000 ft.) are shown in the next slide. The difference between C.U. and effective precipitation is the net

amount of irrigation water required to satisfy crop C.U. The gross amount of irrigation that will need to be applied is:

Net irrigation amount x 100/Irrigation efficiency in percent.

Crop C.U. or ET usually peaks at flowering to seed formation for grain crops and/or during hot, dry, and windy days for crops like alfalfa. For example, alfalfa ET at Yellow Jacket, CO peaks in July and August, while winter wheat ET is highest in June. Thus, not only different crops may have different water requirements for maximum growth; they may also reach their peak water use (demand) at different times of the year. Furthermore, water use efficiency or WUE (crop production/amount of water applied or used by the crop/unit area) usually follows the law of minimum return, meaning that WUE increases with the amount of water applied to a certain point or growth stage then levels off or even decreases afterwards. Applying more water that is needed for optimum crop production could be wasted (some of it may be stored in the soil for later use) through runoff or deep percolation and might even be harmful to the crop by promoting diseases. Crop selection (which crops to grow) and crop allocation (where to grow them and how many acres to allocate to each crop) are always important in any farming operation. They are even more so when water is in short supply. In the example given under "Crop Allocation", whereas only 14 in./acre are available, raising 127 acres of pinto beans (out of 160 acres) would provide the maximum gross return. In other situations, raising more than one crop on the 160 acres could provide the best strategy of utilizing the available water and meeting other goals such as profitability or sustainability.

Proper water management involves excellent irrigation system design, operation, and maintenance; sound irrigation scheduling; and commitment to management. According to Dr. Bob Hill of Utah State University, a well designed irrigation system will deliver enough water to meet the crop (s) needs, spread the water uniformly across the field, and allow maximum water storage in the root zone. In addition, a well-designed irrigation system will minimize water losses due to evaporation, runoff, and deep percolation. Evidently, irrigation scheduling plays a big role in avoiding water waste. Irrigation system efficiencies commonly range from 40 to almost 100% depending on the system used, system components such as the type of sprinkler package on a center pivot, and system operation and maintenance. Design considerations include soil type, field layout and topography, and peak ET rate.

Irrigation scheduling encompasses the amount and timing of irrigation. Sound irrigation scheduling takes into account crop water needs, soil water-holding capacity, and changes in soil water. When scheduling irrigation applications, it is important to know what impact a water deficit could have on the crop. Crops are more sensitive to water deficits at certain growth stages, usually flowering to grain filling, than at others. An integrated approach using ET, soil, and crop information usually gives the best results. As a rule of thumb, most crops should be irrigated when nearly 50% of the available soil water is depleted in the root zone. Several tools are available for monitoring soil moisture and ET.

Water may be the most limiting factor to crop production in the Four Corners area. However, crop yield potential will not be reached if other production inputs and practices are lacking or managed poorly. These include the selection of crops and crop varieties adapted to the soil and climate of the area, proper planting techniques, good pest control, and soil fertility management that is based on soil testing, crop yield goal, and soil-crop-water interactions.

Depending on the implements used and the timing of tillage operations, tillage can be beneficial or detrimental to crop growth and/or water management. Excessive tillage can cause soil erosion, accelerate soil water evaporation, and increase soil compaction. Keeping tillage to a minimum and maintaining a crop cover on the soil surface will reduce evaporation, soil erosion, and runoff. Keeping water application rate at or below the soil infiltration rate can also minimize runoff. The soil amendment PAM (Polyacrylamide) has been shown to reduce sediment loss drastically in furrow irrigation.

In conclusion, water is a precious and limited resource in the Four Corners Area. We have been in a drought since 1999 and this will not be the last drought. Climatic records and tree- ring studies show frequent and sometimes prolonged droughts in the Four Corners area. It is paramount that we manage our water responsibly. Proper water management for crop production includes careful irrigation system design, sound irrigation scheduling, and best soil and crop management practices.

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Al-Kaisi, M., A. Berrada, and M. Stack. 1997. Evaluation of irrigation scheduling program and spring wheat yield response in southwestern Colorado. Agric. Water Management 34 (1997) 137-148. Elsevier Science Inc.

Internet resources

http://co.water.usgs.gov/drought/

http://www.usbr.gov/uc/water/

http://www.wcc.nrcs.usda.gov/snow/

http://www.colostate.edu/Depts/SoilCrop/extension/Newsletters/2003/Drought/index.html

http://ccc.atmos.colostate.edu/publications.php

Options for Water Management during Drought

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Acknowledgments

- A History of Drought in Colorado (CWRRI, CSU)
- Crop Production with Limited Water ("Agonomy News", CSU)
- 15th Annual Central Plains Irrigation Conference & Exposition (Proceedings)
- Bob Hill (USU), G.A. Peterson (CSU), J.P. Schneekloth (CSU), Troy Bauder (CSU), others.

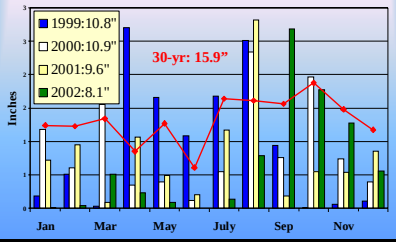
Presentation Outline

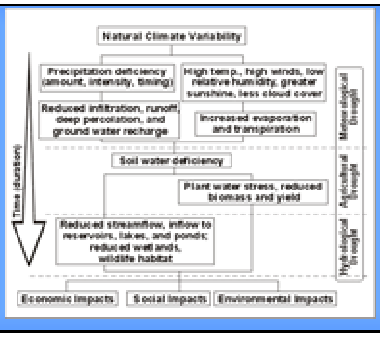
- Drought
- Crop response to water
- Management of limited water supplies
  - Irrigation scheduling/system efficiency
  - Crop selection & allocation
  - Crop & soil management
- Concluding remarks

Drought in SW Colorado

- Dolores Water Conservancy District/FSA
  - Normal allocation: 22.8 in./ac. (up to 30 in.)
  - Year 2002: 6 to 7 in./ac.
  - Year 2003: 12 to 13 in./ac.

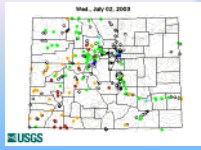
Monthly precipitation at Y. Jacket, Colorado



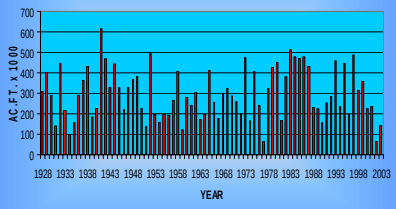


Water Data

- Precipitation amount: NOAA, State Univ.
- Snow pack: NRCS
- Stream flow: USGS
- Reservoir level: USBOR, Water Districts



DOLORES FLOW (1928-2003) AVG. 298,078 AF



Options for Water Management during Drought

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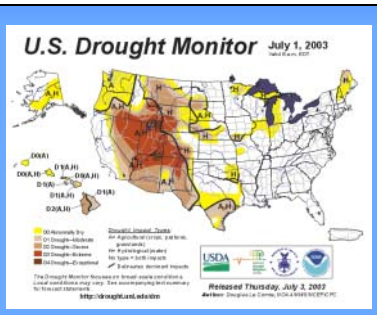
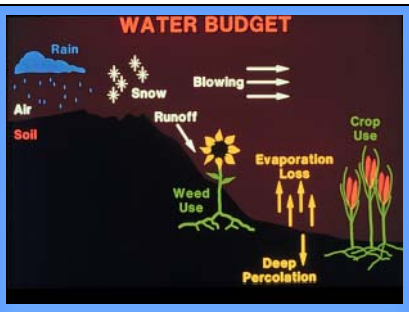
Water Availability Indices

- The **Palmer Drought Severity Index**
- The **Crop Moisture Index**
- The **Surface Water Supply Index (SWSI)**
- The **Standardized Precipitation Index**





Source: G.A. Peterson, CSU

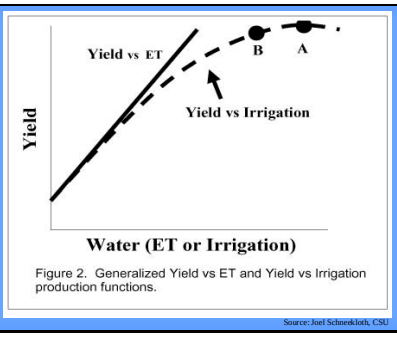
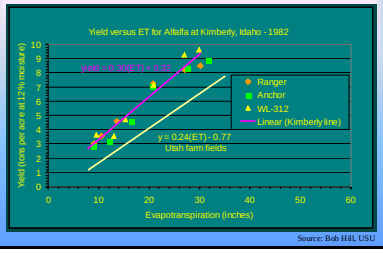


Figure 2. Generalized Yield vs ET and Yield vs Irrigation production functions.

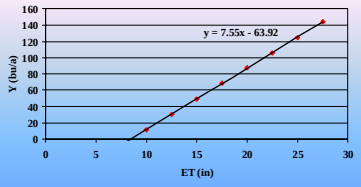
Source: Joel Schneekloth, CSU

Results of such a field study for alfalfa at Kimberly, Idaho



Source: Bob Hill, USU

Crop Yield - ET Function Spring Wheat



Alfalfa Yield Related to Evapotranspiration

Alfalfa produces about 1 ton/acre yield for every 5 inches of consumptive water use (ET) in intermountain U.S. farm fields..

Source: Bob Hill, USU

Management of Limited Water Supplies

for

Crop Production

Options for Water Management during Drought

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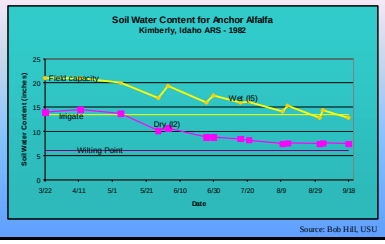
Alfalfa yields were 4.5 ton/acre less with deficit irrigation than with adequate water



Source: Bob Hill, USU

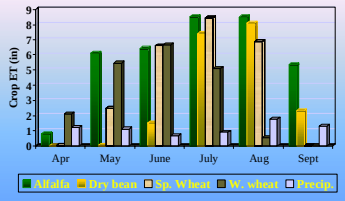
Alfalfa Irrigation Efficiency Yellow Jacket, 2002

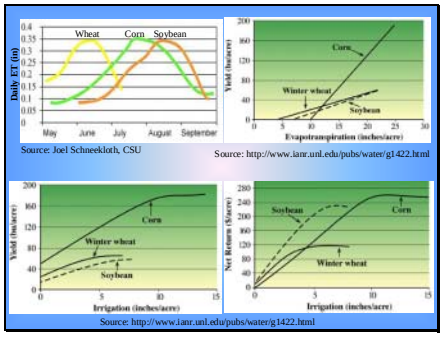
Irrigation (in.)	*Yield T/Ac*	*Effic. in./ton*
30.6	6.7	4.6
(36.0	**6.7**	**5.4)**
25.4	5.7	4.5
20.3	4.6	4.4

Estimated Crop C.U. at Y.Jacket

Crop	C.U. in.	GS. PP in.	Eff. PP in.	Diff. in.
Alfalfa	28	7.5	5.3	22.7
W. Wheat	20	10.8	7.5	12.5
S. Wheat	18	6.0	4.2	13.8
Dry Bean	17	5.4	3.8	13.2
Grasses	23	11.0	7.7	15.3

Crop ET at Yellow Jacket 1992-1998



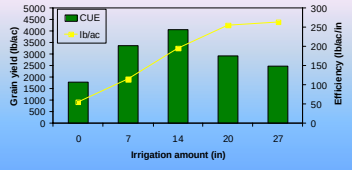


Source: Joel Schneekloth, CSU

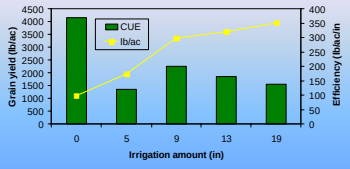
Source: http://www.ianr.unl.edu/pubs/water/g1422.html

Source: http://www.ianr.unl.edu/pubs/water/g1422.html

Spring Wheat Response to Irrigation at Y. Jacket



Dry Bean Response to Irrigation at Y. Jacket



Crop Allocation

- Hypothesis
  - Available water: 14 in./ac. (1.16 AF/ac.)
  - Acres: 160 Total water allocation: 187 AF
  - Crops: Alfalfa (22.7", 5 t/ac.), Winter wheat (12.5", 90 bu/ac.), Dry bean (13.2", 20 cwt/ac.), Spring wheat (13.8", 90 bu/ac.)
  - Irrigation system efficiency: 75%
- What and how much to plant?

Options for Water Management during Drought

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Crop Allocation (Continued)

Crop	Yield /ac.	Unit Price $	C.U. AF/ac.	Max. Acres	Gross Income $
Alfalfa	5 t	90	2.5	74	33,304
Alfalfa	3 t	90	1.2	160	43,200
W. Wheat	90 bu	2.70	1.4	134	32,659
P. Beans	20 cwt	22	1.5	127	56,000
P. Beans	20 cwt	18	1.5	127	45,720

Proper Irrigation Management

- Design and Installation
- Irrigation Scheduling
- Operation and Maintenance
- "Commitment to Management"

Irrigation Management Viewpoint?

Source: Bob Hill, USU

Leak Management - How much?

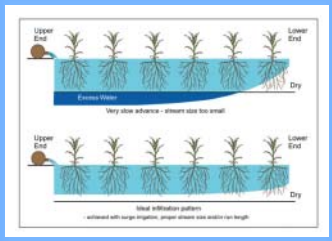
Source: Bob Hill, USU

Good Irrigation System Design

Is realized when there is:

- **Enough water to meet crop needs**
- **Uniform water application across field**
- **Maximum amount of water stored in root zone**

Source: Bob Hill, USU



Source: Troy Bauder, CSU

Readily Attainable Efficiency

- Furrow Irrigation: 40 to 60%
- Siderolls: 60-80%
- Center Pivot - Impact Sprinkler: 85%
- Center Pivot - Spray on Drops: 90%
- Center Pivot - LEPA/In Canopy: 95%
- Subsurface Drip Irrigation: 90-100%

Design Factors Include:

- Field Layout, Topography and Soils
  - Field Shape, water source, elevation differences
- Water Application Rate (in./hr.)
  - Nozzle size, pressure and spacing
- Crop Water Use (Max. ET)
  - Air temperature, Sunshine, Wind, Humidity
  - Crop and growing season

Source: Bob Hill, USU

Options for Water Management during Drought

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Proper Irrigation Scheduling

Depends on system design, maintenance, and operation and water availability.

Irrigation Scheduling is defined as:

- When to irrigate
- How much water to apply

Source: Bob Hill, USU

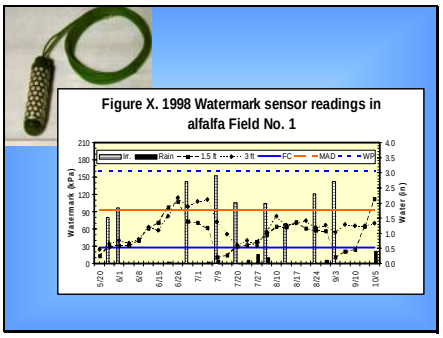
What are the keys to good scheduling?

- Regardless of the aspect(s) we are manipulating, we need to know:
  - Soil water holding characteristics
  - Root zone depth and changes over time
  - Current soil moisture level
  - Running measurement/estimate of crop water use

Common Irrigation Scheduling Approaches

- Irrigate when it is your turn
- When the neighbor irrigates !
- When the plants wilt
- When the soil water dries out
- Follow a soil-water budget – ET calculation
- Some combination of the above

Source: Bob Hill, USU



Basic Rules:

- Most field crops should be irrigated whenever the soil water depletion approaches 50% of the available water in the root zone for optimum growth.
- Most field (grain) crops are especially sensitive to water stress during the reproductive stage (flowering-grain filling).
- Pre-irrigation!

Crop & Soil Management

with
Limited Water Supplies

Crop Management

- Crop variety selection
- Seed source/treatment
- Seeding date, rate & geometry
- Pest control
- Nutrient management
  - Application rate (Soil Testing)
  - Application timing
  - Application (placement) method

Soil Management

- Tillage
  - Control weeds ↑
  - Prepare a seedbed ↓
  - Increase water infiltration ↑
  - Reduce soil compaction
  - Evaporation ↓

Options for Water Management during Drought

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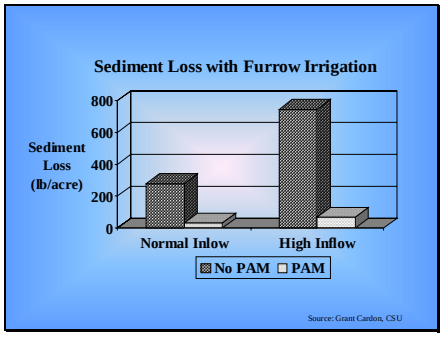
Crop Residue Management

- Reduce evaporation ⇧
- Snow entrapment ⇧
- Reduce runoff ⇧
- Reduce soil erosion ⇧
- Pest control, nutrient management, planting equipment!

Runoff control

- Infiltration rates - soil type
- Application rates - keep it low, wide patterns, droplet size, compaction
- Cultural practices
- Residue, subsoiling, basin tillage
- PAM: PolyAcrylaMide



Concluding Remarks

- Drought is a fact of life in the 4-Corners area.
- Water is a precious resource that must be managed responsibly.
- There are numerous ways to optimize the use of limited water supplies for crop production.

Water Management and Delivery in Shiprock

Martin Duncan, Marlin Saggboy, Mike Isaacson, Bernadette Tsosie, Valerie Redhouse

Introduction

In 1960 the United States transferred irrigation project works including the San Juan Irrigation Systems to the Navajo Nation (Public Law 86-636 passed July 12, 1960). The San Juan Irrigation Systems can be divided into two systems: Hogback Canal and Fruitland Canal. Table 1 lists acreage for both systems as determined by the Bureau of Indian Affairs Crop Utilization Study in 1993 (USBIA, 1993).

Table 1. System acreage for the San Juan Irrigation Systems

Classification	Hogback Canal	Fruitland Canal	Total
Irrigated	2,789	2,380	5,169
Idle	3,793	828	4,621
Irrigable Acreage	8,829	3,335	12,164
Assessed Acreage	9,179	3,548	12,727
Total Project Acreage	9,850	3,830	13,680

Shiprock Irrigation, a department of Navajo Nation Department of Water Resources, operates and maintains the entire San Juan Irrigation Systems. Funding for Shiprock Irrigation is obtained from the general funds of the Navajo Nation. Recently, the San Juan River Dineh Water Users (SJRDWU) was formed to provide for local governance of the San Juan Irrigation Systems. Funding for the SJRDWU will eventually come from an annual water assessment of $1.50 per acre and from ongoing and future settlements.

San Juan River Dineh Water User Association

In 1999, Articles of Incorporation were drafted and ratified thereby creating the SJRDWU. The purpose of the association is to procure, furnish, supply and distribute water at cost, to and for its association certificate holders only, for domestic, irrigation and all other useful purposes (SJRDWU, 1999). In addition to the articles of incorporation, bylaws governing the association were drafted. These bylaws called for a governing board of directors to be elected by the water users. In all, there are (7 or 9) directors, each representing a different area of the San Juan Irrigation Systems. A president, a vice-president, a secretary, and a treasurer were to be elected from the board of directors.

In 2003, SJRDWU hired a superintendent, an office manger and three ditch riders in order to establish a full time office, expend collected monies towards improving the San Juan Irrigation Systems, and provide for the first time ditch riders to operate the San Juan Irrigation Systems. Establishing a full time office has enabled the SJRDWU to conduct daily business, collect and enforce the water assessment, manage rehabilitation and betterment projects, and oversee canal

operations. Because the SJRDWU is independent of the tribal government procedures and bylaws, monies collected from the water users' assessment and other settlements can be readily and efficiently utilized to improve the San Juan Irrigation Systems. The introduction of ditch riders patrolling and operating the canals will benefit water users.

Other accomplishments by the SJRDWU include constructing a check structure on Yellowman Lateral, converting open ditch laterals to underground pipe laterals, the purchase of bridge material and piping, and the installation of new turn out gates. Great strides have been made in the formation and the establishment of the SJRDWU but challenges still face the new organization. The greatest challenge facing the SJRDWU is obtaining the support of farmers in order to become a viable local governing organization. The apathy seen of water users include the low turnout in director elections and the lack of candidates running for the board. Education of farmers on the benefits of having a water users association coupled with noticeable water delivery improvements are the key elements in generating wider support amongst water users.

Eventually, the SJRDWU would like to fulfill the purpose stated in its Articles of Incorporation of managing and operating the San Juan Irrigation Systems. The Navajo Nation Department of Water Resources supports this goal and is working diligently to assist in the establishment of the SJRDWU by providing technical support and a office to conduct business, legalizing the expenditures of water assessment monies collected by the SJRDWU, and transferring responsibilities to the SJRDWU.

Establishing a flow measurement program

To comply with the 2003 Shortage Sharing Agreement (a gentleman's agreement ratified by all San Juan River water users regulating diversions for the 2003 season), remote flow meters were installed near the head gates of both canals. The sensing instrument utilized for the flow meters is an ultrasonic level meter. This technology was selected because of the low maintenance requirement of the meter. The ultrasonic meter communicates with a satellite transmitting module which transmits four 15-minute readings every hour through the Federal GOES satellite system. The data is then processed and published on the world wide web on a page located at *sanjuanflow.info*. The purpose of publishing the diversions to Hogback and Fruitland Canal is to ensure to other San Juan River water users the Nations' compliance with the 2003 Shortage Sharing Agreement.

The 2003 Shortage Sharing Agreement limits Hogback Canal's diversion to 170 cfs and Fruitland Canal's diversion to 100 cfs. Historically, Shiprock Irrigation operates Hogback Canal utilizing a diversion of 220 cfs and Fruitland Canal with a diversion ranging from 80 to 130 cfs. Normally, these higher diversions have led to higher spill rates but have allowed for limited operation requirements of the canals. The 2003 diversion limits, while sufficient for actual irrigable acreage, will require more rigid operating requirements in order to successfully deliver water, thus, demonstrating the need for a flow measurement program. For the year 2003, the flow measurement program will consist of the two remote flow meters coupled with daily recording of stage at key locations along both canals. This will assist operators in distributing water in response to the limited diversions and provide for limited accountability for delivering water. The goal for the future is to expand the program till eventually the entire system is capable of scheduling and accounting for all water delivered.

Proposed O&M Boundary for Shiprock Irrigation

The immediate threat to reliable water delivery in the Shiprock area is the poor shape of the delivery infrastructure. This is largely due to the inadequate funding provided by the Navajo Nation in operating and maintaining the San Juan Irrigation Systems. As a result, organized canal operation for the San Juan Irrigation Systems is mostly non-existent and maintenance focuses on responding to emergencies rather than the preferred preventive maintenance.

To correct this situation, the Navajo Nation needs to increase funding or delegate current responsibilities to others. The advent of the SJRDWU makes the latter alternative the more viable option. Currently, Shiprock Irrigation, operates and maintains the entire system from diversion dam to farmers gate. By transferring a portion of this stewardship to the SJRDWU, the Navajo Nation will be able to match limited resources with actual operation and maintenance requirements, allow for the development of the SJRDWU, and utilize funding from outside sources.

The proposed O&M boundary for Shiprock Irrigation include the diversion dams, the main canal systems, and the main drainage systems. If current funding levels are maintained by the Navajo Nation, the proposed O&M boundary will allow the Nation to spend roughly $2,500 per maintained canal mile which is marginally comparable to similar systems. Currently, the Nation by taking care of the entire system spends approximately $700 per maintained canal mile. (Keller-Bliesner, 2003). One immediate benefit of creating an O&M boundary for the San Juan Irrigation System is the opportunity for the Nation to delegate responsibility to the SJRDWU for the operation and maintenance of canals and ditches outside of the Shiprock Irrigation boundary. This change will empower the SJRDWU and facilitate effective local governance over the irrigation system. In addition, monies collected by the water assessment and other settlement can be used locally without interference from tribal government procedures.

Conclusion

Many improvements to water management and delivery are required in order to safeguard water resources in the Shiprock area for current water users and the future. Perhaps, the greatest achievement so far is the formation and the establishment of SJRDWU. This organization provides a foundation for the establishment of local governance over the San Juan Irrigation Systems. The local governance will allow for wider farmer participation in water issues and greater accountability in water delivery.

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Sharing the Shortages: The San Juan River 2003

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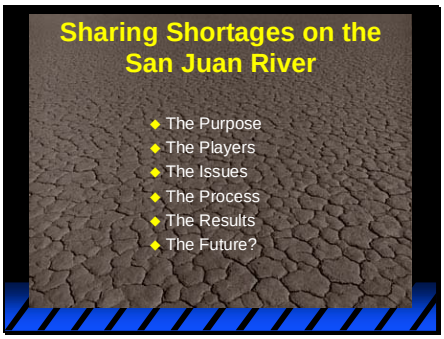
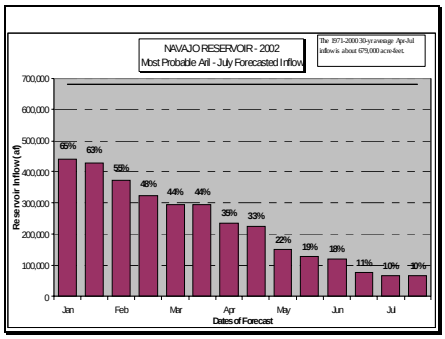
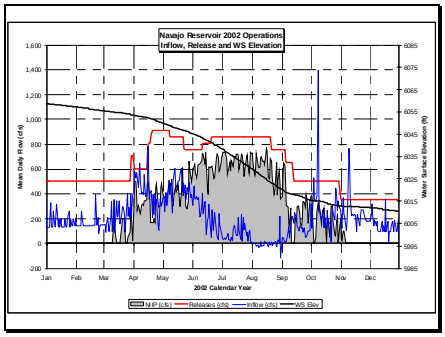


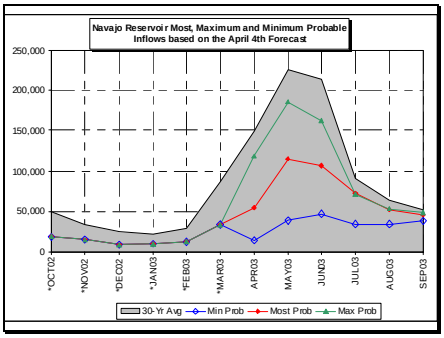


Year 2002 Navajo Inflows

	Inflow (af)	% of Average
January	10,800	51%
February	8,800	30%
March	13,900	16%
April	24,500	16%
May	26,700	12%
June	13,800	6%
July	4,800	5%
August	(100)	0%
September	6,500	12%
October	18,400	37%
November	14,800	44%
December	8,800	36%
Total	151,700	15%

10%





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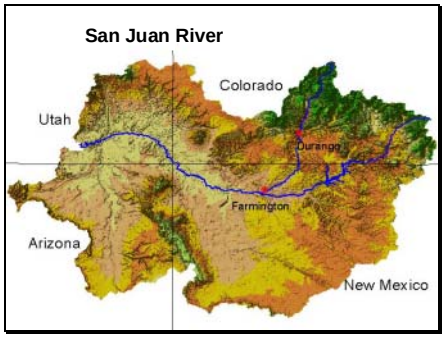

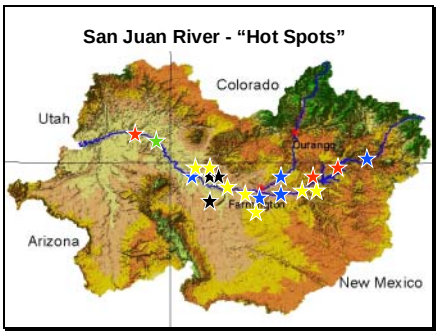

Sharing the Shortages: The San Juan River 2003

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The Issues

- Public Law 87-483
- Endangered Species Act
- Ongoing Adjudication of Water Rights
- Unsettled Claims of Navajo Nation
- Lack of Administration
- Differing Legal Opinions
- Mistrust of Government

The Process

- Public Meeting in September 2002
- Meetings with Water Users
- Development of Recommendations
  - "Make-up" Water for Power Plants
  - Included NAPI Forebearance Concept
- Endorsement of Recommendations
- Principles of Implementation

The Results

- Recommendations
  - Limit Diversions
    - Negotiated Amount
  - Share in Shortages
    - Shortening Irrigation Season (based on CIR)
    - Ceasing Irrigation Diversions mid-Season
    - Reducing Total Volume of Diversions by %
    - Reducing Instantaneous Flow by %

The Results

- Principles of Implementation
  - Establish Mitigation Fund
    - $240,000 up-front
    - $888,000 pay as you go

The Results

- Cooperative Plan
- Avoided Litigation
- Current Anticipated Shortage = 1.3%

The Results

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- Current Release
  - 1,000 cfs

The Results

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  - 414 cfs (7-day moving mean)

The Results

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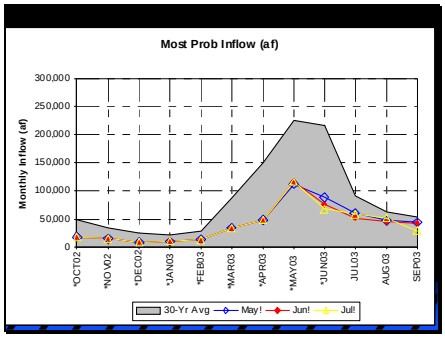

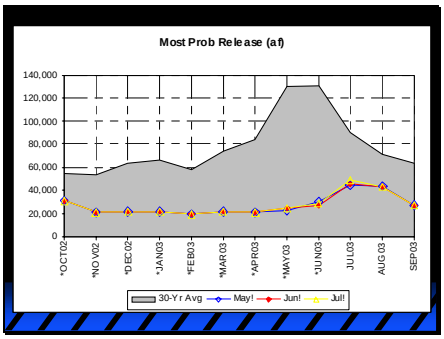

The Results

- Cooperative Plan
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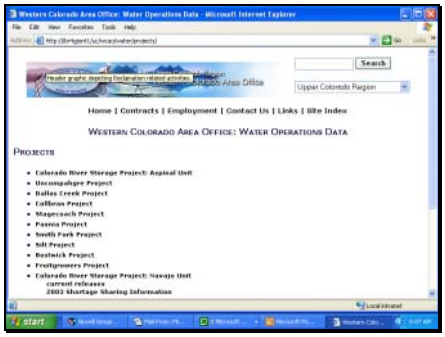

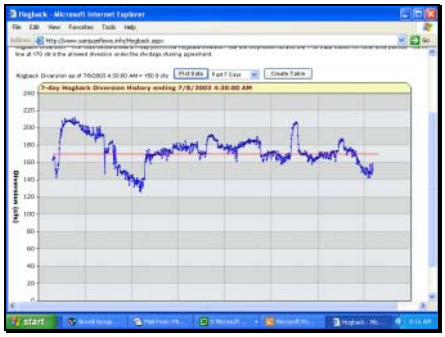

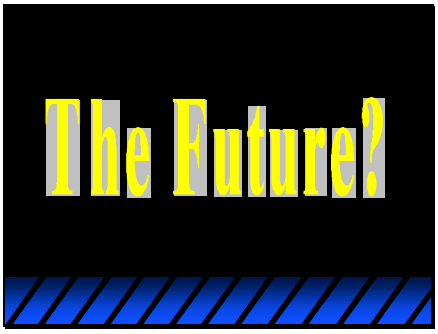

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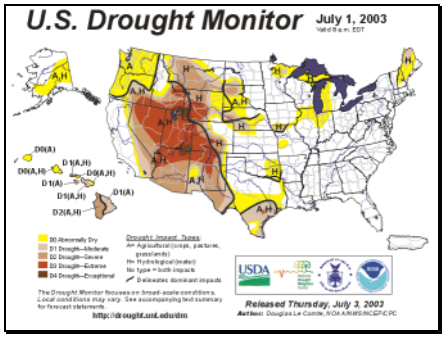

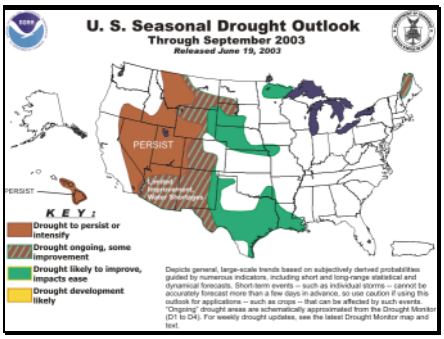

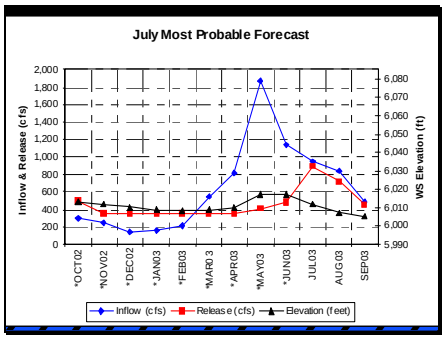

Field Day Photos

I got this water from the cooler over there!

Discussing irrigation in a cornfield

Dan Smeal and the drip system at the NMSU.

Fritz cooling off by the pivot!

I'm telling you, the water is in the cooler over there!!!

The group is looking over a drip irrigation system.

The tour group slows down for a photo!

Center pivot with catch cans setup for a distribution test.

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