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Proceedings of the Third Annual Four Corners Irrigation Workshop

Abdel Berrada
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Colorado State University

Knowledge to Go Places

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Proceedings of the Third Annual Four Corners Irrigation Workshop

July 11 & 12, 2002
Cortez, CO

Agricultural solutions for a semi-arid environment

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Cover Photograph: Water level in McPhee reservoir on July 12, 2002 at the inlet structure.

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- Mick O'Neill of New Mexico State University, Israel Broner of Colorado State University, Ed Martin of the University of Arizona, and Bob Hill of Utah State University for their valuable suggestions for the program content. Without their support and encouragement, I may have succumbed to the thought of canceling the workshop due to the severe drought of 2002.
- All the speakers for doing a great job of presenting important information at the workshop and for taking the time to write and submit papers for the workshop proceedings.
- Mark Stack, Paula Newby, and Thomas Hooten of the Southwestern Colorado Research Center for helping with the organization of the workshop. Paula Newby and Thomas Hooten were also instrumental in putting the workshop proceedings together.
- Dan Bishop (farmer), Paul Evans, General Manager of the Ute Mountain Ute Tribe Farm and Ranch Enterprises and his staff, and John Porter, former General Manager of the Dolores Water Conservancy District (DWCD) and his staff for their contribution to the field tour. Contributors to the field tour also include Dan Champion, Rod Clark, Dan Fernandez, Ed Martin, Kenny Smith, and Mark Stack. A special thanks goes to Mike Rich of NRCS-Cortez for arranging the first stop of the field tour.

The workshop and the proceedings could not have been done without the financial contribution of DWCD and the United States Department of the Interior/Bureau of Reclamation (BOR)/Upper Colorado Region. Both organizations, in addition to the Southwestern Colorado Water Conservation District have been very supportive of agricultural research and education, particularly that pertaining to irrigation water management in southwestern Colorado and the Four Corners region. Special recognition goes to Pat Page, of BOR's Western Colorado Area Office in Durango and John Porter of DWCD for their unrelenting support of research and education in the Four Corners region.

Abdel Berrada
Workshop Coordinator
November 18, 2002

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Workshop Program

Day 1, July 11, 2002 – Cortez Conference Center	
7:30 - 8:30	**Registration**
8:30 – 9:00	Welcoming and Introductions: Abdel Berrada, Colorado State University-Yellow Jacket, CO and Mick O'Neill, New Mexico State University Agricultural Science Center – Farmington, NM
9:00 – 12:00	Irrigation System Design and Maintenance:
	Main line systems: Rod Clark, Natural Resources Conservation Service-Alamosa, CO
	Gravity-fed systems and siderolls: Bob Hill, Utah State University, Logan, UT
	Center pivots: Israel Broner, Colorado State University, Fort Collins, CO
	Open discussion and morning wrap-up
12:00 – 1:00	**Lunch**
1:00 – 4:30	Chemigation: Kenny Smith, Colorado State University, Cooperative Extension, Montezuma County, Cortez, CO
	Weed Management: Rick Arnold, New Mexico State University, Agricultural Science Center, Farmington, NM
	Salinity: Grant Cardon, Colorado State University, Fort Collins, CO
	Total Maximum Daily Loads: Carla Brown, Colorado State University-Tri River Area, CO
	Nutrient management to meet water quality standards and regulations: Ed Martin, UA at Maricopa, AZ
	General discussion about environmental issues facing irrigated agriculture in the Four Corners Area
	Bureau of Reclamation Water Management Program in Four Corners Area: Pat Page, Bureau of Reclamation, Durango, CO
	Four Corners.com: David Montoya, Hesperus, CO
4:30 - 5:00	**Afternoon wrap-up, Final comments, Announcements**

Workshop Program

Day 2, July 12, 2002 – Field Trip	
7:30 – 8:00	**Arrive and Bus Boarding**
Stop 1	Montezuma Valley Irrigation and NRCS: Salinity program and soil moisture availability assessment
Stop 2	Southwestern Colorado Research Center: Subsurface drip irrigation and Orchard irrigation
12:00 – 1:00	**Lunch – Provided by Dolores Water Conservancy District**
Stop 3	Dolores Project/McPhee Reservoir/Great Cut Pumping Plant/Dolores Water Conservancy District Field Office
Stop 4	Ute Mountain Tribe Farm and Ranch Enterprises
4:40 – 5:00	**Workshop wrap up and Departure**

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Third Annual Four Corners Irrigation Workshop
Cortez, Colorado
July 11-12, 2002

Introduction

Michael K. O'Neill[1] and Abdel Berrada[2]

It is with great pleasure that we return to Cortez for the Third Annual Four Corners Irrigation Workshop to discuss ways to increase water application efficiencies for our crops and landscapes. Water issues are in the media every day. The region is suffering from the worst drought in many years and wildfires are burning thousands of acres in all Four Corners states. Last year, irrigation was turned off in the Klamath valley and a way of rural livelihood was socially, economically, and politically marginalized. With better precipitation in the area during the winter, irrigation ditches are again flowing but for how long?

Closer to home, total precipitation in January to June 2002 amounted to 0.62 inches (23% of normal) in Farmington, NM and 0.88 inches (13% of normal) in Yellow Jacket, CO. Snow pack in the San Juan and La Plata mountains during last winter was 25-80 percent below the long time average. Reservoirs are 50-90 percent of capacity and stream flows are virtually nonexistent in many watersheds. With less water to distribute, irrigation districts have had to cut back drastically. Instead of the allotted 22.8 acre inches normally planned for in the Dolores Water Conservancy District, irrigators have to get by with 6.3 acre inches. Forced fallow is the name of the game. It is impossible to farm every allocated acre because there just is not enough water to go around. Concentration of crops in limited areas and efficient water-use are imperative. Better management of crops will require the use of new technologies developed through agricultural research and adaptation of tried-and-true technologies to better suit a water-limited situation.

Table 1. Runoff, stream flow, and storage of the Dolores and San Juan Basins on the Upper Colorado River system as of June 2002.

	Runoff Volume (% of 30-yr avg.)	Stream flow (% of 30-yr avg.)	Storage A.F.	% of Full	% of Avg.
Dolores Basin McPhee Reservoir	17	5-37	195,400	51	60
San Juan Basin Navajo Reservoir	4-21	13	1,171,500	69	80

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This workshop is being held at a time when everyone is conscious of limited water. During previous workshops, we were able to discuss irrigation issues in the context of abundant water supplies. Not so this year! We all know what happens when crops do not receive adequate moisture. They wither and die, farming operations cease, and economic opportunities are dashed.

The organizers considered the recommendations from the 2001 workshop held in Farmington. A number of recommendations were made about topics that would be of further interest to participants. The ten top topics suggested by the 2001 participants include the following:

1. Flood irrigation to gated pipe
2. Fertilizer and chemical injection
3. Weed control
4. Water quality
5. Farm gate water regulations and diversions
6. Irrigation in orchards and nurseries
7. Economics of various irrigation systems
8. More on pivot irrigation systems
9. Alternative crops on small acreages
10. Automation of drip and sprinkler systems

Considering our area and the expertise at hand, we have included topics that touch upon most of these suggestions. As you can see from the program, we will cover gravity and pressurized irrigation systems, weed control in irrigated agriculture, chemical and fertilizer injection, and issues revolving around water quality. We were not prepared for the water deficit that we are experiencing this year but we need to incorporate water conservation and improved irrigation efficiencies in our discussions so future generations will have adequate quantities of this precious resource.

We want to thank the organizers for this Third Four Corners Irrigation Workshop. They include Craig Runyan and Mick O'Neill from New Mexico State University, Abdel Berrada and Israel Broner from Colorado State University, Ed Martin from the University of Arizona and Bob Hill from Utah State University.

We hope you benefit from this workshop and take home something useful.

Irrigation System Design and Maintenance
for
Underground, Plastic Pipelines

Rod Clark[3], PE

Abstract

A very common method to deliver irrigation water from its source to irrigated fields and ultimately the irrigation system itself is accomplished with underground, plastic pipe. Several parameters exist that determine pipe size, pressure rating, fittings, and other pipeline appurtenances for proper operation of the pipeline. For the purpose of this discussion, design criteria will be focussed on typical pipelines within the Dolores Project area. All criteria are obtained from the USDA-Natural Resources Conservation Service.

Introduction

A component of the United States Bureau of Reclamation's Dolores Project includes the conversion of previously non-irrigated cropland to irrigated cropland. This was accomplished with the construction of the Dove Creek Canal that conveys irrigation water from McPhee Reservoir to Dove Creek, Colorado. Located in strategic areas, pumping stations were constructed to pressurize water from the canal into an underground delivery pipe system. A system of monitoring the pressures and water demands controls the output of the pumping stations to maintain a constant pressure in the delivery pipelines. At each field turnout point, a pressure regulator with on/off valving is housed that provides each individual producer with a connection to the field irrigation system. The US Bureau of Reclamation's responsibility was the construction of the water delivery system. Any construction of an irrigation system downstream of each field turnout was the responsibility of each individual landowner. The United States Department of Agriculture's Natural Resources Conservation Service (USDA-NRCS) assisted producers with the design of these irrigation systems. This assistance was primarily the design of underground pipelines and sprinkler systems.

Design Criteria

The USDA-NRCS pipeline standards for underground plastic pipe are divided into two sections, one for high pressure and one for low pressure. The definition for low pressure pipelines is pipeline from 4 to 18 inch in diameter that are subject to internal pressures up to 50 pounds per square inch (psi). The standards define high-pressure pipelines as

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pipelines ranging from ½ inch to 18-inch diameter that are closed to the atmosphere and that are subject to internal pressures of 80 psi or greater. These definitions leave a void for pipelines that are subject to internal pressures between 50 and 80 psi. The ASAE Standard, ASAE S376 defines high pressure pipelines as pipelines from ½ inch to 15 inch nominal diameter that are closed to the atmosphere, and subject to internal pressures, including surge pressures, up to 315 psi. Additionally, the low pressure pipeline definition is pipelines from 4 inch to 15 inch nominal diameter that are subject to internal working pressures, not including surge pressures, less than 50 feet of water or 21.6 psi. For my work, I use the ASAE definitions and apply the criteria accordingly. This is also consistent with NRCS national standards that specify the use of high-pressure standards for any pipelines with internal pressures greater than 50 psi.

The design criteria exist for the primary purpose of insuring safe and proper function of the pipeline. Choosing an adequate pipe diameter will provide the required capacity and pressure at the irrigation system. It will also maintain a safety factor against water hammer and surge pressure problems. The design criteria for maximum velocity and maximum internal pressures helps provide that safety factor. The maximum design velocity is five feet per second (fps) based on full pipe flow. Water hammer and surge pressures are related to the velocity of water in the pipeline. Calculations of these pressures result in significantly higher values with velocities greater than 5 fps. The maximum internal pressures under working conditions are limited to 72% of the pressure rating of the pipe. Maximum static pressures should not exceed the pressure rating of the pipe. The combination of limiting internal working pressures and velocity has proven adequate for the design of underground, plastic pipelines.

The capacity of the pipeline is based on the greater of the two criteria:

1. The capacity shall be sufficient to deliver the volume of water required to meet the peak-period consumptive use of the crop or crops to be irrigated.
2. The capacity shall be sufficient to provide an adequate stream for all methods of irrigation planned.

For design purposes, friction losses shall be no less than those computed by the Hazen-Williams equation, using a roughness coefficient, C, equal to 150. The use of Manning's Equation for full pipe flow may also be used. Usually, a Manning's n value of 0.009 yields friction losses slightly higher than Hazen-Williams equation using a C of 150.

Outlets, such as those used to deliver water from the pipeline to an individual sprinkler, shall have adequate capacity at the design operating pressure. For a typical sideroll system, a 4-inch riser with a stub valve is adequate. I recommend using a threaded fitting between the riser and mainline tee. This makes the repair of broken risers much easier. Analysis of the friction loss and minor losses through the outlet should be done to insure proper operating conditions.

Pressure relief valves should be installed at the end of the pipeline or end of pipeline laterals. Pressure relief valves should be no smaller than ¼ inch nominal size for each inch of the pipeline diameter and shall be set to open at a pressure no greater than 5 psi above the pressure rating of the pipe. Capacity tables are usually available from manufacturers and can be used to specify the size and type of pressure relief valve for a given situation.

Air venting is a critical item that should not be overlooked. Air must be released when filing, draining or during the operation of any pipeline. Trapped air in a pipeline can cause problems with reduced capacity and surge or water hammer. There are three types of air vents commonly used on irrigation pipelines. An air-release valve is a continuously acting valve that has a small venting orifice, generally ranging between 1/16 and 3/8 inch in size. This valve releases pockets of air from the pipeline once the line is filled and under working pressure. An air-and-vacuum valve, which has a large venting orifice, exhausts large quantities of air from the pipeline during filling and draining. It is sometimes called an air-vacuum-release valve or air-vent- and-vacuum-relief valve. It is not continuous acting because it does not allow further escape of air at working pressure once the valve closes. A combination air valve is sometimes referred to as a combination air-release and air-vacuum valve or combination air-and-vacuum relief valve. It is continuous acting and combines the function of both the air-release valve and the air-and-vacuum valve. Air-and-vacuum valves should be installed at the entrance and at the end(s) of a pipeline, and at the upstream and downstream sides of an inline valve. At all summits, a combination air valve shall be installed. An air vent should also be installed at any point where the downhill grade changes by more than 10%.

Provisions for draining the pipeline should be incorporated if a hazard to freezing exists. I recommend to always provide drainage since this feature is useful for maintenance activities. Recommended drains, if possible, are the types that drain to daylight or completely drain the pipeline to a ground surface location. Other types are pump-out and dry well installations.

Flush valves are usually not required but depending on the quality of water in the pipeline, may be needed. Where high loads of sediment or other foreign material is expected flush valves need to be installed, normally at the end of the pipeline. For the Dolores Project, flush valves are not necessary.

Thrust blocks are concrete blocks formed around the pipe at abrupt changes in vertical or horizontal grade. They are also use to anchor in-line valves and at the end of pipelines. Their function is to transfer the thrust from axial changes in flow from the pipeline to the adjacent ground. They are formed against undisturbed ground, typically the trench sidewall. The size of the thrust block is computed from the following:

$$A = [(98HD^2)/B] * \sin(a/2)$$

A = Area of thrust block in square feet
H = Maximum working pressure in feet
D = Inside diameter of pipe in feet
B = Allowable passive bearing pressure of the soil in lbs/ft^2
a = Deflection angle of the pipe bend

The area of the thrust blocks for dead ends and tees shall be 70% of the area of the block required for a 90-degree deflection angle of pipe bend. If the allowable soil bearing pressure is not known, a table for use is available in the NRCS 430 standards. For designing pipelines in the Dolores Project, I use the pressure rating of the pipe for the maximum working pressure in thrust block calculations. This is due to the possibility that the pressure regulators in the turnout boxes may malfunction and allow higher pressures in the irrigation system.

Installation standards are also very important for the long term functioning of the pipeline. It starts with safe trench walls. For most irrigation pipeline construction, vertical sidewalls are safe unless the soils are saturated, noncohesive, or both. Laying back of the sides or stepping may be necessary to avoid unstable trenches. The trench bottom should be smooth and allow the pipe to be supported throughout its length. If the trench bottom is rocky or contains solid rock, then a minimum of 4 inches of bedding material consisting of fine soil particles should be placed beneath the pipe. An initial backfill material consisting of soil particles no larger than 1-inch diameter is placed around the pipe with particular attention to making sure it is placed and compacted around the haunches of the pipe. A trench width usually 18 inches greater than the outside diameter of the pipe makes this easier. The initial backfill should be placed and compacted to a minimum depth of 70% of the diameter of the pipe. This is to provide support for the pipe against the soil above the pipe. For normal installations, NRCS recommends a minimum of 2.5 feet of cover over the pipe. For deeper installations, a pipe deflection calculation should be done to insure the pipe is safe against collapse. The final backfill around the pipe should contain no clods or rocks larger than 1-inch diameter for a distance of at least 9 inches from the pipe. Beyond that, the backfill material should not contain any clods or rocks larger than 6 inches diameter. For a day's operation, the pipe should be fitted together, placed in the trench, and as a minimum, the initial backfill should be placed. Pipe that is fitted together and left in the trench overnight may have a tendency to pull apart due to the cooler night temperatures and contraction of the pipe. All air vents and outlets should be straight and plumb before backfilling. The proper type of glue should be used for all fittings. The manufacturer's recommendations for glue should be followed very carefully, as different sizes of pipe require different types of glue. Also, the glue only works well in certain temperature ranges and should not be used outside of the specified, recommended ranges.

Maintenance

A properly operated and maintained irrigation pipeline is an asset to any agricultural enterprise. Periodic maintenance will insure satisfactory performance of a pipeline. Some general recommendations to develop a good operation and maintenance program are as follows:

- Check to make sure all valves and air vents are set at the proper operating condition. Repair all valves, gates and regulators to the system requirements following the manufacturer's recommendations.

- Maintain the depth of cover. This is usually more evident for the first year after construction. Periodic grading or filling of the settling trench may be necessary.
- Limit traffic over the pipe to those locations designed for such activities.
- Avoid any farming practices that might interfere with the pipe. Operations such as deep ripping may harm the pipe.
- Remove all foreign debris that hinders the system operation. Check air vents for sticks or trash that would make the ball seal inoperable.
- Drain the system and the components in areas that are subject to freezing.
- Fill the pipeline slowly. The maximum flow while filling should not exceed 1-fps velocity.
- Immediately repair any vandalism, vehicular, or livestock damage to any outlets and appurtenances.

Summary

Utilizing buried PVC pipelines is a practical means for the delivery of irrigation water and the design of those pipelines are very important for proper function and operation. The USDA-NRCS design standards for underground, pressurized pipelines are to be met or exceeded for all pipelines considered under the scope of this report.

References

United States Department of Agriculture, 1989. Irrigation Water Conveyance, High Pressure, Underground, Plastic Pipeline 430-DD.

United States Department of Agriculture, 1989. Irrigation Water Conveyance, Low Pressure, Underground, Plastic Pipeline 430-EE.

Management of Gravity Fed and Sideroll Sprinkler Irrigation Systems

Robert W. Hill[4]

An efficient sprinkler system is the result of good system design, proper irrigation scheduling, careful operation, and timely maintenance. Good sprinkle irrigation requires an understanding of soil-water-plant relationships and that irrigation timing and amount depends on soil water holding capacity, weather, and crop growth progress. Adequate system design, installation, proper operation and maintenance are important for realizing the benefits of sprinkler irrigation over the system lifetime.

Introduction

Sprinkler irrigation has been an important part of agricultural production in the Western United States since the1950's. About 48 percent (Irrigation Journal, 2000) of the 17 Western States' irrigated acres are watered with sprinklers, including hand move, wheel move, center pivot and other types. Sprinklers can be a good investment when properly designed, installed, maintained and managed. For every acre-foot of water supplied to an efficient sprinkler system a farmer can expect to harvest about 1-3/4 ton of alfalfa and 46 bushels of wheat. In contrast, the expected harvest with a typical surface irrigation system (flood or furrow) is less than 1-1/4 ton of alfalfa or about 30 bushels of wheat for each acre-foot of water supplied to the farm. Sprinklers produce more yield than typical surface irrigation systems per acre-foot because sprinklers apply water more efficiently.

Not all water applied by an irrigation system is used by the crop. Some water is lost to deep percolation, evaporation, or runoff. Application efficiency (Ea) is a term that tells how much of the water applied by the system is actually stored in the root zone for crop use. A good sprinkler system has an Ea of about 70 percent which means that 70 percent of the water applied by the sprinkler heads is actually stored in the soil for crop use. The actual Ea depends upon how evenly the sprinklers distribute water and other factors such as operating pressure, nozzle size and spacing, wind, air temperature and humidity (day versus night), irrigation scheduling and maintenance condition. The average efficiency of surface irrigation in the intermountain West is probably less than 50 percent as compared to the higher sprinkler efficiency of 70 percent.

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On sloping fields, or in a gravity fed sprinkler system, there may be considerable pressure differences between sprinkler heads on high and low ends of the line. In this situation, flow control nozzles may be used to improve the uniformity of water application. Flow control nozzles apply water at approximately the same rate over a wide range of water pressure (i.e. from 40 - 80 psi).

Gravity Pressure Sprinklers

Wheel moves and hand moves are used on almost all of the gravity-pressurized sprinkler systems in the Intermountain West. Utah's mountain valley topography is favorable to developing gravity-pressurized pipelines. Much of our irrigated area in mountain valleys is in close proximity to canyon streams. Thus, it is often economic to install a pipeline up the canyon to gain about 110 feet or so of elevation induced head. This also has the advantage of reducing open channel water seepage losses in the canyon mouth alluvium and extends the available water supply.

Many previously surface irrigated systems (private irrigation companies as well as individuals) have converted over to gravity pressure wheel move irrigation. This switch from the traditional (often pioneer built) surface irrigation to gravity pressurized sprinkler has created some interesting situations. The value of "head end" water access opportunities in preference to a "tail end" location in multiple user surface irrigation systems is well known. However, when a conversion to gravity pressure sprinklers occurs, the historically "tail end" irrigators become switched to the "head end" position in that they now have the highest pressure. For some, this is the first time ever that they have had access to abundant water instead of the tail end dribble they are used to. These advantages are often short-lived as the irrigation company board of directors have responded by requiring pressure or flow regulated nozzles and strict adherence to water deliveries proportionate to water stock shares owned.

During drought conditions, gravity pressure sprinkler systems may be sufficiently short of water to necessitate using the water on turns. As an example, an irrigation company with a gravity sprinkler system in South Central Utah imposed (in late June 2002) a three day on, three day off turn for approximately half of the system in rotation. This irrigation company had previously (about 15 years ago) required six gpm flow control nozzles throughout their system. However, field measured nozzle flow rates indicated about 1 gpm less flow rate at higher elevations (40 psi) than at lower elevation (80 psi) fields. Additionally, the presence of leaks in the lower elevation fields has created an unfavorable hydraulic situation for the higher elevation irrigators. The water master and county extension agent are currently measuring nozzle and leak flow rates (with a five gallon bucket and stop watch). This will be used to determine what additional reductions will be required in the number of operating nozzles per share of stock, to allow the higher elevation users to get their proportionate share of the water.

Internet Site for Additional Information

The web site address for USU Extension electronic fact sheets can be located at: http://extension.usu.edu/publica/engrpub2.htm

Select:

ENGRBIE/WM/05 - Maintenance of Wheelmove Irrigation Systems
ENGRBIE/WM/07 - Sprinklers, Crop Water Use, and Irrigation Time
ENGRBIE/WM/08 - Wheelmove Sprinkler Irrigation Operation and Management
ENGRBIE/WM/35 - Drought Response - Agriculture Water Management Alternatives

**Water Management Under
Center Pivot Irrigation**

Israel Broner[5]

A center pivot is a moving irrigation system (lateral) that rotates around a fixed point (pivot). The application rate is the inches of water that the irrigation system applies per hour. The application rate of a center pivot varies laterally because the center-pivot lateral covers more area per unit length toward the outer end. This characteristic of the center pivot complicates its design. With proper design and installation, a center-pivot sprinkler system can achieve high irrigation uniformity. When designing a sprinkler irrigation system, the systems application rate should match the soil's intake rate (in/hr) and surface storage. Soil intake rate is the rate at which a soil can absorb or take in water. A match is not always possible with movable irrigation systems.

The desired application rate of an irrigation system depends on crop water requirements, the application time, and soil type. Application time is the time that it takes to sprinkle any place in the field. The application time depends on the radius of throw of the sprinkler head. The larger the radius of throw, the longer any point in a field will receive water under a given speed of travel.

There is a trade-off between the application rate and the radius of throw of the sprinkler head used. The smaller the radius of throw, the higher the instantaneous application rate has to be. This is due to the shorter application time that each point in the field receives.

When center pivots were introduced, high-pressure impact sprinklers were used. The application time was longer and the application rates were lower because of the larger radius of throw. The high-pressure high-angle impact sprinklers had lower irrigation uniformities, especially under windy conditions.

As energy costs increased, lower pressure sprinkler systems were developed to reduce energy costs and increase irrigation efficiencies. The main drawback of a low-pressure sprinkler system is its reduced radius of throw. This reduction significantly increases the instantaneous application rate to enable the system to apply the same application depth at the same time. A high application rate can often lead to runoff if proper tillage is not applied, resulting in reduced irrigation efficiencies.

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Classification of Sprinkler Systems

Center-pivot sprinkler systems are classified according to pressure or nozzle type. Although there is no definite boundary between high, medium and low pressures, it is commonly accepted to have the following classifications:

- High-pressure systems have pressures of more than 50 psi at the pivot.
- Medium-pressure systems have 35 to 50 psi at the pivot.
- Low-pressure systems have less than 35 psi at the pivot. LEPA (Low-Energy Precision Application) and LDN (Low Drift Nozzle) can operate on pivot pressures of 15 to 25 psi.

Nominal operating pressures at the sprinkler head or water-emitting devices are constant for a particular head.

- Nominal pressures for LEPA devices are 6 to 10 psi.
- Spray nozzles, rotators and spinners are 10 to 25 psi.
- Small impact heads with modified nozzles are 20 to 45 psi.
- Small impact sprinklers with round nozzles are 30 to 60 psi.
- Large impact sprinklers are 45 to 80 psi. The range for large impact sprinklers depends on nozzle type and size.

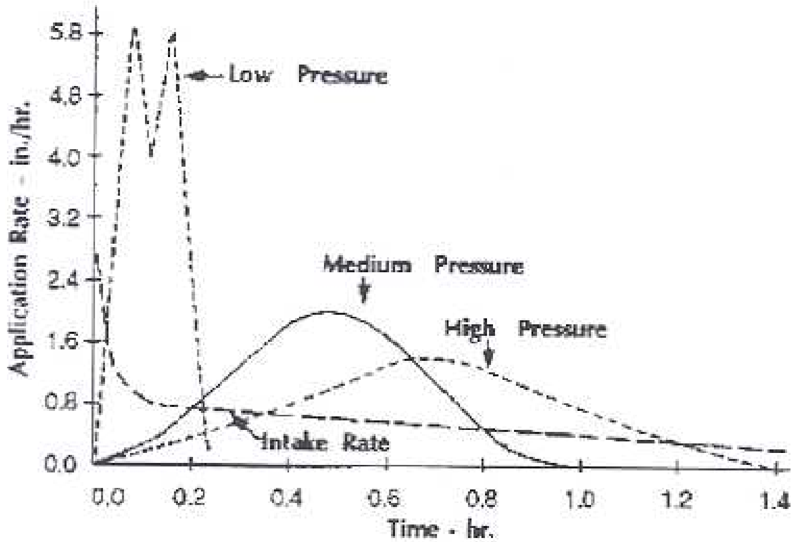

Figure 1: Typical application rates at a radius of 1,000 feet from the pivot.

Pressures needed at the pivot depend on pressure losses in the lateral due to friction losses and elevation differences along the lateral. To find the necessary pressure at the pivot work back from the last emitting device and add pressure losses or gains due to friction and elevation changes.

Impact sprinklers usually operate at high to medium pressures, are installed on the lateral pipe, and irrigate over the crop. Spray and rotary nozzles operate at medium to low pressures, are installed on the lateral pipe or on drop tubes or pipes, and result in "down in the crop" irrigation. Irrigation down in the crop reduces evaporation and wind drift.

Figure 1 shows the effect of different sprinkler packages (nozzle-type and pressure) on the application rate. There is a definite trend of higher application rates for lower pressures. Application rates can be as high as 10 to 14 inches per hour for spray nozzles and much higher for LEPA systems.

A user should select a sprinkler package with an application rate that matches the soil's intake rate, satisfies crop water requirements, and functions under local climatic conditions (wind). Proper tillage might overcome possible runoff problems.

Design Considerations and Irrigation System Capacity

Crop water requirement (evapotranspiration, ET) is the amount of water a crop uses during a period. Crop water requirements change seasonally and usually peak in July for warm season annual crops (not winter wheat). An irrigation system should satisfy the peak crop water requirements or net irrigation requirement.

To find the gross irrigation requirement (irrigation system capacity), divide the net irrigation requirement by the irrigation system efficiency (fraction of one). To calculate irrigation system capacity, allow for expected down time for maintenance and expected failures. This approach doesn't consider available water stored in the soil and water added from rain.

To calculate irrigation system capacity considering the soil water-holding capacity, rainfall probability approach, use the analysis in Figure 2. Figure 2 represents 60 years of climatic records that used this approach. The net capacities meet corn water needs nine out of 10 years, without depleting more than 50 percent of the available soil water. The data from Figure 2 was used to calculate required irrigation system capacities in GPM/acre for three soils and three center-pivot systems (Table 1). Irrigation system efficiencies for the three systems were found in a comprehensive study conducted on the high plains of Texas. If you design, operate and manage your system properly, you can assume the same irrigation system efficiencies if no runoff occurs. If you see water runoff in or out of the field, the water distribution in the soil will not be uniform and areas of over-irrigation and under-irrigation will appear.

The required system capacities in Table 1 assume a seven-day per week operation (24 hours per day) with no down time during the period of peak ET. Increase required irrigation system capacities to allow for expected down time. For example, if you consider one day per week down time, divide the required irrigation system capacity by 0.86 (1 minus 1/7) to allow for expected down time.

The available water stored in the soil is a reservoir that supplies water during peak water-use periods. The higher the available soil water, the less irrigation system capacity is required (Figure 2). This approach uses the available soil water in determining the required irrigation system capacity. It also assumes the system will replenish the soil profile to field capacity before peak use. Thus, when the peak water-use period begins, the soil profile is full and the water stored in the soil can compensate for the system capacity that is lower than the water use rate. Nine out of 10 years, the length of the peak water-use period will be short enough to deplete no more than 50 percent of the available water, thus not causing water stress. The irrigation system efficiency affects the required irrigation system capacity as well. As seen in Table 1, the higher the system efficiency, the lower the required irrigation system capacity.

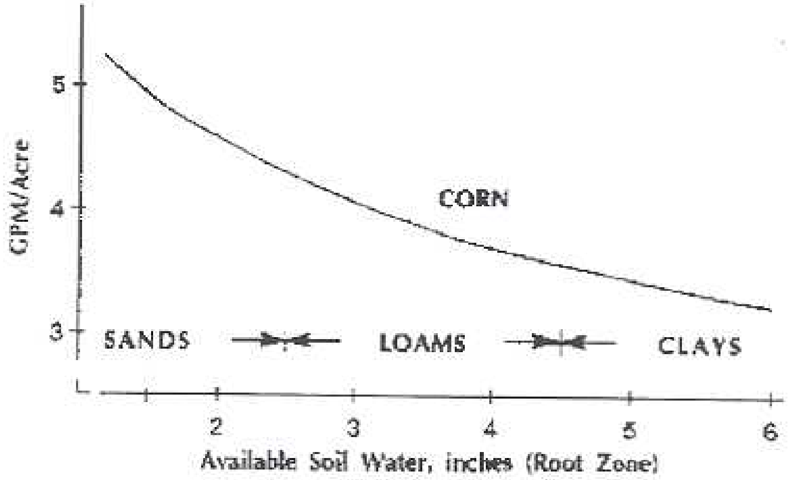

Figure 2: Net irrigation system capacities for corn in eastern Colorado.

The required system capacity values in Figure 2 are based on the assumption that the capacity will be adequate nine out of 10 years. In the year the system capacity is inadequate, the crop is water-stressed and some yield reduction will occur. If the user is willing to take a higher risk, a system can be designed to meet crop water requirements less frequently by reducing the system capacity. This will result in a smaller initial investment in the irrigation system. Table 2 gives required system capacities for two probabilities that do not exceed 50 percent depletion of the available soil water in eastern Colorado. When designing a new system, consider the trade-off between initial system cost, energy demand and power-use charges, system capacity and the chance of yield reduction from water stress.

Table 1: Required irrigation system capacity for three soils and three irrigation systems in gallons per minute per acre (GPM/acre).

	Impact low angle 85%*	Spray nozzle 90%*	LEPA 95%*
Sand (2.0 in)	5.4	5.1	4.8
Loam (3.5 in)	4.6	4.3	4.1
Clay (5.0 in)	4.1	3.9	3.7

*Expected irrigation system efficiency.

High-Pressure to Low-Pressure Conversion

A change from high-pressure to low-pressure systems, if done properly, reduces pumping costs. However, low-pressure systems require sprinkler heads (water-emitting devices)

Table 2: Required irrigation system capacities in GPM/acre for two probabilities with no down time and no runoff.						
Probability	**Available soil water will not be depleted more than 50% (1 year out of 10)**			**Available soil water will not be depleted more than 50% (1 out of 2 years)**		
System soil	**Impact sprinkler 85%***	**Spray nozzle 90%***	**LEPA 95%***	**Impact sprinkler 85%***	**Spray nozzle 90%***	**LEPA 95%***
Sandy	6.2	5.9	5.6	4.2	4.0	3.8
Loam	5.3	5.0	4.8	3.6	3.4	3.2
Clay	5.1	4.8	4.6	2.9	2.7	2.6
*Expected irrigation system efficiency.						

that usually have a smaller radius of throw that results in higher instant application rates (Figure 1). Higher application rates for lower pressures are the main trade-off between high- and low-pressure systems. However, there are several other factors to consider if you change from high- to low-pressure systems or to LEPA systems. Table 3 summarizes the trade-offs between high-, low- and LEPA-pressure systems. Table 3 also compares the energy costs for a typical center-pivot with irrigation efficiencies corresponding to the ones in Table 2. Energy costs were calculated using the following equation:

$$\text{Energy Cost } (\$) = (A * I * P * C * 0.2) / (E_I * E_P)$$

where:

A = irrigated area (acres)
I = net water requirement (inches)
P = pressure required for lift and pressurization at the pivot (psi) (to convert lift from feet to psi divide by 2.31)
C = cost of electricity ($/kwh)
E_I = irrigation system efficiency (fraction)
E_P = pump plant efficiency (fraction)

Table 3 shows energy costs assuming high uniformity (no runoff) for three typical sprinkler packages. If irrigation efficiency increases by 10 percent (for example, when changing from one system to the other) an additional 10 percent of the total energy costs is saved. The effectiveness and efficiency of an irrigation system greatly depends on management and operation. The designed irrigation system efficiency can be accomplished if the system is managed and operated properly. If not, expect lower irrigation efficiencies and higher pumping and other costs. In many instances, conversion to low pressure may increase energy costs if runoff losses increase.

Table 3: Trade-offs between high-pressure, low-pressure and LEPA systems.			
System (pressure)	**High**	**Low**	**LEPA**
Typical pivot pressure (psi)	80	35	25
Application rate	Low	High	Very high
Droplet size	Large	Small	Variable
Evaporation and drift losses	Depends on wind speed	Small if using drop tubes	None
Potential runoff	Small	Moderate	Very high
Effect of elevation differences	Small	High	High
Energy Cost* $ (lift of 200 feet)	$12,764	$8,799	$7,650
Energy Cost* $ (lift of 400 feet)	$19,399	$15,064	$13,586
* Pumping cost for applying 24 inches, system capacity 850 GPM irrigating 126 acres, pump efficiency 65 percent, and power cost of $0.07 kwh.			

If you convert an existing center-pivot system, you must consider changing pump characteristics. Each pump works most efficiently at a certain pressure and flow rate. Do not overlook changes in the pump if the conversion of an existing system changes the required pressure.

Management Considerations of Center Pivots

Once designed and installed, the only system parameters you can control in a center-pivot are the speed of travel and direction of travel. The speed of travel regulates the application depth. The faster the speed of travel, the lower the application depth. By controlling the speed of travel, you can alleviate runoff problems. However, a practical lower limit to the application depth exists. Application depths lower than 1/4 inch are not very effective. The result is little contribution to the soil water storage.

Important components of proper irrigation systems management are irrigation scheduling and monitoring the depth of applications. This ensures that you don't over-irrigate or under-irrigate. Do not operate high-pressure center pivot systems under windy conditions. The soil-water intake rate can be reduced through soil sealing from the impact of big water droplets.

Runoff is the main management consideration for low-pressure center pivot systems. If these systems are used on low-intake rate soils or sloping terrain, apply tillage practices to catch water at the point where it hits the ground.

The effect of elevation changes on water distribution uniformity along the lateral is more severe in low-pressure than high-pressure systems. For example, in a 35-psi system at the pivot and 20 psi at the last sprinkler, the discharge will drop 18 percent for a 15-foot rise in elevation. In a 75-psi system at the pivot and 45 psi at the last sprinkler, a 15-foot elevation rise will cause only a 7 percent discharge drop. Application rates of low-pressure systems can vary and depend on nozzle placement and mode. LEPA nozzles have different modes of operation that can affect the application rate. A popular feature of the LEPA and LDN nozzles is the chemigation mode. It sprays an upward stream of water, washing insects off the lower side of the leaf, and applying chemicals to the under side of leaves..

Understanding Chemigation

Kenny Smith[6]

Introduction

Chemigation is the application of any chemical through an irrigation system that utilizes water as the transport mechanism. Examples of chemicals include herbicides, insecticides, fertilizers, fungicides, nematicides, growth regulators, and miticides. With the increased regulation in the application of pesticides and fertilizers by State and Federal agencies including the U.S. Environmental Protection Agency (EPA), growers and commercial applicators must use prudent management practices to protect surface and groundwater pollution and the health and safety aspects of the use of these products. Chemigation can reduce the statistical chance of misapplication due to non-point source pollution, worker exposure, and off-target application.

Regulation

The application of pesticides through irrigation systems requires strict adherence to label instructions. Always remember... ***The label is the Law!*** The U.S. EPA was given the authority in 1980 to conduct a Label Improvement Program which included revising pesticide labels to address product application in irrigation water. The agency's regulations regarding chemigation were published in March 1987 as PR-Notice 87-1. This notice that became effective in April 1988 required pesticide registrants to include labeling information regarding chemigation of their product. Remember that this set of regulations was passed by a federal agency and various states also have regulations regarding chemigation and pesticide use. The Colorado Department of Agriculture administers Commercial Applicators and Qualified Supervisors in the state of Colorado as well as regulation of chemigation permits.

Advantages and Disadvantages of Herbigation

Application of herbicides through center pivot irrigation systems involves certain advantages and disadvantages (Ogg et al., 1988).

<u>Advantages</u>

1) Reduces the cost of herbicide application
2) Reduces energy consumption
3) Potential to reduce labor costs

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4) Reduces equipment needs
5) Reduces soil compaction
6) Reduces operator hazards
7) Potential to reduce environmental hazards
8) Increased herbicide activity
9) Provides opportunity for more uniform application of product
10) Insures timely application of herbicides
11) Compatible with reduced till or ridge-till farming practices
12) Reduced phytotoxicity

<u>Disadvantages</u>

1) Requires greater management input
2) Additional equipment may be required
3) Potential to increase environmental hazards
4) Increased application time as compared to aircraft or ground rigs
5) May require unnecessary irrigation

Chemigation Pumps

There are two main types of injection units that are used extensively in production agriculture. The two types of mechanical units are **piston** (or positive displacement) **pumps** and **diaphragm pumps**. These are typically powered by electric motors and can be adjusted for various flow rates within a designed range.

Chemigation pumps should be selected so that chemicals can be applied at the labeled rate. Injection pumps are commonly purchased with two heads – one for injection of low rate applications of insecticides and herbicides and the other for injection of fertilizers that require larger volumes. Diaphragm pumps are used extensively for low rate chemical injection. Changes in injection rates can be made while running so accurate injection can be conveniently established.

Important factors to consider in the selection of a chemigation pump includes the following characteristics: accuracy, calibration tube, adjustable while running, agitation capability, corrosion resistance, and completely drainable. The chemigation unit should also be properly sized for tank capacity in relation to field size.

Literature

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CALIBRATION WORKSHEET FOR INJECTION PUMPS ON CENTER PIVOTS

Farmer Name:____________________ Date:________________

Legal Description:__________________ Crop: _______________

Pivot Speed Setting:________________% Nozzle Pkg.:____________
(Drop, Low Angle, etc.)

Distance from pivot to outer edge of field ________________________
(Radius of field)

$$\frac{3.14 \times r^2 \ \_\_\_\_\_\_\_\_\_\_}{43560 \text{ sq. ft./Acre}} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \text{ Acres in Field}$$

Distance from pivot point to outside wheel track ______________________
(Radius to Outside Tower)

2 x Radius x 3.14 __________________ = Circumference of Outside Track

Distance Last Tower moves in 10 minutes = _______________ feet.
(Convert to ft/min.)

$$\frac{\text{Circumference } \_\_\_\_\_\_\_\_\_}{\text{ft./min. } \_\_\_\_\_\_\_\_\_\_\_\_} = \_\_\_\_\_\_\_\_\_\_\_\_\_ \text{ Revolution Time (minutes)}$$

$$\frac{\text{Acres } \_\_\_\_\_\_\_\_\_\_}{\text{Rev. Time } \_\_\_\_\_\_} = \_\_\_\_\_\_\_\_\_\_\_\_\_ \text{Acres Treated/minute}$$

Chemical (s) to be Applied ______________________
Total Rate ______________________ in ml/Acre _____________
(pt., qt., etc.) (29.6 ml/oz.)

Chemical rate in ml ________ x ________ Acres treated/min. = __________
#ml/min. to be pumped.

Weed Management in Irrigated Crops

Richard N. Arnold[7], Dan Smeal[8], and Michael K. O'Neill[9]

Introduction

Weed competition can reduce quality, yield, harbor insects and disease, and interfere with harvesting operations. Arnold et al. (1) found that season long interference from weeds can reduce corn yields as much as 63%. In dry beans researchers found that weeds caused yield reduction of over 60% (1,3,4,5). During 1975 to 1979, annual average losses caused by weeds in crops and pastures were estimated at about 7.5 billion for the United States and almost 1 billion for Canada (2). An overall view of weed control in spring seeded and dormant alfalfa, winter wheat, dry edible beans, pasture and rangeland, and field corn will be presented.

Dormant Alfalfa

When alfalfa stands decline by natural causes, weeds become quickly established and directly compete for growth resources. Downy brome and winter annual mustards are troublesome weeds in northwestern New Mexico and southwestern Colorado. Herbicides that will be discussed are Karmex, Velpar, Raptor, Sinbar, Poast, Select, Sencor, and possible tank combinations.

Seedling Alfalfa

In seedling alfalfa, competition from weeds can reduce stand establishment and quality. Broadleaf weed control in spring-seeded alfalfa with Raptor or Pursuit in combination with Poast, Select, or Buctril will be presented.

Small Grains (Winter Wheat)

Jointed goat grass, downy brome spp. and volunteer ryegrass are troublesome weeds that reduce food quality of winter wheat. Other weeds like Russian thistle, winter annual mustards, and kochia, to name a few, reduce yields and interfere with harvesting operations. Weed control research in winter wheat that has been conducted by Dr's Westra, Wilson, and Miller will be discussed. Herbicides that will be discussed will be Maverick, Everest, Beyond, Starane, Stinger, and Curtail.

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Dry Edible Beans

Black nightshade, pigweeds, kochia, common lambsquarters, and Russian thistle are serious competitors in dry edible bean production and quality. Research done at the New Mexico State University Science Center at Farmington (NMSU), was very instrumental in the EPA registration of Pursuit for mainly broadleaf weed control in dry edible beans. Other herbicides that will be discussed for weed control in dry edible beans are Basagran, Select, Eptam, Duals, Outlook or Frontier, Pursuit or Raptor, Sonalan, and Poast.

Pasture and Rangeland

It has been estimated that over 100 million acres on the North American continent are struggling against invasive noxious weeds. In northwestern New Mexico and southwestern Colorado, Russian knapweed and Canada thistle are very strong competitors in pasture, range, and in non-cropland areas. Research results concerning control of Russian knapweed and Canada thistle will be given. Herbicides to be discussed will be Stinger, Reclaim and Curtail, Crossbow, Grazon P+D, and Tordon 22K.

Field Corn

There are numerous herbicides registered for weed control in field corn. Research at NMSU will show those herbicides that best control annual broadleaf weeds common to northwestern New Mexico and southern Colorado. Herbicides to be discussed will be Guardsman Max, Balance, Bicep Magnums, Callisto, Steadfast, Option, Stinger, Epic, Axiom, Define, Clarity, and Celebrity Plus.

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Salinity Issues in Colorado

Grant E. Cardon[10]

Introduction

Of the four major river basins in Colorado, three have significant salinity concerns. On the West Slope, in the Colorado River basin (in its main as well as sub-basins) water users have been dealing with salinity issues for several decades, particularly as lower basin states deal with salts downstream. On the East Slope, salinity issues are rapidly coming to the forefront in the South Platte and Arkansas River basins. Each river system has unique characteristics that affect the way salinity problems are expressed and need to be dealt with. There are no easy general solutions for salinity management and so an introduction to the specific conditions of each basin and the salinity issues that arise in each, must be a starting point for further understanding. This presentation attempts to describe the conditions in the three major river systems related to salinity, the issues associated with each system, and describes a current study in the Arkansas River basin where salinity management is being aggressively studied.

Colorado River Basin

Basin Profile

In the Colorado River basin within the state of Colorado, ample quantities of high quality, low salt surface water are found. Many of the water rights on the river within this state have yet to be fully developed, and so water is generally plentiful for other users on the West Slope. As a result, traditional, low efficiency, flood irrigation systems have been the norm for a long time. This condition, by default, keeps much of the region well leached from salt buildups as there is excess water flowing through the soils and returning to the river system. However, extensive saline geologic marine deposits underlie many of the basin soils (e.g., Mancos Shale formation). Return flows from the saturated zones below much of the irrigated areas of the Colorado River basin in Colorado, contain high salt loads dissolved from these geologic sources and significantly affect downstream water quality.

Basin Salinity Issues

The primary salinity issues in the Colorado River basin in Colorado revolve around interstate compacts with lower basin states and Mexico, as concerns over the exporting of salts have increased over the years. Efforts have been undertaken to reduce salt load by

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reducing return flows that can come in contact with geologic saline rock and sediment formations. A good example of this effort, local to the Four Corners region, is from the McElmo Creek watershed. In McElmo Creek, a large-scale attempt to improve on-farm irrigation efficiency has resulted in a reduction of almost 16,000 tons of salt per annum returning to the river. The improvement in on-farm irrigation efficiency and uniformity has been brought about by conversion to surge and sprinkler irrigation systems. The primary benefit of these improvements, with respect to salinity, are realized outside of Colorado, in the lower basin states and Mexico.

South Platte River Basin

Basin Profile

The South Platte basin is a water-short system in most years. Irrigation in the region has traditionally been accomplished by flood and furrow systems. Even today, a little over 50% of the irrigated acreage is managed with furrow systems. On-farm irrigation inefficiency, over the more than 100 years of irrigation agriculture, has created a shallow alluvial aquifer along the river. Return flows from the aquifer have historically provided an additional benefit for downstream irrigation as growers were able to obtain rights to the returning water. On a basin-wide basis, it is estimated that water is diverted up to seven times, as excess water flowing back to the river is repeatedly used before exiting the state.

Unlike the Colorado River basin, the South Platte basin has many fewer geologic sources of salt. Moreover, there are few on-stream reservoirs, so the basin drains fairly freely back to the river. Salt build-up is primarily a result of evaporative accumulations as the water is repeatedly cycled through the system and concentrates along its journey. In some localized areas, shallow water tables further promote salt accumulation as water moves to the surface by capillary action and is evaporated away, leaving the salts behind in the soil and remaining water.

The predominant, naturally occurring salt in the South Platte system is Gypsum (or, Calcium Sulfate, $CaSO_4$). Gypsum, of all the salts, is of lowest concern with respect to plant salt injury potential. It is also not nearly as detrimental to soils compared to Sodium salts which can quickly destroy soil structure. Water quality varies from 200-300 ppm TDS upstream, to about 2000 ppm TDS at the Nebraska state line.

Basin Salinity Issues

The fastest growing population areas in Colorado are found upstream along the South Platte and its tributaries (Metro-Denver, Boulder, Ft. Collins, Longmont, and Loveland). Because of the increased demand for water in these urban areas, much pressure has been brought to bear on irrigated agriculture for water trading and transfers. Cities desire the higher quality water upstream, the rights to which are owned by the higher priority irrigation water users. In many cases cities have proposed, and have traded, treated municipal waste water for the high quality, upstream water. This can cause a shift in the salt chemistry of the irrigation waters derived from the traded, treated waste water which is higher in sodium and chloride compared to the gypsum-dominated natural condition.

In addition to the water transfers themselves, associated water storage facilities downstream of cities, designed to provide control of flow timing for irrigation water users, have also been proposed. These reservoirs may expose geologic salt sources to saturated conditions not previously experienced, and may dissolve long-sequestered salts into the waters returning to the river.

Another issue of concern is that there is little information on current conditions regarding the severity and extent of soil and water salinization in the South Platte basin. Moreover, only one or two studies have been conducted on the potential salinity-related impacts associated with the marketing of water in the basin. Accompanied with the uncertainty of the current condition, there has been a shift over the last ten years to vegetable crops which are more sensitive to salt injury than the historic field crops (corn, wheat, barley, alfalfa, and sugar beets) grown in this region .

The prevalence of surface/furrow irrigation systems in the South Platte basin, makes the standard recommendation of leaching fraction as a salinity management option, irrelevant, even possibly detrimental, due to the non-uniformity of water application under these systems. To effectively apply a leaching fraction that will move salts out of the root zone, without continually pushing salt- and chemical-laden water below the root zone and into the shallow aquifer, requires the use of sprinkler or drip irrigation systems. The use of these highly uniform and efficient systems offers great potential for improving and managing saline conditions in the basin. However, wide-spread adoption of sprinkler and drip irrigation will inevitably reduce return flows to the river and may drastically alter the river and groundwater system, potentially causing significant impacts on junior water rights holders downstream. The changes in the flow regime of the river may also have undesirable implications for endangered species concerns, and interstate river compact compliance on both the water quality and quantity fronts.

Arkansas River Basin

Basin Profile

The most severe salinity problems in the state are found in this river basin. As in the South Platte basin, a century or more of irrigation agriculture has produced a shallow alluvial aquifer along the length for the river. However, unlike the South Platte basin, significant geologic salt sources underlie the Arkansas River basin soils. In addition, the presence of large on-stream water storage facilities (Pueblo and John Martin Reservoirs) alters the drainage and flow patterns in the basin causing it to be less free draining than the South Platte river system. Higher evaporative demand also occurs in the region, being 1.5 to 2 times higher than the South Platte basin. All these conditions contribute to surface water salt contents which range from 300 to 500 ppm TDS upstream, to about 5000 ppm TDS at the Kansas border. Though still dominated by Gypsum, the salt chemistry, presumably due to the greater influence of geologic salt sources, tends to be higher in Sodium and Chloride than the waters of the South Platte basin.

Basin Salinity Issues

Because of the differences between the South Platte and Arkansas River basins listed above, the alluvial aquifer comes in contact with, and dissolves, large quantities of salt from geologic sources. Moreover, due to the more restricted drainage conditions of the basin, water table levels are rising in the basin soils causing salinity levels to rapidly increase due to capillary rise and evaporative concentration.

Current and emerging river management is also cause for concern related to salinity problems. The moratorium on the pumping of post-compact wells in the lower Arkansas River, ordered as part of the Kansas v. Colorado compact ruling, may serve to compound the rising shallow groundwater problem, at least over the short term. Reservoir operation has also raised the riverbed, due to the reduction of channel-scouring flows, causing further restriction on water table drainage. Many fields in the basin now lie below the drainage freeboard of the river, requiring pumping of water up into the river if salt balance in these soils is to be attained, or maintained. In addition, the sale of water rights upstream, which is becoming more of an issue each year as the cities of Pueblo and Colorado Springs try to enhance and increase their water supplies, reduces salt-diluting flows in the lower reaches of the river, and may exacerbate localized salinity problems and impacts, at least over the short term. The long-term impacts of these water transfers is not well understood.

There is strong evidence for rapidly increasing salinity levels and associated loss of productivity in the irrigated areas of the lower Arkansas River basin. However, the lack of an historic data base cataloging the extent and severity of saline soil conditions, and the lack of groundwater and surface water quality and flow data, make it difficult to fully characterize the water and salt balance in the basin or analyze the economic impact of salinity on the region.

Arkansas River Basin Salinity Study

To address the salinity-related issues noted above, a comprehensive study has been underway since 1998 and is a cooperative effort between the Departments of Civil Engineering, Soil and Crop Science, and Ag and Resource Economics at Colorado State University. Support for the study, technically and financially, has come from a large number of agencies including local irrigation districts and the Southwestern Water

Conservancy District, Colorado DWR, Colorado State Agricultural Experiment Station, Colorado State Cooperative Extension, USDA-CSREES, USDA-NRCS, USDA-FSA, USBOR, and USGS.

Study Description - Phase I
The first phase of the study covers a 35 mile stretch of the river basin immediately upstream of John Martin reservoir between Manzanola and western Bent County. Approximately 135,000 acres on over 80 cooperator fields are covered by the study area. In addition to assessing and monitoring salinity conditions on these fields, more than 170 surface and groundwater salinity sample points are also monitored. To model water and salt balance in the study area, the hydraulic and hydrologic properties of the shallow aquifer have been measured.

Soil salinity measurements have been taken in the spring and fall using direct (saturated paste) and indirect (Electromagnetic, EM38) methods. Measurements of water table depth and salinity are taken weekly (in the cropping season) or biweekly (non-crop season) year-round. Measurements of water elevation, land elevation, and points and amount of irrigation diversions are recorded for hydrologic modeling purposes.

Selected Study Results - Phase I
In 1999, the average soil salinity in the study region was about 2.7 dS/m (or 1900 ppm TDS), ranging from 0.5 to 18 dS/m in the spring, and 0.5 to 8 dS/m in the fall. The 1999 average groundwater salinity was about 3.9 dS/m (or 3100 ppm TDS). Average water table depth in 1999 was approximately 1.5 m (5 ft). From these conditions, crop losses of between 10 and 20%, or about $3.5 million in sales, were estimated for the study area.

The 2000 crop year was much drier than 1999. For 2000, the average water table depth decreased and the average soil salinity decreased to about 2.4 dS/m (or 1700 ppm TDS) presumably due to less evaporative concentration and improved leaching below the root zone. Hydrologic model results showed evidence of a large addition of salt from a source other than irrigation water (based on salt and water balance).

General Study Conclusions
Increased irrigation efficiency, reflected in reduced diversions of irrigation water in the basin, may serve to reduce water table buildup and salt dissolution from geologic sources. Improved drainage is imperative in the basin to keep salinity levels in check. Both of the above have water rights and river water management implications that will have to be institutionally and politically addressed if the salinity conditions are to improve over the long term. Careful, coordinated planning is going to be needed to meet the technical needs of salinity management while protecting the rights of individual concerns (growers, irrigation and municipal water districts, federal and state agencies, and non-agricultural water users). Finally, significant economic impact seems to be occurring over a wide area and demands additional, complete study.

Summary

Soil and water salinity issues are wide-spread and extremely variable across the state. More attention must be given to the basin-specific needs so that long-term, sustainable management of salinity, and the productivity and quality of soil and water resources, can be accomplished. There are no simple, one-size-fits-all solutions to salinity issues in Colorado. This makes it vitally important and prudent for all stake-holders, public and private, local to federal, to take an active role in characterizing and monitoring current soil and water salinity conditions, and investigate the complexities of soil and water management on the salt balance of each basin, individually.

Total Maximum Daily Loads (TMDL) and Non-Point Source Pollution Case Study: Phase I Mercury TMDL for McPhee and Narraguinnep Reservoirs

Karla A. Brown[11]

Abstract

A Total Maximum Daily Load (TMDL) can best be described as a watershed-wide allocation plan to determine the maximum amount of a pollutant that can load into a stream or reservoir, so as to still meet State water quality standards or fish tissue guidelines. A TMDL is a planning document, designed to assess the causes and sources of impairment in a stream or reservoir, and to allocate the responsibility for reducing pollution inputs to meet a waterbody's designated uses. In March 2002, Phase I of the Mercury TMDL for McPhee and Narraguinnep was released for public comment. These reservoirs are located in the Four Corners region of southwestern Colorado. This paper briefly evaluates how the McPhee and Narraguinnep TMDL was developed, and attempts to assess the potential real-life implications of this TMDL for irrigated agriculture and local communities in the Four Corners area.

Introduction

A Total Maximum Daily Load (TMDL) is a watershed-wide allocation plan to determine the maximum amount of a pollutant that can load into a stream or reservoir, so as to still meet State water quality standards or fish tissue guidelines. A TMDL is a planning document, designed to assess the causes and sources of impairment in a stream or reservoir, and to allocate the responsibility for reducing pollution inputs to meet its designated uses.

The TMDL program has been part of Section 303 (d) of the Clean Water Act since the 1972 Water Pollution Control Amendments. However, the main emphasis of the Clean Water Act has always been federal permitting of point sources (end-of-pipe discharges). For point sources, TMDLs may be implemented through reductions in effluent limits via the National Pollution Discharge Elimination System (NPDES) discharge permits. However, in the case of non-point pollution sources, either voluntary controls or locally enacted controls are the only means of TMDL implementation. No permits are required for non-point source discharges. Best management practices are the means of control. However, over time slow or insufficient improvements in water quality made it obvious that point source controls alone were insufficient to meet water quality goals in many watersheds.

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Section 303 (d) of the Clean Water Act requires States to identify waters that do not meet water quality standards with point source controls alone. These streams are then placed on the State's 303 (d) list. Once listed, the State is required to prioritize these waters for TMDL development. Recent litigation brought forward by the Sierra Club and others forced States to actively prioritize and develop TMDLs across the nation. The following TMDL developed for the McPhee and Narraguinnep Reservoirs is an example of one of the many TMDLs currently underway in the State of Colorado.

TMDL Case Study: Mercury TMDL for McPhee and Narraguinnep Reservoirs

The Phase I TMDL developed for McPhee and Narraguinnep Reservoirs provides a good example of the TMDL process in action. When TMDLs are developed, one of the main questions often voiced by the local public involves how this process may impact local economies, lifestyles, or the environment. The following sections attempt to describe the information used in development of this Phase I TMDL, including summaries of the proposed major mercury sources within the watershed and the reductions needed to meet fish tissue targets. Finally, pollution reduction recommendations cited in the TMDL are discussed, including the potential implications of these suggestions for irrigated agriculture and local communities.

Background

McPhee and Narraguinnep Reservoirs have been on the State's 303 (d) list for some time, including iterations of the list promulgated in 1993, 1994, 1996, and 1998. Both reservoirs were listed as not supporting their designated uses due to elevated fish tissue concentrations of mercury, not due to exceedance of ambient water quality standards.

The TMDL for these reservoirs was completed in 2002, and made available for public comment in March 2002. Due to insufficient preliminary data, the Narraguinnep and McPhee TMDL follows a phased approach. Phase I is primarily concerned with summarization and collection of data, modeling of results, and development of preliminary loading allocations and estimates. Phase II will continue the data collection needs identified in Phase I, with additional modeling and better development of load allocations.

In Narraguinnep and McPhee Reservoirs, although the State ambient water quality criteria for mercury have not been exceeded, the geology, location, and chemistry of the reservoirs lead to a situation where mercury in fish tissue can bioaccumulate to levels that exceed State guidelines. Mercury concentrations observed in some of the predominant game fish in these reservoirs are above the State standard of 0.5 micrograms/gram (wet weight) total mercury, which may present significant health risks to persons who consume the fish.

The most significant health concerns regard chronic exposure to low concentrations of methylmercury (predominant form found in fish tissue) for the developing fetus and children. For example, EPA guidance from 1992 provides a lower toxicity value reference dose of 0.075 micrograms/kg/day for women who are pregnant, nursing, or plan to become pregnant. This is the equivalent of approximately one meal per month. Elevated mercury concentrations in fish tissue at these reservoirs led the State of Colorado to post fish consumption advisories at both locations.

Phase I TMDL Development

To understand the end result of the Narraguinnep and McPhee TMDL and its potential implications for the local community, it is necessary to investigate how the mercury sources were assessed, how the numeric target for completing the TMDL was selected, as well as the quality of the data used.

The historical background and technical basis for the development of the TMDL was compiled by the consulting firm, Tetra Tech (Tetra Tech 2000, 2001). Initial investigations of watershed mercury concentrations in the reservoirs were undertaken by the USEPA in 1985 and the U.S. Geological Survey (USGS) and U.S. Bureau of Reclamation (USBOR) in 1989 and 1992. However, due to high detection limits and lack of ultra-clean sampling and analytical technology, these data are of limited value. Tetra Tech undertook extensive water and sediment sampling of the area in 1999, sampling some 23 different mine seeps and creeks, and collecting some 31 water and sediment samples from both reservoirs. Additional data on mercury concentrations in fish were compiled from existing data from the CDOW and USFWS, as well as from additional Tetra Tech fish samples collected in 1999. Information on potential levels of atmospheric mercury deposition were estimated from the only deposition monitoring sites available, limited to sites at Buffalo Pass and Caballo. In addition, several stations from the National Atmospheric Deposition Program were used as surrogates to estimate general deposition rates.

Suspected major sources of mercury included: mining activity, watershed background, atmospheric deposition, and transfer from McPhee to Narraguinnep. Of the mining sources, three areas were identified as significant contributors, including the areas of Rico, Dunton, and LaPlata. Watershed background sources were assessed to be attributable to the geologic parent materials of the area, as well as potential inputs from hot springs. Atmospheric deposition may result from coal-fired power plants, cement kilns, or incinerators. There are significant coal-fired power plant emissions in the area. Power plants within a 200-mile radius were assessed as potential mercury sources. Of the 14 plants evaluated, the San Juan and Four Corners plants were assessed to provide the largest potential contributions.

The TMDL also identifies the numeric mercury target that it will try to meet, as well as the target fish species to be used in all subsequent evaluations. In McPhee Reservoir, Tetra Tech used creel studies from 1993 to assess which top predators also constituted a high percentage of the total annual catch. Based on this information, the selected target for the TMDL analysis in McPhee is an average tissue concentration in 15-inch smallmouth bass of 0.5 micrograms/gram or less. Although a similar creel study was not available for Narraguinnep, the walleye, which is the top predator sport fish and also the fish with the highest reported methylmercury body burden, was selected. The selected target for TMDL analysis in Narraguinnep is the average tissue concentration in 18-inch walleye of 0.5 micrograms/gram or less.

Compilation of historical and newly collected data allowed Tetra Tech to estimate annual source loading into both reservoirs. They then modeled the results to simulate source loading, mercury cycling and bioaccumulation in the reservoirs. This allows a determination of the mercury loading rate that is necessary to meet the target fish tissue concentration. The following table shows the calculated relative mercury contributions from various sources, as well as the percent reduction estimated to meet the fish tissue target.

Table 1.0 Estimated Mercury Sources and Reduction Required (McPhee and Narraguinnep TMDL, 2002).

McPHEE	Annual Source Loading (%)	Reduction Required (%)
Direct Atmos. Deposition	8.23	75.0
Watershed Background	30.13	10.0
Mining Areas	61.64	50.8
NARRAGUINNEP		
Direct Atmos. Deposition	47.12	75.0
Watershed Background	32.62	66.0
Transfers from McPhee	20.36	40.5

In the Phase I TMDL document, recommendations on how to obtain these large reductions are few and far between. However, the authors do provide some suggestions. Regarding the atmospheric deposition component, they suggest that "reduction of coal-fired emissions within several hundred miles of the Reservoir," might help achieve the proposed 75 percent reduction goal. In addition, they also suggest that a portion of the load reduction might be achieved "through reduction of long-range background from increased emissions controls on mercury in the United States and elsewhere."

Recommendations for remediation of watershed background levels are no better defined, consisting primarily of suggestions that "some reduction in background loading is expected if reductions in atmospheric deposition onto the watershed are achieved." Reductions in the contributions from the mining areas near Rico, Dunton, and LaPlata consist only of potential voluntary measures. It is important to note however, that the proposed 40.5 percent reduction related to inter-basin transfers to Narraguinnep, refers only to reductions proportional to the concentrations of mercury in McPhee Reservoir. This recommendation does not reflect a proposal to reduce the quantity of water diverted into Narraguinnep.

Phase II TMDL Development

The Phase II McPhee and Narraguinnep TMDL will attempt to address the data gaps identified in Phase I, and to better assess actual contributions of mercury to the reservoirs, including continued water and sediment sampling. Also in January 2002, the EPA installed a mercury deposition monitoring site at Mesa Verde. This should improve the significant deficiencies in the atmospheric deposition data used in this Phase I TMDL. It is also proposed that the USGS collect sediment cores from Narraguinnep Reservoir, to evaluate the rate of mercury accumulation in these sediments since the reservoir was first constructed in 1907.

Conclusions

TMDLs have been the subject of significant litigation, controversy, and confusion in recent years. For some, TMDLs represent merely a numeric calculation and a numeric limit, for others they describe a watershed remediation and planning process, and for yet others they loom as a misguided attempt by the federal government to move towards regulation of non-point source pollution.

TMDLs are currently under development in watersheds across the nation, and some are being implemented via NPDES permits, local ordinances, and individual voluntary action involving best management practices. However, in many watersheds, TMDL development struggles with complex non-point source water quality problems, where local involvement, adequate funding, or State and federal cooperation may not be in place to facilitate actual on-the-ground remediation. The McPhee and Narraguinnep mercury TMDL illustrates how TMDL development may require extensive costly data collection, and complex scientific modeling and analysis. Even after the reservoir mercury sources are adequately assessed, achieving the reduction goals cited may involve complex inter-state or even global initiatives. Therefore, although some may argue that TMDLs represent a watershed planning tool on paper only, the involvement of local stakeholders is crucial to determine the feasibility of voluntary remediation alternatives, allow community awareness of the potential human health risk implications of non-attainment of water quality goals, and provide local political pressure to encourage more stringent emissions limits for industry.

Literature Cited

Colorado Department of Public Health and Environment. 2002. Total Maximum Daily Load for Mercury in McPhee & Narraguinnep Reservoirs.

Tetra Tech. 2000. Review of Past and 1999 Mercury Data and Related Information for Six Colorado Reservoirs.

Tetra Tech. 2001. Technical Support Document for Developing a Total Maximum Daily Load for Mercury in McPhee and Narraguinnep Reservoirs, Colorado. The technical support document can also be found on the Internet at http://www.EPA.gov/region8/water/files/files.htm.

Nutrient Management To Meet Water Quality Standards

Edward C. Martin[12]

Application of Manure/Compost on Irrigated Agricultural Fields

The application of manure to agricultural fields has always been promoted to help increase soil organic matter, improve soil structure and add a "natural" source of nitrogen to crops. However, recent developments at the National level may have made this practice a little harder to follow.

In 1997, then Vice-President Gore asked the EPA to revisit the 1972 Clean Water Act and address those items that were not specifically addressed in the original act. As a result, on March 9, 1999, the EPA, with the USDA, released the Unified National Animal Feeding Operation Strategy. The strategy provided a foundation for the development of regulations aimed to protect the Nation's water resources from degradation due to Animal Feeding Operations (AFOs). Guidelines are given to help AFO owners and operators to take action to minimize water pollution from confined housing facilities and land applications of manure. Within the document, a Nutrient Management Plan (NMP) is defined that will give guidelines to each individual owner/operator on the management of their facility.

The NMPs are defined as management plans that will integrate feed management, manure handling and storage, land application of manure and other aspects of operating an AFO. Many aspects of these components have been well researched and they are based on sound scientific principles to help develop the plan. However, many questions remain on the proper application of manure to agricultural lands, especially as applied to conditions found in the West and Southwest.

Under the guidelines for the "Land Application of Manure" the Unified AFO Strategy calls for the application of manure to be in balance with the nutrient (i.e., nitrogen and phosphorus) needs of the crop grown. Thus, manure should not be applied in excess of the nutrient uptake of the crop. At minimum, the nutrient plan should prevent the application of nutrients that will exceed the capacity of the soil and the crop to assimilate the nutrients and prevent pollution through either runoff or leaching.

This balance of nutrient application and crop uptake can be delicate in many areas where the mineralization rate is high and the soil's capacity to retain organic nitrogen is low. Many soils in the Western U.S. are not able to retain high amounts of organic matter. Furthermore, in areas where winter temperatures are mild and summer temperatures

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relatively moderate, the mineralization of nitrogen occurs throughout the year. This creates not only an opportunity for leaching but also the ability to utilize nitrogen from manure applications throughout the year.

In Arizona, like many western states, cattle feedlots are extremely large. In the state, only nine feedlots exist. However, three are 32,000 head or more, three are 16,000 – 31,999 head and the last three are less than 15,999 head (1998 Arizona Agricultural Statistics). Of the historic seven states in reporting "cattle on feed" used by the USDA, four are in the Southwest/Western U.S. – Arizona, California, Colorado, and Texas (IA, NE and KS are also included).

Dairies and other AFOs in the Southwest are also relatively large when compared with operations in the upper Midwest and East. In Arizona, 94% of the dairies contain more than 500 head. In 1998, Arizona ranked second in the nation in animal units per dairy operation.

Application of Manure/Compost on Irrigated Agricultural Fields

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Manure Applications

- The application of manure to agricultural fields has always been promoted to help increase soil organic matter, improve soil structure and add a "natural" source of nitrogen to crops.

Manure Applications

- However, recent rules concerning the environmental impact of these applications have made (or soon will make) this practice a bit more complicated.....

The Clean Water Act

- In 1997, then Vice-President Gore requested that the EPA develop plans to address those water quality issues not properly addressed in the initial act.
- As a result, new regulations were put into place for Animal Feeding Operations

AFO/CAFO

- AFO
  - Animal Feeding Operation
- CAFO
  - Confined Animal Feeding Operation
  - Concentrated Animal Feeding Operation

* The new rules/regs only apply to CAFOs... for the most part

CAFO/AFO

CAFOs are:

- 1000 feed cattle
- 700 dairy cows
- 2,500 swine
- 500 horses
- 10,000 sheep
- 55,000 turkeys
- 100,000 laying hens
- 5,000 ducks

NPDES – National Pollutant Discharge Elimination System

- COMPRHENSIVE NUTRIENT MANAGEMENT PLAN (CNMP)
  - Best Management Practices (BMP)
  - Nutrient Management Plan (NMP)

The Plan

- The plan specifies rules and regulations for the handling and storage of animal waste on the CAFO site to prevent discharge of any animal waste off site.
  - Storage pond design (size, liner type and thickness), Run-on, Runoff, handling systems, etc.

The Plan

- The plan also specifies that animal waste may not be applied at a rate that exceeds the capacity of the soil and planned crops to assimilate the waste applied, based on the most limiting nutrient.
  - You can't apply more than the plants use and soil can hold – this applies to all growers that apply animal waste, not just CAFOs.

Limiting Nutrient

- Phosphorus
  - Used in areas where the potential for surface water contamination is high due to runoff.
- Nitrogen
  - Used where the potential for surface water contamination is low.

Arizona

- Arizona is one of the first States in the Western U.S. to implement the NPDES Permit system for agriculture – many industrial and municipal waste water facilities already have these in place.
- Due to the low amount of surface water, nitrogen was chosen as the limiting nutrient for Arizona.

The Rub….

- Although we may know how much nitrogen a plant uses, balancing manure applications with plant use and soil capacity has not been extensively studied.

Research – The first cut

We designed a study to determine the effect of adding manure and compost to a production alfalfa field.

Effects of Manure/Compost Applications

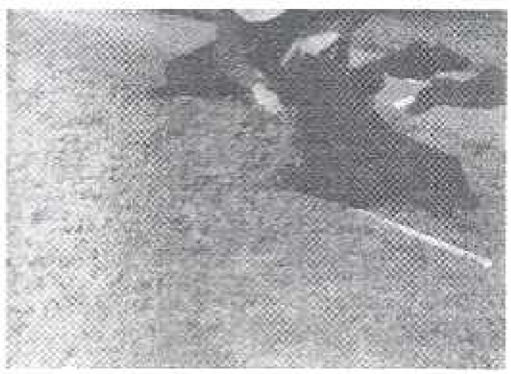
- Effects on the soil – Salt build up, phosphorus loading, nitrogen loading
- Effects on leachate (drainage water) – Measure soil water and analyzing it for nitrate concentration – could be critical to irrigated agriculture.
- Effects on crop yield

What We Do

- First we cut the alfalfa
- Then we sample it for yield and take a sub-sample and analyze for nitrogen content
- Then we sample our manure and compost for nitrogen content
- Then we apply the manure or compost in an amount equal to the nitrogen removed by the cutting

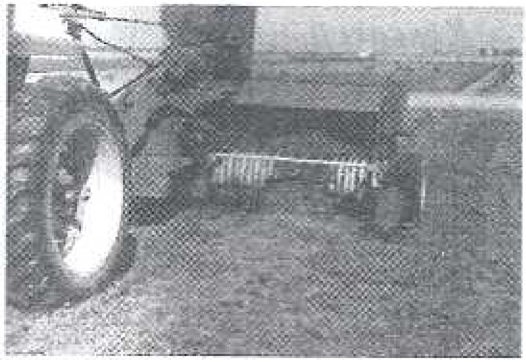
Sampling

- After the alfalfa is mowed, we sample a 2 meter length of wind row – bag and analyze it



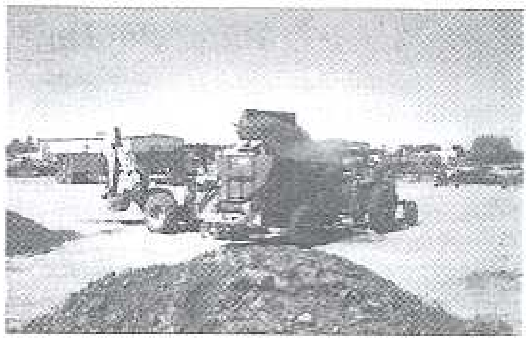
Sampling

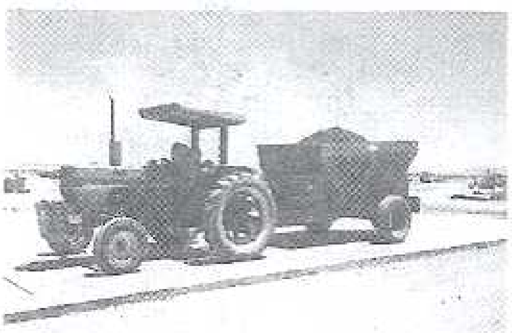
- After bagging, the samples are weighed, dried, and analyzed for nitrogen content
- The hay is then baled and removed from the field



Manure/Compost Applications

- Next, the manure (or compost) is loaded in the spreader
- And weighed





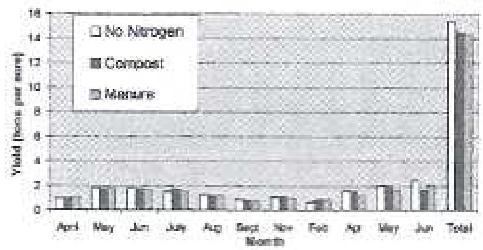
Manure/Compost Applications

- Then the manure/compost is applied to the field at the appropriate rate and the spreader is weighed again to determine the exact amount applied

Some Results

- Alfalfa yield has been the same across all treatments
- The manure treatment does have some quality problems with large chunks of manure in the bales

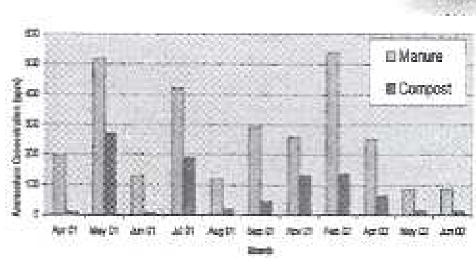
Alfalfa Hay Yield

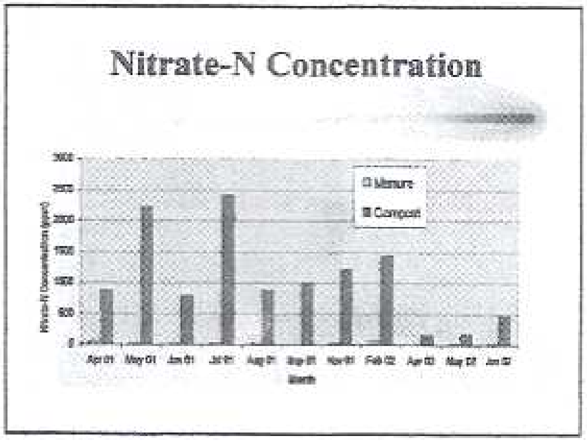


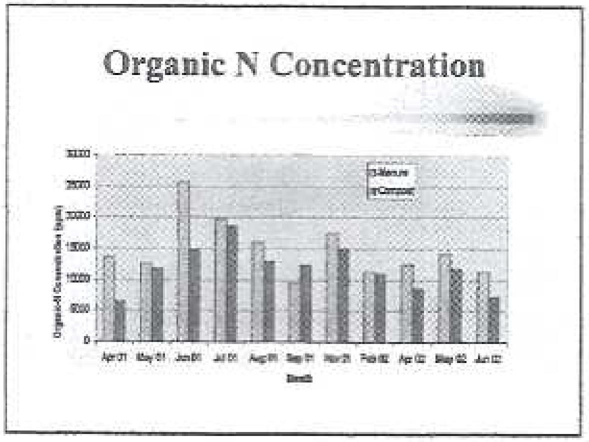
Manure and compost composition varied

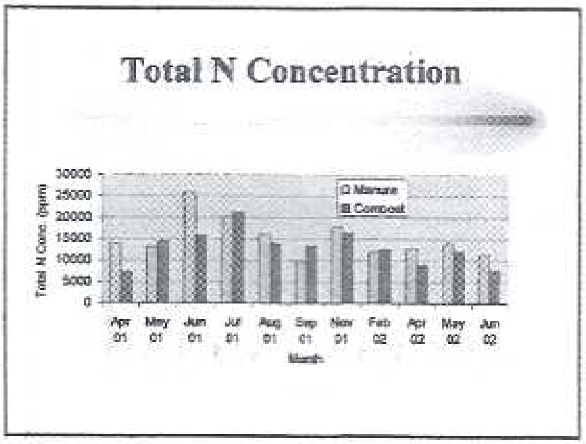
- Manure was higher in Ammonium
- Compost was higher in Nitrates
- About equal in Organic N
- About equal in Total N

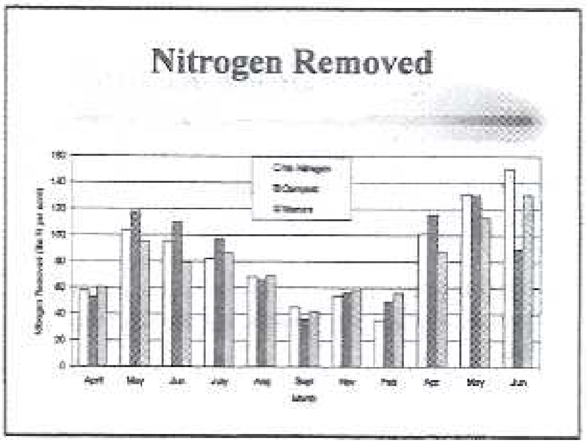
Ammonium Concentration

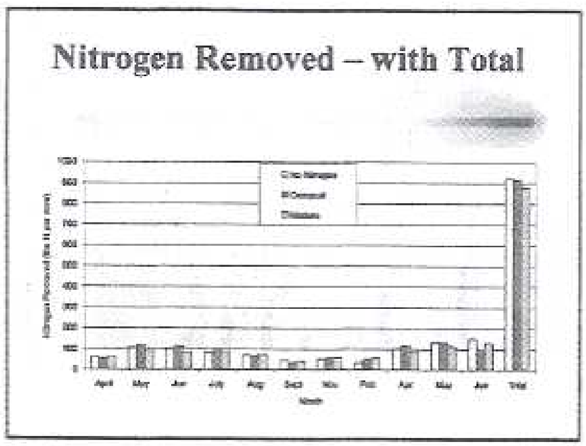


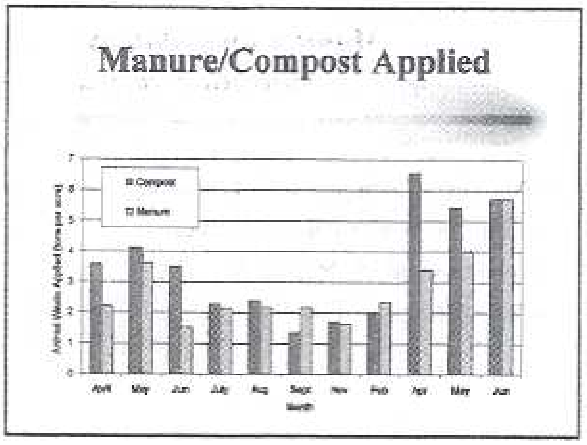

Nitrate-N Concentration
Manure
Compost


Organic N Concentration


Total N Concentration
Manure
Compost
Total N Conc. (ppm)
30000
25000
20000
15000
10000
5000
0
Apr 01
May 01
Jun 01
Jul 01
Aug 01
Sep 01
Nov 01
Feb 02
Apr 02
May 02
Jun 02

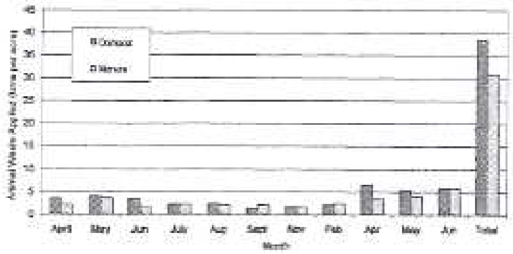

Nitrogen Removed


Nitrogen Removed – with Total


Manure/Compost Applied

Manure/Compost Applied

with total



Other Analyses

- Salt build-up in the soil (EC)
  - No significant signs yet
- Phosphorus build up in the soil
  - No significant signs
- No significant leaching yet

For More Information

http:ag.arizona.edu/animalwaste

Ready for the field tour!

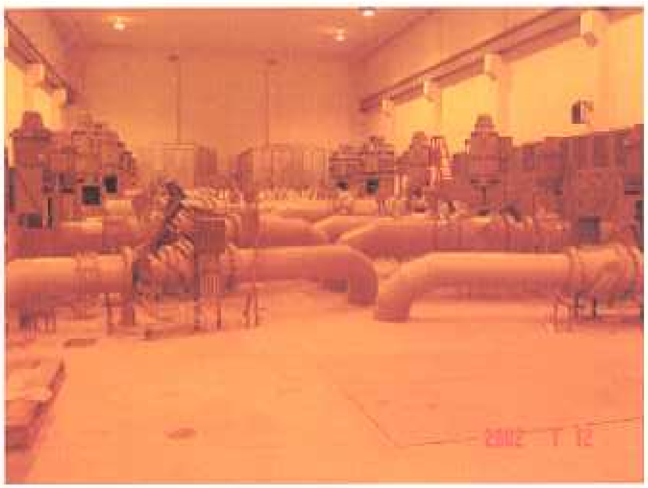
Salinity project and irrigation improvement

Orchard Demo Project at Yellow Jacket, CO.

Are there any raspberries left?
I'm hungry!

What is SDI?

Subsurface Drip Irrigation
Demonstration Project



Great Cut Dike pumping station
7-12-02

Not much water left in McPhee
on 7-12-02

Attentive audience
in Cortez (7/11)

and at the Ute Mountain Ute Tribe Farm & Ranch (7/12)

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