# *Water and Energy Conservation with the AM400 Soil Moisture Monitor*

**Prepared for**

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## INTRODUCTION


(M. K. Hansen Company photo)

The AM400 Soil Moisture Data Logger has drawn attention and praise from both farmers and conservation organizations alike, as an innovative tool that helps farmers make better irrigation decisions and increase crop yields while reducing water, pumping, and fertilizer costs. The monitor, which became commercially available in 1999, is produced by the M. K. Hansen Company of East Wenatchee, Washington.[1]

The National Center for Appropriate Technology (NCAT) – a private, nonprofit organization with offices in Montana, Arkansas, and California – has been involved in irrigation efficiency work and studies since the late 1980s. As part of a water conservation project, the Montana Rivers Project, NCAT installed the first AM400 monitor in Montana in April 2000, and we subsequently installed about 50 AM400s in the Jefferson, Boulder, Big Hole, and Blackfoot river basins. We provided installation and trouble-shooting help, downloaded data from each monitor every year, printed out soil moisture graphs for participants, and met with most participants annually to provide data and get their feedback.

In June 2002, NCAT was awarded a grant by the Montana Department of Environmental Quality for a project funded through the 319 Water Quality Grant Program of the U.S. Environmental Protection Agency. This project, "A Watershed-Based Approach to Irrigation Efficiency," helped local groups in several Montana watersheds install AM400 monitors. These watersheds included the Jefferson, Boulder, Big Hole, Blackfoot, Ruby, and Shields. NCAT installed other monitors for NorthWestern Energy irrigation customers in Montana, as part of an energy conservation program, the Efficiency Plus Irrigation Program.

As of March 2004, 195 AM400 monitors had been sold in Montana, more than in any other state.[2] NCAT was directly involved in installing at least 82 of these monitors. Drawing on four years of experience with the AM400 monitor, and hundreds of conversations with irrigators, agency staff, and researchers, this report addresses the following questions:

- What is a profile of a typical successful user of the AM400?
- How well does the AM400 hold up under normal field conditions?
- How easy is the AM400 to use, and what technical assistance do users need?
- How easy is the AM400 to install, and what are the most common installation problems?
- What water and energy conservation impacts can realistically be expected by users of the AM400?

[1] The M.K. Hansen Company is at 2216 Fancher Boulevard, East Wenatchee, Washington 98802, phone (509) 884-1396, web address www.mkhansen.com. "AM" stands for "Agricultural Monitor."

[2] Mike Hansen, personal correspondence.

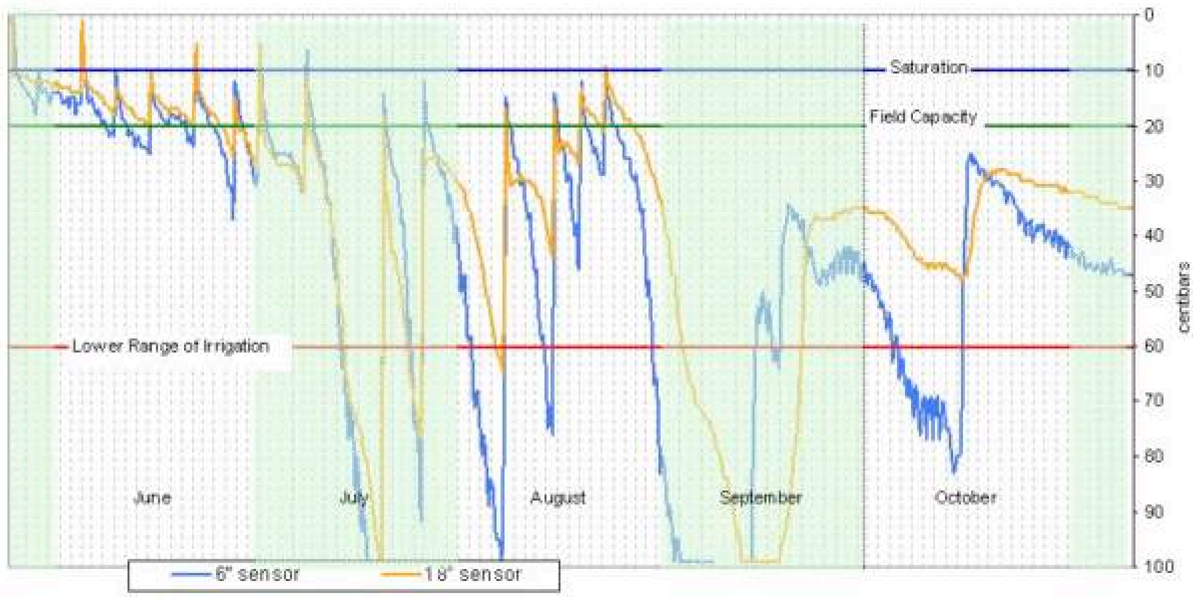
## HOW THE AM400 WORKS[3]

A *data logger* is an electronic instrument that takes periodic measurements (of temperature, relative humidity, pressure, or some other property) and stores these readings in memory. The AM400 takes measurements of electrical resistance every eight hours. It does this by sending a weak electric current (from two penlight batteries) through up to six *Watermark sensors*.

Watermark sensors – made by the Irrometer Company[4] – work on the principle that wet soils tend to conduct electricity better than dry soils. These sensors, each about the size of a wine bottle cork, are little more than a pair of electrodes embedded in granular material, resembling sand, and covered with protective mesh and plastic. As the soil gets wet, water is wicked into the granular material inside the sensor, and electrical resistance between the electrodes decreases.

Watermark sensors (NCAT photo)

AM400 users can check current moisture readings at any sensor. These readings are in *centibars*, a measure of soil water tension – roughly how hard the plant has to work to extract water from the soil. The larger the centibar reading, the drier the soil. AM400 users can also check current soil temperature at a *thermistor* (temperature sensor) buried in the soil. Using thermistor readings, the AM400 is programmed to make small corrections for soil temperature, which affects electrical resistance. An advantage of data loggers like the AM400 is that no matter how busy the irrigator gets, the monitor automatically checks and records soil moisture every eight hours. The monitor displays the previous 35 days of measurements in a bar graph on its display screen, enabling the irrigator to see moisture trends and patterns at a glance. The AM400 also stores ten months' worth of readings in memory, and these readings can be downloaded to a computer and graphed.




Soil moisture graph showing an entire irrigation season. (NCAT)

[3] For more detail, see *Installing and Using the AM400 Soil Moisture Monitor*, included with this report.
[4] The Irrometer Company is at P.O. Box 2424, Riverside, California 92516, phone (951) 689-1701, web address www.irrometer.com.

The AM400 currently sells for $389, including thermistor.[5] Depending on the number of sensors purchased (at $25 to $30 apiece) and the amount of cable purchased (at $.04 to $.25 per foot), the typical AM400 installation costs $450 to $700. The M.K. Hansen Company also offers a downloading cable and a graphing program (called AM400 Chart) for $55.

In the increasingly crowded world of soil moisture measuring and monitoring devices, the AM400 is moderately priced, sophisticated, and user friendly. The AM400 is designed for irrigators who are making practical irrigation decisions in the field, while also observing crop conditions, weather, seasonal changes, equipment, and other factors. The AM400 helps demystify the irrigation process, but it is not intended to be the sole basis for irrigation decisions, or to substitute for the experience and good judgment that are at the heart of farming.


(NCAT photo)

The AM400 is limited to a maximum of six soil moisture sensors, and the most common installation configurations involve one to three monitoring locations, with two to three sensors buried at different depths at each location. The AM400 is intended to provide reference points, not an exhaustive picture of moisture in all parts and depths of the field. The monitor is normally mounted on a fixed post in or near the field. Sensors can be located up to 1000 feet away from the monitor without significantly compromising the accuracy of readings.

## CASE STUDIES

The case studies below are drawn from NCAT's experience over the past four years, and are chosen to illustrate some typical experiences with the AM400. While the names are fictitious, the studies describe actual persons, situations, and events.

**George Adams** and his brother raise hay and pasture for their livestock as well as some small grains. One of their irrigation systems is a pivot that irrigates 140 acres of alfalfa. The soils in this field are gravelly and have a high intake rate. The source of water is a small reservoir and the water supply is limited, especially during drought years.

George is a problem solver with a sunny disposition, a person who isn't easily defeated even by the severe water shortages he's had to cope with for the past several years. He's active in the local watershed group and wants to see more producers in the area getting interested in the watershed issues. Before installing the AM400 on this field three years ago, George was already investigating ways to make better use of the ranch's limited water supply. For example, he tried irrigating all of the acreage under the pivot early in the season and then only watering half of the acreage after the first cutting of hay. When water levels dropped at the end of the summer, he tried plugging every other nozzle on the pivot to keep the pressure up so he could continue watering.

George reported that his irrigation practices didn't change very much during his first year using the AM400 monitor. The device did give him a much better idea, though, how the water was moving

[5] For a more complete description of the AM400, including current pricing information, installation instructions, software documentation, and a user's guide, visit the manufacturer's web site, www.mkhansen.com.

down through the soil. He said, "The year before I wasn't getting water deep enough. This year I wanted to saturate it then let it go longer between passes to let the water go deeper, by slowing down the pivot. Yield was fantastic." In subsequent years, George has monitored soil moisture in the spring and started irrigating earlier. He says he's learning that he has to start irrigating earlier, in May, and then can slack off a little. If he starts later, he never catches up. He has successfully integrated the AM400 into his water management plan and sees it as a useful tool for limited water situations. He says, "Instead of trying to water everything, I can set priorities for short water supplies."

**John Jefferson** installed an AM400 monitor three years ago. He's conservative in his outlook and very focused on the bottom line. John told us that he was interested in running his pumps less in order to save money. He also wanted to optimize crop growth. He has a combination of alfalfa and grass planted on 140 acres and irrigated by a pivot. During low water years, John has to alternate his pivots, running only two out of the four at any one time. He starts irrigating early so he can get water on all of his fields before he is forced to start shutting down pivots on an alternating schedule.

Three years of using the AM400 have not caused John to make major changes to his water management methods, but have confirmed his belief that he is not overwatering and is making good use of water. The monitor has helped him save water during spring rains and late June snowstorms. "We saved two to three days of watering because the ground was wet after a late snow," Jefferson says. At an approximate cost of $.04 per kilowatt-hour for electricity, he saved about $100 in these three days alone.

John's AM400 is mounted on a fence post facing a well-traveled county road. When the soil moisture monitoring project first began in the area, neighboring irrigators stopped by daily to check the soil moisture levels in his field. John said, "I checked the monitor two to three times a month. The neighbors checked it several times a week." John couldn't decide if he should be annoyed or amused that his neighbors were so interested in his AM400.

(NCAT photo)

**Tom Burr** is a retired engineer with a dry and sarcastic sense of humor. He took up farming after his retirement, and enjoys growing alfalfa along a stream that dries up most years during the late summer. He uses a diesel-powered pump to provide water to wheel lines on a 40 acre alfalfa field.

Tom installed an AM400 four years ago. At that time, he had one long wheel line for his entire field. During the first year, Tom looked at the monitor about every other day and says that it "helped me worry." In other words, the monitor helped him see how dry things were, but he couldn't do much about it. Tom thought it would take about five years until he fully trusted the soil moisture readings as a basis for his irrigation decisions. He commented, "It's very hard to convince yourself to stop irrigating."

In the first year, the soil moisture monitor also confirmed what Tom had suspected: namely that it was taking him too long to cross his field. By the time he reached the far end of the field with his wheel line, several days had passed and the soils at the starting point had become too dry. Based on

(NCAT photo)

this information, he decided to re-route his mainline and split his wheel line into two sections. This new arrangement allows him to cross the field faster and cut hay on one half while irrigating the other half.

In the year 2000, when he installed the AM400, Tom was too busy to bury the cable and left it lying on the surface of the ground. While cutting hay, he got the cable tangled up in his baler and a large section of it needed to be replaced. Tom called the cables "a pain in the ass."

The following year was slightly wetter. Checking his monitor four to five times a week, Tom often found that he had adequate soil moisture and was able to wait a few days between irrigations. He says, "I probably saved one set due to the reliable way the monitor had of tracking how much water was on the field." For Tom, saving one irrigation set is equivalent to saving about 12 percent of his annual diesel fuel bill for irrigation.

After three full seasons of using the monitor, Tom finds that he is looking at it less often. He has developed a confidence based on experience about what the readings are likely to be. Also, because of the severe and chronic water shortages in the valley, he has little flexibility in how he irrigates. He generally needs to use whatever water he can get and for as long as he can get it. He believes that the monitor would be most useful in a wetter year when he has more options.

**Jim Clinton** takes a scientific and innovative approach to farming. His intelligence, ingenuity, and efficiency have enabled him to raise a family of four on less than 30 acres of land. Jim currently runs sheep in an intensive grazing rotation on grass pasture. He is a meticulous record-keeper, constantly looking for ways to cut costs and increase his yields.

Since Jim intensively grazes shallow-rooted grass pasture, he waters frequently and for short periods of time. He installed an AM400 four years ago when he was still irrigating with hand line and wheel lines. He checked the monitor daily and called it "one of the best things to come along for a long, long time." Jim was fascinated by the readings, and quickly became convinced that he was overwatering. He had been running five to six-hour sets through the growing season, switching to eight-hour sets during hot weather. In his second year with the monitor, he ran two-hour sets in the spring, three-hour sets through May, and four to five-hour sets when it got hot. "Soil moisture has always been the missing link…The meter said that six hours was all we needed. Even if it started out at 90 centibars, we got down to 10 centibars within six hours."

Knowing the centibar measurements in his soil allowed Jim to describe his situation to soil specialists. He says that "In today's farming, inputs are more expensive. Crops take more inputs and more expensive inputs…Sooner or later, precision will be demanded." Jim also appreciated the energy savings he was able to achieve, saying, "The way it's been in ranching, it's tough to make it. When you can cut back your power bill, you've really done something."

Two years ago, Jim installed two small pivot irrigation systems that allow him much more control over the irrigation process and also save labor. He says, "Without the monitor, I would have run the pivots a lot more than I did."

**Chester Hendricks** has a well-deserved reputation for hard work, good judgment, and shrewd business decisions. He loves farming and he does it seriously and expertly. While a dismal agricultural economy has sunk many farming operations in Montana, Chester has enjoyed steady financial success that has enabled him to buy a series of increasingly valuable ranches. He is always upbeat and never seems to be in a hurry. He makes farming and ranching look easy.

When he joined our project, Chester was growing peas and alfalfa with a pivot irrigation system on about 350 acres. Because he was pumping irrigation water from a well, he was able to continue irrigating long after his neighbors had run out of water, during an exceptionally hot dry summer. On the other hand, coarse soils with poor water-holding capacity made for some challenging water management.

Chester immediately recognized the AM400 as a valuable tool, and he took full advantage of it. He looked at the monitor "every day, at least, and sometimes two or three times per day." He used 20-30 centibars as a moisture target, and ran his pivot faster when the soils appeared to be drying out quickly. He also sometimes shut down after a rainy or cloudy day.

Chester told us that he bases most of his decisions on careful observation of the crop. He called the AM400 "a tool to manage the crop along with visual observation of the crop…It's a tool, but so is looking at the crop." Chester believes that the AM400 definitely made a difference to his total production. He "didn't let the crop get hurt" by the hot dry weather, and enjoyed excellent yields, "one of our best crops ever." He commented, "Heat isn't all bad…If you can water the crop, it really grows."

Chester was surprised that evapotranspiration rates got so much higher once the plants started getting taller. "An 18-inch crop pulls a lot more moisture than when the plants are smaller and younger." He was also impressed by "How much effect wind and humidity make on depletion of soil moisture…Unbelievable." He saw some tremendous moisture drops take place in just a four to six hour period.

After a year in our project, Chester bought a new, larger ranch in another part of Montana.

(NCAT photo)

**Marty Johnson** is a highly experienced and professional ranch manager who turned 70 last year. He has strong opinions on every subject, a salty vocabulary, a large repertoire of funny stories, and a somewhat long-suffering and cynical attitude toward his employers: a couple who own the ranch and use it for recreation but are not very involved in day-to-day decision making. In 2002, Marty was kicked by a cow during calving season and suffered broken ribs. He has threatened to quit dozens of times.

Marty irrigates 200 acres of alfalfa with wheel lines and hand lines. The soils range from almost pure sand to “gumbo” soils and spring seeps near the river bottom. Marty’s main irrigating challenge has been keeping the coarse soils at the top of the sloping field wet without turning the lower part of the field into a quagmire.

Marty installed an AM400 in the year 2000, and from the start he loved it. He said, “I don’t have to remember all this stuff. I just push the damn button.” In his first year with the AM400, he looked at the monitor every day and says that he made constant adjustments in his irrigation management. The information allowed him to reduce 100 nozzles from nine gallons per minute to seven gallons per minute. Marty was also able to shut off lines for two or three days at a time.

In subsequent years, Marty has continued to rave about the AM400. He said, “I’ve been doing this for 31 years and I thought there was nothing about irrigation that I didn’t know…This has certainly changed the way I look at it all.” When we looked at Marty’s power bills in 2001 and 2002, however, we found only slight savings, if any. In an interview with a local newspaper, Marty said that he is using the same amount of water that he always did, just using more in some fields and less in others. In each of the four years that we’ve downloaded data from Marty’s AM400 monitor, we’ve found very wet readings, consistently at or above field capacity. Much as we’ve tried to pin Marty down, we find it difficult to say whether he’s saving water or not.

**Andy Tomkins** installed a monitor two years ago on a field with sandy soil irrigated by a newly installed pivot irrigation system. He’s always friendly when we visit him, and active as a volunteer in various community groups. During his first year with the AM400 monitor – also his first year with the pivot – the field had an old stand of alfalfa on it. During that year, all of Andy’s sensors remained extremely wet, above field capacity. He said that his previous experience with this field was that it “dried up instantly.” Because the pivot was new, he was probably overcompensating for previous problems. During the second year, the field was plowed and Andy planted a new seeding of alfalfa. The monitor again showed soil moisture between field capacity and saturation for the majority of the season.

It appears to us that Andy is not successfully using the AM400 for feedback on his irrigation management. From our conversations with him, we have the impression that he may be misinterpreting what he sees on the display screen, or he may not be clear on the concepts of saturation and field capacity. We’ve found it challenging to discuss these issues without insulting Andy’s intelligence.

**Sarah and Ben Grant** are enthusiastic hobby farmers who have tried growing alfalfa, oats, and buckwheat on 20 or 30 acres of land. They irrigate with wheel lines and hand lines. Prior to installing the AM400, they generally looked over the fence and irrigated the way their more experienced neighbors did. They were eager to have all the help they could get in learning how to irrigate better.

During the first year, Sarah and Ben looked at the monitor “a lot.” They had very little flexibility in how they irrigated, though, since by the time they got across their fields the soils had dried out at the starting point and they needed to start over again. The main difference the monitor made for them was that they “weren’t in such a panic” to move the wheel line. When they saw on the monitor that the soils had adequate moisture, they knew that they could get back over the field without drying out the crop.

The Grants did not think they saved any water or energy by using the AM400, but they learned that their soils were holding moisture better than they had previously thought. This enabled them to be less panicky during the hot dry weather. After three years, the Grants decided they had learned everything they were going to learn from the AM400, and they gave their monitor to a neighbor.

Another hobby farmer, **Zack Dallas**, is a retired college professor who installed an AM400 monitor on a small field of grass and alfalfa in 2001. Through the entire time we have known Zack, his monitor has shown consistent readings of zero to five centibars at 18 inches deep – essentially the same readings as if the sensor were in a bucket of water. From the surrounding marshy terrain, it appears likely that Zack's field sits above a high water table.

Under these conditions, only shallow watering should be necessary. Nonetheless, year after year Zack has continued to water this field heavily, running 12-hour sets. He has also experienced every imaginable maintenance problem: A couple years into the project, he called to say that the monitor was malfunctioning. Our technicians found that Zack had opened the box and replaced the terminal strip on the pins incorrectly. A year later, cows rubbed the monitor off the post and also chewed and crushed the cable.

(NCAT photo)

We also saw severe overwatering at **Warren Johnson's** farm. Warren irrigates several hundred acres with pivots, wheel lines, and hand lines, and he installed an AM400 in one of his pivot fields. During 2002, his first year with the monitor, Warren's field was extremely wet, almost continuously at or above field capacity all summer long. Warren's irrigation manager, Ted, tried repeatedly to convince Warren to cut back on his watering, telling him that this alfalfa was drowning and turning yellow as a result. These efforts were unsuccessful, and Warren staunchly maintained – despite the wet readings on his monitor – that his crop was turning yellow because it was not getting enough water. In 2003, Ted was replaced by a new irrigation manager.

## MAINTENANCE ISSUES

Between 2000 and 2004, NCAT had experience with 82 AM400 monitors, including installing, repairing, and downloading data. We recorded 91 maintenance incidents with these monitors: 67 incidents that we classified as "installation problems" and 24 incidents that we classified as unrelated to installation. These numbers reflect some sites with multiple maintenance incidents, as well as some incidents reported under more than one category.

### *Installation-Related Problems*

The 67 maintenance incidents attributable to human error during or after installation included:

- *Cable or splice problems or damage* (20 incidents). Most of these problems involved bad splices, leaving cable above ground where livestock, wildlife, and machinery damaged it, or plowing up cable that wasn't buried deeply enough. In a very few cases we saw bad cable with a break in it. One owner melted his cable while burning weeds.
- *Wiring problems inside the AM400* (19 incidents). These included broken wires, incorrect terminal strip installation, and dead batteries.
- *Thermistor installation* (12 incidents). These included bad splices, incorrect wiring at the terminal strip, and other installation errors.
- *Sensor installation* (eight incidents). These included bad splices, incorrect wiring at the terminal strip, and air pockets around sensors. In many cases, the soil became so dry that sensors lost soil contact, stopped giving readings, and took days or weeks to recover once moisture was applied.
- *Livestock or wildlife damage* (eight incidents). We saw cases of livestock rubbing on posts and damaging monitors, wildlife chewing on unburied cable, and rodents chewing on buried cable.

### *Problems Unrelated to Installation*

The 24 maintenance incidents unrelated to installation included:

- *Circuit board problems* (six incidents). These included relay problems, internal problems, and display problems.
- *"Acts of God"* (five incidents). These included a monitor run over by a phone company truck, a cable struck by lightning, a thermistor ripped out of the ground when a cable was snagged by a passing car, and a monitor on a golf course that was smashed by golf ball.
- *Undetermined causes* (13 incidents). These included unexplained breaks in data, spikes in data, and lack of data. 10 of these 13 incidents may have been attributable to corrosion on battery terminals from moisture and dust.

### *Maintenance Conclusions*

While the number of maintenance incidents has been high, the vast majority of these problems have been caused by human error: poor installation, human-caused damage (especially cables being cut), and inadequate protection from animals. Mechanically, the AM400 monitors in NCAT's study have held up extremely well, especially considering the severe conditions to which these devices have been exposed. Most of these monitors have been left in the field through the winter months, subjected to wide daily temperature fluctuations and sub-zero temperatures.

## USER-FRIENDLINESS

### *Installation Problems*[6]

When NCAT first began promoting the AM400, we thought that ranchers and farmers would easily be able to install these devices by themselves. The high frequency of installation-related problems, though, strongly suggests that we were wrong. We now believe that most average users need installation help. Below are some main installation challenges.

*Digging holes for the sensors:* In gravelly or rocky soil, digging an 18 or 30-inch deep hole can be a challenge, especially for a person without a specialized soil auger or soil sampling device. The Irrometer Company, manufacturer of Watermark sensors, recommends using a 7/8" diameter rod as a digging tool in normal soils and a 1" – 1 ¼" diameter rod in coarse or gravelly soils.[7] A shovel works fine in many cases, although care must be taken not to compact the soil or leave air pockets.

*Establishing good soil-to-sensor contact:* The Irrometer Company cautions that "With coarse or gravelly soils, it is sometimes difficult to get a snug fit between the sensor and the soil."[8] Without this snug fit, the sensors do not wick moisture from the soil properly. NCAT receives several phone calls each year from irrigators who are certain that their monitor is broken or the sensors have quit. In almost every case, the problem is extremely dry soils or air pockets around the sensor. Under these circumstances, it takes prolonged wetting from irrigation or precipitation before the sensor will respond.

*Making secure splices:* Although they are usually experienced with electrical wiring, many farmers and ranchers do not have appropriate tools for handling the fine wire (18 to 24 gauge) required by the AM400. Since splices are soaked repeatedly, any weakness will eventually cause a failure.

*Burying cable:* When cable is not buried, it is often damaged by haying or harvesting equipment or (less frequently) animals. For short cable runs in soil that is not too rocky, a shovel, mattock, or similar tool is adequate for digging a shallow trench and burying cable. For long cable runs, rocky soil, or where the cable needs to be buried deeply, a trenching device is almost essential. Some irrigators in NCAT's program have gotten together and rented a trencher. One rancher designed an implement for the 3-point hitch on his tractor, allowing him to make a trench and lay cable at the same time. Some irrigation equipment installers have also been willing to trench in cable for their customers who were installing an AM400 along with a pivot irrigation system.

Home-made cable-laying implement. (NCAT photo)

[6] For more detail on installation problems and techniques, see *Installing and Using the AM400 Soil Moisture Monitor*, included with this report.
[7] "Watermark Soil Moisture Sensor," pamphlet #15. Riverside, CA: Irrometer Company, Inc.
[8] Ibid.

### *Interpreting the Readings*[9]

While many irrigators immediately understand the readings they are seeing on their AM400 monitors, most irrigators need some help and coaching. Below are some main problems:

*Elementary misunderstandings:* We've encountered the following, to name a few:

- Thinking that the top of the graph represents the surface of the soil and lower means deeper.
- Thinking that soils should be kept at or above field capacity at all times.
- Thinking that soils can safely be dried out to 100 centibars between irrigations.
- Using the shallowest sensor as the basis for irrigation decisions, and ignoring the deeper sensors (even when these are in the middle of the root zone).
- Thinking that the monitor is broken when the sensors are merely too dry to give readings.

*Unrealistic expectations:* New AM400 users often ask for simple guidelines or rules of thumb, such as a centibar number that indicates plant stress or a number that means it's time to irrigate. They expect the AM400 to tell them when to irrigate, and they are sometimes disappointed when they learn that the device does not meet this unrealistic expectation. It is possible to give some general guidelines that apply to everyone, but risky to give anything more detailed. Irrigators should be encouraged to develop their own guidelines for their crops and soils, and they should understand that this will probably take time. The AM400 is intended to provide a new kind of useful information, but it does not replace the experience, subtle observations, and good judgment that make someone a good farmer. Farming is difficult. The AM400 takes some of the guesswork out of irrigating, but it does not make farming easy.

*Centibar readings:* As explained above, the AM400 gives soil moisture readings in *centibars*, a measure of soil water tension. Many irrigators are unfamiliar with this concept. Furthermore, irrigators tend to think in terms of inches or depth of water applied. Because of the variable water-holding capacity of different soils, there is no simple way to convert centibar measurements into inches of water. At the same centibar reading, for example, clay soils may hold two or three times the volume of water that sandy soils can hold.

(NCAT photo)

*Scale problems:* Some irrigators have been confused by the changing scale on the monitor's graphic display. When the AM400 is first connected, it normally shows a range from 0 to 25 centibars (cb). At 25 cb, soil is still quite wet – near field capacity in many soils. But the graphic display makes a fall from 0 to 25 cb look severe. When the monitor records its first reading above 25 cb, it re-scales and begins to show the range from 0 to 50 cb, in order to display all readings. When the first reading above 50 is recorded, the graph re-scales to show the range from 0 to 100 cb. When the first reading above 100 cb is recorded, the graph re-scales to show the range from 0 to 200 cb.

[9] For more detail on interpreting and using readings from the AM400, see *Installing and Using the AM400 Soil Moisture Monitor*, included with this report.

## WATER AND ENERGY CONSERVATION WITH THE AM400

From an energy or water conservation standpoint, monitoring soil moisture in a sprinkler-irrigated field is about as important as monitoring temperature in a heated building. The AM400 is a powerful and user-friendly tool that enables many irrigators to make substantial improvements in their irrigation management. Not all irrigators improve, though, and not all management improvements translate into water or energy savings.

### *Some Characteristics of Successful AM400 Users*

(NCAT photo)

1. Serious and experienced professional farmers, trying to optimize yields and maximize profits, are promising candidates for successful use. Part-time and hobby farmers enjoy using the AM400, but they are often lacking in motivation or experience with soils and crops. As one irrigator said, "Serious people who want to make money will buy it. Once they decide they want it, they don't mind paying retail prices."

2. Irrigators who are interested in the AM400, and open to re-thinking their approach to irrigation management, generally get more out of it. One indicator of interest is willingness to pay for the AM400. Many of the AM400 monitors in the NCAT study were either heavily subsidized or installed free of charge. We believe that this partly explains the high frequency of maintenance problems and damaged equipment that we have seen.

3. Owners of pivot irrigation systems are more likely to benefit from the AM400 than operators of hand line, wheel line, or wild flood systems. Pivot operators have better control over how they apply water. Wheel line and hand line systems are often designed to be moved twice per day, running 12 hours in each location and moving across an entire field over a period of several days. The systems are often designed so that by the time an irrigator gets across the field, soils at the starting point have dried out and the irrigation cycle must start over again. There is little flexibility in how such a system can be managed.

4. Irrigators who face chronic water shortages are promising candidates for successful use. When irrigators are forced to reduce water use, they become more interested in finding ways to make better use of limited water supplies. On the other hand, irrigators facing severe water shortages sometimes have few management options. They use water whenever it's available.

5. Irrigators with access to installation help are more likely to be successful with the AM400. At the outset of this project, NCAT underestimated the severity of installation problems. We learned that irrigators who purchase an AM400 on their own often don't get around to installing it, or have problems with the installation. This is true even though installation is not particularly complicated and most irrigators are experienced in dealing with electrical wiring. One indicator of success seems to be an active local equipment dealer who sells the AM400 and stays involved with the irrigator.

6. Irrigators who learn about the AM400 by word of mouth and talk to each other seem more likely to benefit.

### *Lessons Learned about Water and Energy Conservation*

Below are some lessons learned from NCAT's four-year effort to promote water and energy conservation through use of the AM400 monitor:

*1. Overwatering may be less common than expected.*

NCAT studied water application at 43 irrigated fields in southwestern Montana between 1997 and 2003. For each field, we measured actual application rates and then calculated total hours of operation based on power bill information supplied by the irrigator. With these numbers, plus acreage, we were able to calculate total annual irrigation water applied, in inches. We found that these irrigators applied an average of 22.3 inches of water to their fields, with pivots using somewhat less water than hand lines and wheel lines. Sprinkler irrigation systems have widely varying application efficiencies between 60 and 85 percent – meaning that only 13.4 to 19.0 of these 22.3 inches entered and remained in the root zone as net irrigation.

Comparing these application amounts to Natural Resources Conservation Service estimates of crop water requirements for southwestern Montana, we found that only three to six of these 43 field clearly exceeded the annual crop water use requirements for alfalfa – by far the most common crop grown in the area. This result is perhaps not surprising considering that many Montana irrigators deal with underdesigned delivery systems, chronic water shortages, equipment breakdowns, power outages, inadequate system pressure, and other problems that limit their water application.

*2. Better water management sometimes means increased water and energy usage.*

Many irrigators underwater their crops. We've seen this frequently in irrigators who have made the change from hand or wheel line systems to a pivot. During a 12-hour set, a typical wheel line system might put down four inches of water. A pivot, on the other hand, may apply only one third to one half inch of water during each rotation, depending on speed.

(NCAT photo)

New pivot owners need to learn that irrigating with a pivot is a drastically different process from irrigating with a hand line, wheel line, or flood system. Irrigators who are underwatering generally increase their water and energy consumption when they have access to the kind of excellent soil moisture information that the AM400 provides.

*3. Factors beyond anyone's control can severely limit achievable water and energy savings.*

Besides the obvious impacts of weather, irrigation decisions depend upon a host of practical constraints. These include water rights, labor cost and availability, cropping changes, the behavior of upstream irrigators, and the importance of getting along with the neighbors.

*4. Irrigators understandably care more about crop yields than they do about water or energy savings.*

Energy for water-pumping is a minor operational cost in relation to high-value crops (such as potatoes), and only moderately significant in relation to the low-value crops that dominate Montana agriculture.  A 2002 survey of irrigated croplands showed the following annual crop values per acre in Montana: potatoes $2,928; sugar beets $856; alfalfa hay $315; corn $296; all hay $278; barley $193; wheat $190; oats $151 (Montana Agricultural Statistics Service).  In 2003, NCAT studied energy costs for 64 electric distribution irrigation customers of NorthWestern Energy and found an average annual energy cost of $23.41 per acre.  Using these average numbers for rough comparison purposes, electrical energy would amount to seven or eight percent of the value of an alfalfa hay crop, 12 percent of the value of a wheat crop, and less than one percent of the value of a potato crop.


(NCAT photo)

Admittedly, for many Montana irrigators – and especially those who are growing low-value crops – energy costs are consuming an increasingly significant percentage of already-slim profit margins. At the same time, crop yield and (to a lesser extent) crop quality are clearly the main economic drivers on almost all irrigated farms.  Water, costing little or nothing for most Montana irrigators, is hardly an economic consideration at all.

Even a modest yield increase in a low-value crop – say, one half ton of alfalfa per acre – is worth at least an additional $35 - 40 per acre at typical prices, far more than most irrigators could possibly spend on increased energy consumption.  Even a doubling of energy consumption (if this were possible) would probably be economically advantageous for most irrigators if it resulted in a slight improvement in crop yields.  No matter how much irrigators may dislike high power bills and welcome improved energy efficiency, they understandably view energy conservation as secondary to crop yields.

*5. Money spent improving irrigation equipment generally brings more energy conservation, dollar for dollar, than money spent improving irrigation management.*

Working with irrigators on management changes is a slow and sometimes frustrating process.  It is unrealistic to expect dramatic behavioral changes in the first year or two.  For irrigators, time is always scarce during the growing season and they have a lot of other things to worry about.  A successful approach needs to provide good tools, convenient technical support, ongoing training, and allow a period of years for experimentation and gradual change.

NCAT's experience has been that hardware improvements bring about greater energy savings – and bring them about faster – than educational efforts aimed at changing irrigation management behavior.  For example, since 2002 NCAT has administered the Efficiency Plus Irrigation Program for NorthWestern Energy.  During 2003, this program provided about $300,000 for energy-saving irrigation equipment improvements.  These improvements are expected to save 1,155,437 million kilowatt-hours and 3,158 kilowatt-months annually, worth $75,574 at current energy prices.  Many of these improvements also brought other substantial benefits, such as water conservation, increased crop yields, labor savings, and fish and wildlife benefits.

*6. Western water rights laws greatly complicate efforts to conserve water.*

In the western United States, water laws are based on a seniority system, with every water right assigned a priority date reflecting the earliest historical use of the water. By law, earlier priority dates trump later dates. For example, 1890 right holders are entitled to their full allocation before any upstream 1900 right holders may take a drop. This "first in time, first in right" principle essentially gives irrigators a right to continue using water according to historical patterns, regardless of how inefficient those patterns may be. Also, irrigators who do not use the full quantity of water to which they are entitled may be held (in certain circumstances) to have abandoned part of their water right. While successful charges of abandonment are unusual, and irrigators who conserve water do have legal options for protecting their water rights, the "use it or lose it" feature of western water law unfortunately holds a sword over the heads of irrigators who reduce their water consumption.

## FINAL THOUGHTS

The AM400 is an well-designed, sophisticated, durable, moderately priced, and user-friendly tool that is enabling many irrigators to achieve significant management improvements, water savings, and energy savings. The discussion above, though, paints a realistic picture of the difficulties to be expected by anyone who tries to save water and energy with the AM400 or related tools and approaches.

Changing human behavior in the area of water and energy conservation is notoriously difficult, and the AM400 does not make these difficulties disappear. Measuring the success of the AM400 depends on how you define success. It's certainly unrealistic to expect dramatic and widespread reductions in water and energy usage to result from a soil moisture monitoring demonstration project. On the other hand, NCAT has seen this kind of demonstration project succeed in producing constructive changes in people's attitudes and awareness. For example, by introducing the AM400 to six different local watershed groups we've seen benefits such as:

- Increased peer pressure to irrigate more scientifically.
- Better understanding of the most likely opportunities for conservation, including a better ability to identify irrigators with the strongest potential for reducing water and energy consumption.
- Improved communication among water users.
- Reduced secrecy and suspicion among water users.
- Reduced tensions and social conflict over water use.
- Greater receptivity to new ideas and experimentation, in hardware, crops, and management practices.

(NCAT photo)

One person summed up his experience with the AM400 this way: "Groups and agencies do demo projects for awhile and are usually disappointed by grower response. But in the wake of the demonstrations, a small group picks up on it, maybe as few as one or two guys. Then it grows from a nucleus. …The good news is that it does tend to grow from that point on its own."