6-1987

A Demonstration and Evaluation of the Use of Climate Information to Support Irrigation Scheduling and other Agricultural Operations (CAMaC Progress Report 87-4)

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CAMaC Progress Report 87-4 June 1987

A DEMONSTRATION AND EVALUATION OF THE USE OF CLIMATE INFORMATION TO SUPPORT IRRIGATION SCHEDULING AND OTHER AGRICULTURAL OPERATIONS

Summary Report to the
United States Department of Commerce
National Oceanic and Atmospheric Administration
National Climate Program Office

On Cooperative Agreement NA80AA-H0087

by

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TABLE OF CONTENTS

I. BACKGROUND

The funding for this project was provided in part by the National Climate Program Office, a division of the National Oceanic and Atmospheric Administration. This report has been organized to provide: (1) background information on the project; (2) a description of the Automated Weather Data Network (AWDN), developed between 1980 and 1986; (3) research associated with the collection of data from AWDN; and (4) near-real time climate services. Conclusions and recommendations for the future are given in the final section.

1.1 National Climate Program

The National Climate Program Act was passed in 1978. The legislation was needed, according to the Senate Commerce Committee, to respond to three major needs: better federal planning and management, more research on basic climatic phenomena, and more effective use of climate-related information (see Appendix 1 for a more detailed discussion of these objectives). Before the passage of the National Climate Program Act there was no national plan whereby objectives, funding responsibilities, and prioritites related to climate activities could be coordinated. The period preceding the National Climate Program was characterized by both overlapping and duplication in the conduct of certain national climate activities and low visibility, which resulted in little or no progress on other climate problems. In setting their priorities, federal agencies recognized the need for climate activities from time to time, but with no national coordination. The Senate report also recommended increased involvement of state and local governments and the private sector in receiving and using climate information.

The bill signed by President Carter on September 17, 1978, established a National Climate Program Office (NCPO) in the Department of Commerce and authorized $60 million and $75 million for this office in 1979 and 1980, respectively. Although this level of funding was not achieved, the formation of the National Climate Program nevertheless stands as a significant event in the history of U.S. policy toward climate data collection, services, and research.

As we mentioned earlier in this section, the aim of the National Climate Program Act was to develop a coordinated national approach to climate research and services, with emphasis on the involvement of all affected parties (federal, state, and local governments and the private sector). The work undertaken in this project is an example of the applied climate research and development of climate services called for in the National Climate Program Act. The reader is referred to a recent publication (NAS, 1986) for further information concerning progress in the National Climate Program.

1.2 Review of Project Problem Statements

Our climate can be thought of as a resource to man, as is the case, for example, when we say that the expected rainfall for an area is a resource for growing crops. Certain climatic phenomenon, on the other hand, take their toll on society--for example, excessive rainfall that causes flooding. Whether climate is considered a resource or a drain, better information about the climate in a more timely fashion will help decision makers to accurately assess the weather and climate effects.

1.2.1 Irrigation

More than 60 million acres of land are irrigated in the United States. Since the 1950s, in the High Plains region, most of the irrigation development has been based on ground water resources. Much of the increase in irrigation acreage since the 1960s has been due to the installation of center pivot irrigation systems. These systems are expensive to install and operate. The rapid growth of irrigation has been accompanied by declining ground water levels in many parts of the Plains. Cost of energy to pump ground water increased greatly during the decade following 1973. Overuse of water hastened the decline of the water tables, increased energy costs still further, and also contributed to environmental problems such as the leaching of minerals into the ground water system.

At the beginning of this project it was known that more efficient use of irrigation water and irrigation systems was possible. Commercial companies and university extension groups were already providing assistance to irrigators to help them determine the proper amounts and timing of irrigation applications. In Nebraska, the Agricultural Network (AGNET) interactive computer information service was providing ready access to irrigation "scheduling" programs. The most serious weakness in the available scheduling programs being used at that time appeared to lie in the uneven quality, frequency, representativeness and accessibility of the weather and climate information used in these programs.

1.2.2 Better ET Estimates and Monitoring Capability

Climate and weather know no state boundaries. It was obvious from the beginning of the project that the monitoring project would have to reach regional proportions before phenomenon like drought could be successfully monitored. Droughts occur with varying frequency and severity throughout the world. The High Plains region of North America is among the most frequently and most severely affected. Compared with efforts that have been made to warn citizens about flood and other natural hazards, relatively little had been done in the United States to systematically survey and warn of impending drought. Australia made considerable progress in developing a drought warning system (Lee, 1979). The lateness of the U. S. government response to the drought of 1976-77 was, in part, caused by difficulties encountered in identifying those areas that were most adversely affected. The rate at which drought developed in each affected area and the specific effects on crops and animals were difficult to assess at that time (Wilhite, 1983).

Regional cooperation in the collection and interpretation of weather and climate information appears necessary to adequately monitor and subsequently deal with drought adversity on the regional scale. Concentration on drought is especially appropriate because approximately 40% of all insurance indemnities for crop losses in the United States for the period 1939-78 were for that cause (Boyer, 1982). Further, one-quarter of the United States' land surface comprises soils that are subject to drought--the primary environmental limitation to crop production.

1.2.3 Problems with Drought Detection

The Palmer Drought Index (Palmer, 1965) is widely used by government agencies to indicate the extent and severity of drought. It is also used to assess the potential impact of drought on agriculture and water supply. Computation of the index requires data on precipitation and evapotranspiration (ET). The former is measured while the latter must be calculated from measured meteorological variables. The Thornthwaite method (1948) is used to estimate the ET term used in the Palmer Drought Index. ET estimated by Thornthwaite's method is a poor approximation of actual ET because it uses only two parameters--day length and temperature. There is considerable evidence (e.g., Rosenberg, 1974) that the Thornthwaite method severely underestimates evapotranspiration in regions other than those with humid climates. A better estimation of ET for such regions is provided by the Penman method (1948), and certain variations on it that have been calibrated in subhumid and semiarid regions. The Penman method requires measurements of solar radiation, air temperature, humidity and windspeed--data that can be provided by AWDN. Thus, improvements in the drought index were needed and could be implemented within the framework of AWDN.

Additionally, more than one index is needed to assess the affect of drought on all the major crops of the region. During the severe drought incident of June and July 1974 the dryland soybean crops in eastern Nebraska and western Iowa were virtually defoliated because very little water was available in the soil root zone. Corn plants wilted and dried up during this spell. When rain began in early August, the soybean crop revived, and, being indeterminant, it produced new leaves and flowers. A respectable soybean yield was achieved. In contrast, dryland corn produced little or no yield. One index cannot reflect both high and low yields; thus, in this instance, the Palmer drought index and its cousin, the crop moisture index, were inadequate as indicators of the potential impact of drought on the yield of specific crops. A similar incident occurred in 1977. Even with these weaknesses the Palmer Drought Index was still the principal criterion used by federal officials for declaration of drought disaster areas (Wilhite, 1983). New crop specific indices are needed that can account for differences in the crop's sensitivity (Nairizi and Rydzewski, 1977) to the atmospheric demands placed on it at any one time.

1.2.4 Need for Near-Real Time Monitoring Service

The final problem was the lack of an information system to provide timely and reliable information to media; the general public; and local, state and federal officials. An information system would include the systematic monitoring of weather and climate data, conditions of soil moisture availability, condition of crops and prospects for crop yield, and circumstances surrounding pasture and animal production. To minimize losses due to drought the user of the weather information needs to receive the information in a timely fashion. It was clear that no complete information system of this nature existed in the United States.

1.3 Objectives of the Project

By 1983, project planners had defined three new objectives: to demonstrate (promote?) regional cooperation in Nebraska, South Dakota, and Wyoming; to develop improved regional drought severity measures and crop-specific indices; and to extend the project to two additional states. The new objectives, which are discussed in greater detail in Appendix 2, were an outgrowth and a continuation of the original objectives.

II. THE AWDN SYSTEM

2.1 Expansion in the High Plains Region

In 1980 CAMaC undertook this NCPO-funded study to demonstrate and evaluate the use of climate information to support irrigation scheduling and other agricultural operations. Initially (in 1981), five stations were deployed in Nebraska to collect near-real time data for use in the project. The growth and development of this network (Hubbard et al., 1983) was rather rapid, owing to the fact that climatologists discovered interested parties in the private sector, local and state governments and the federal sector (ARS and others) who were willing to cooperate on climate problems of mutual concern for their collective benefit. Better, more timely information from the collection of near-real time weather data was a common goal. A natural expansion of this activity into the surrounding states occurred in subsequent years because regional-scale monitoring of drought and soil moisture was desired (see Table 1.). The cooperative nature of the network activity is underscored by the fact that NCPO did not purchase all of the stations in the network. The interested states, agencies, local governments and private sector businesses account for more than 80% of all stations purchased for the network.

Table 1. Annual expansion of the Automated Weather Data Network. Numbers in parenthesis represent stations closed.

Year	Number of Weather Stations			
	Nebraska	Cooperating States	TOTAL	NET
1981	5	-	5	5
1982	14	-	14	14
1983	17	4	21	21
1984	23	6	29	29
1985	26(1)	21	47	46
1986	32(1)	23(3)	55	50
1987*	33(2)	23	56	49

*As of May.

NCPO supported the regional expansion of the AWDN and the basic research necessary to develop monitoring techniques. When monitoring techniques include physical models together with a regional network such as AWDN, the result is a climate product that provides new information about climate impacts in areas like drought and crop yield assessment.

The AWDN has developed into a regional-scale research and service activity, based at the Center for Agricultural Meteorology and Climatology (CAMaC). Its development from the grass roots up has brought cooperators together in the early stages of development and ensured active participation of local government and the private sector. This evolution has helped to make the AWDN project successful. In particular, the AWDN has included a strong role for applied research and participation by cooperators on a volunteer basis.

2.2 Components of the AWDN System

The hardware and software components of the AWDN system have not remained static since the network began in 1980. Initially the system was designed around an IBM mini-computer, but as micro-computers that were both powerful and economical to maintain became available it was decided to redesign the system. In 1985 and 1986 a new AWDN operating system was designed and implemented on an IBM PC-AT. The new system is less costly and more flexible. The main hardware components[1] are shown in Table 2.

Table 2. The hardware for the AWDN computer and an AWDN station.

Central Office	Station
IBM PC-AT	Campbell CR21X (or CR10)micrologger
monochrome monitor	CM10 tripod
20 MB hard disk	022UDS Large enclosure
1.2 MB floppy disk	T107B thermister
360 KB floppy disk	T/RH207 thermistor/RH probe
Epson FX-80 printer	014A Met One wind sensor
2-20MB Bernoulli cartridge system	024A Met One wind vane
Microcom AX2400 modem	019 Cross Arm
Campbell PC201 card	015 Pyranometer Mount
Campbell PC203 power-up box	LI200S Licor silicon Pyranometer
HP-7470A plotter	LI2003S Licor Base and Level
	RG2501 Sierra Tipping Bucket (1mm)
	DC103A Answer Modem
	PCRC-11 1% RH chip
	41002-3 Gill radiation shield
	Assorted hardware

[1]Mention of manufacturer's name does not imply endorsement of a product over those offered by other manufacturers but is merely provided for the convenience of the reader.

Station placement is an important consideration. We have developed guidelines (shown in Appendix 3) on station siting which seem to satisfy our needs on the High Plains of the United States.

The weather data is transmitted by telephone communications to a mainframe computer (AGNET). Subscribers to AGNET are able to obtain the most recent weather data for use in irrigation scheduling and other operations. The linkages in our new Automated Weather Data Network (AWDN) are shown in Figure 1. The Center for Agricultural Meteorology and Climatology (CAMaC) computer system is the IBM PC-AT system described above.

The AWDN currently calls forty-nine stations. The current map for the AWDN is shown in Figure 2. A complete list of stations is shown in Appendix 4. We collect both hourly and daily data from each weather station. The data collection takes place during the early morning (approximately 1 a.m.). The capacity of the AWDN system as currently configured is well over 100 stations.

It was necessary to develop new data management tools for use with AWDN. In a word, what we aimed for with these new tools was flexibility. We have and will continue to promote seven "standard" sensors. Our "standard" sensors make up the backbone of our network and from them we take nine hourly readings. However, we wanted the flexibility to employ other sensors, if it were deemed necessary, without rewriting the software used in the AWDN system. The data loggers employed by the network do not present any obstacle here except that an upper limit does exist on the number of sensors that can be attached at a given station.

The weather station data loggers provide a programmable interface for other sensors that we use. When such sensors are installed at the field site, the data logger must be programmed to make measurements on a fixed time interval. The programs and wiring schematics that are used at the Mead and Lincoln (Nebraska) stations are shown in Appendix 5 and 6, respectively.

Our data management system is designed so that a unique measurement receives a code. Some of the codes that we have assigned are shown in Appendix 7. The standard codes for hourly data from a station are 100, 200, 300, 400, 500, 600, 700, 800 and 900. At research sites there is often a need for a special measurement of some type. As you can see from Appendix 7, we can easily accommodate such special measurements (e.g., Shadow Band Radiation, Code 1000).

Every station that we call has its own station information file (SIF). The SIFs for the Mead and Lincoln stations are shown in Appendix 8 and 9, respectively. In addition to giving location and information for the station and describing the raw data tables produced by the station, these files also track the important events that occur with respect to that station. The last data to be received from the station, the last data to be quality controlled by AWDN, and the last data sent to AGNET are tracked by the system and recorded in the SIF file. The file also describes how the data logger in the field is programmed. The importance of this information becomes clearer when one understands the data storage methods that we employ.

Suffice it to say that the software we have developed needs the SIF file for each station so that it can build sufficient space into the master file for the various measurements being collected. Many housekeeping chores like archiving data require the SIF file to efficiently schedule data storage and transmission.

The software is supported in an automated framework, as shown in Figure 3. In this diagram, circles represent larger computers to which we are linked. Ovals (ellipses) are software programs that accomplish certain of the automated tasks. The rectangles are data files that are used by the AWDN system for various purposes. The TELCOM software is available commercially from Campbell Scientific, Inc. (see footnote 1), and is used to retrieve raw data from the stations. The raw data files (F:SXX.DAT) are then converted by the CONV program to the MASTER data file. Data from federal networks is also retrieved through the use of the XTALK AFOS program and converted to the

MASTER data file via CAFOS. Quality control tests (QCTEST) are then performed on all of the data collected. Finally, a data file is prepared by the BAGFIL program and transferred by the XTALK UPAGNET program to AGNET.

Quality control consists of performing various procedures on each of the measurements collected. Some of the procedures are shown in Appendix 10. For code 110 (maximum air temperature) you will see a comparison code (111) immediately to its right. The 111 code is for minimum air temperature and the comparison is to check that the maximum does indeed exceed the minimum. The code is further compared against an upper and lower limit. For maximum air temperature the limits are +40C to -20C. The procedures actually performed on all measurements with code 110 are procedure 5 and 7. The quality control program currently uses 12 procedures, which are defined in Appendix 11.

When the quality control procedures indicate erroneous data or the data is found to be missing, the quality control software makes estimates from surrounding stations by use of an inverse weighting function according to distance from the station (see Goodin et al., 1979, or Johnson, 1982, for reference to this technique).

Calibration and maintenance are very important components of the AWDN system. For the standard sensors, maintenance consists of the following:

Anemometer--replacement of bearings every 12-24 months.

Wind vane--field check of the potentiometer for 0° to 360° range and readjustment of the calibration coefficients or replacement of the potentiometer.

Pyranometer--recalibration annually (Hubbard et al., 1987a).

Humidity--replacement of hygroscopic chip annually at the beginning of the growing season.

Soil temperature--check for 0°C during the freeze-thaw cycle.

Precipitation--field test of the tipping mechanism with a known amount of water and adjustment when necessary.

Maintenance involves approximately four site visits per year. One is scheduled in the fall and one in the spring. The remaining two are made at opportune times that correspond to the need for station repairs at the site or a nearby station. The grass is trimmed during these visits and the bare soil plot is checked. Bare soil is maintained by use of a soil sterilizer between visits. All equipment and instrument shelters are checked visually and cleaning is performed as necessary.

The new configuration of the AWDN system has worked quite well. The computer communicates with the remote stations through the telephone network. During the course of developing the AWDN system we have had some success with Radio Frequency (RF) communications where telephone lines were not feasible. In some cases we have used tape recorders to store the data on site, but this has not been as satisfactory as the RF or telephone linkages for our purposes. The main drawback to tape recorders in our experience was the lack of daily contact with the station and delays in needed maintenance.

2.3 Transferability of AWDN Technology Outside the High Plains Region

A description of AWDN would not be complete without a discussion of possible changes that may be required to apply the technology outside of the High Plains area where it was developed. As mentioned in the previous section, the system software was designed to be flexible. The data logger is already in wide use and the AWDN system would easily adapt to other regions without changing the basic software.

In other environments it might be necessary to develop other quality control procedures and/or calibration methods. The latter is highly dependent on the type of sensors employed as well. If the system were to be employed in a very humid climate, one would certainly consider using a different humidity sensor.

In general, the AWDN was developed for the environment of the High Plains but, if it were to be used in another environment, we assume it would work well if the climatic extremes were not greatly different from those encountered on the High Plains.

III. RESEARCH TO TAKE ADVANTAGE OF NEW AWDN SYSTEM

Evaluations were made of the degree of improvement possible in weather-related information products and of the real potential for irrigation scheduling applications. During recent years, attempts have been made to obtain user feedback on the existing products and make improvements in these products (Hubbard et al., 1985, and Meyer et al., 1986).

Supalla and Rempe (in Rosenberg et al., 1983) surveyed irrigators to determine their current scheduling practices and to study the potential for improved scheduling practices. Of the potential barriers to adoption of more exact scheduling methods, lack of knowledge was found to be most important. Irrigators considered the availability of weather data and better estimates of evapotranspiration as important aids to improved scheduling. An education program focusing on irrigators who farm coarse-textured soils, have high-yielding wells and pump their irrigation water from great depths was proposed as the most effective means of increasing the use of scientific irrigation scheduling in Nebraska. Hubbard and Klocke (1986) discussed the concept of using near-real time data in irrigation scheduling.

Studies to determine the accuracy of evapotranspiration formulas were carried out by Norman and Nielsen (in Rosenberg et al., 1983). It was found that the use of the daily Penman model in irrigation scheduling is acceptable.

Systematic errors may occur during a regular cycle of wetting and drying, but the positive errors appear to cancel the negative errors.

User feedback was obtained (Meyer et al., 1986) to determine what improvements in near-real time products or, alternatively, what new products were desirable. It was found that better ET projections were needed. Other studies to determine the affect of random and systematic error in weather measurements on the accuracy of the resulting ET calculation have also been conducted (Meyer et al., 1987a). It was found that solar radiation and humidity errors would cause the largest decrease in accuracy of the ET calculation. We have also evaluated the use of weather service forecasts in ET projections (Meyer et al., 1987b). Improvements in the forecast of NWS variables would increase the accuracy.

A study of the spray loss above a sprinkler irrigated canopy was undertaken by Thompson and Spurgeon (in Rosenberg et al., 1983). It was determined that the applications could be made more uniformly if the speed of rotation of the center pivot irrigation system were adjusted (lower for high spray loss situations and higher for low spray loss situations).

Other special studies have been carried out to utilize the new system in various ways. After the development of improved products for irrigation scheduling, NCPO supported applied research to examine the feasibility of monitoring drought and other climatic phenomena with the AWDN (Hubbard, 1987a). This work is aimed at monitoring the affect of recent weather on specific crops and particularly during drought. The first crop-specific weather index was developed for winter wheat (Booysen, 1987).

Related studies, not funded by NCPO but working toward a product for use with AWDN involve work in integrated pest management. One example of this work is a project that aims to predict the population of spider mites in corn.

Earlier work showed that mite development is closely related to environmental conditions in the corn field (Perring et al., 1984, and Toole et al., 1984). Field studies are being conducted and models developed that can predict the temperature and humidity conditions inside corn fields; such predictions are based on hourly data from nearby AWDN stations and the irrigation history of the field of interest (Sagar, 1987).

The above studies provide evidence that excellent capability exists to monitor weather data on the High Plains in near-real time, perform meaningful analyses, and disseminate information to a large audience of users (i.e., perform climate services) in real time. The studies performed at CAMaC have been well received, having produced useful products for use by the extension service, consultants, other business personnel and the public.

IV. NEAR-REAL TIME CLIMATE SERVICES

Subscribers to the AGNET system are able to take advantage of the near-real time data through a variety of computer products. These are:

BEEFGROWER--simulates the performance of beef cattle in the feedlot given the near-real time weather data and a projection of what the future weather will be like.

BINDRY--estimates drying time in a natural air grain-drying system and the rate at which grain can be loaded into the bin.

CROPSTATUS--allows users to select from twenty up-to-date weather summaries related to crops and animals.

ET--calculates Penman evapotranspiration for selected times and crops by stations, regions and/or states.

IRRIGATE--forecasts the irrigation schedule on a field-by-field basis; based on user-recorded rainfall, previous irrigations and soil moisture, and the recent weather conditions from the AWDN.

NEWSRELEASE--allows user to select from weather advisory released by University experts, predetermined maps of precipitation and temperature and the five- and ten-day National Weather Service forecast.

WEATHER--provides listings and/or maps of weather data for AWDN and AFOS weather data.

Access to these products has reached a significant level, as can be seen by examining Table 3. The number of accesses will vary from year to year depending on the type of weather experienced by producers and other users. Streamlining of software also results in a change in access patterns, as is the case with ET and IRRIGATE. ET has been revised each year to gradually provide more and better information; as a result, use of the IRRIGATE program has gradually decreased. Although no attempt has been made to assess the total time that AGNET users are spending with these products, it is quite apparent that a significant frequency of use has been attained over the past four years.

Table 3. Access to weather based products on the AGNET system.

Product	1983	1984	1985	1986
BEEFGROWER	5276	4973	4482	3769
BINDRY	589	1273	1075	172
CROPSTATUS	NA	3654	1847	1447
ET	1032	1067	1319	1529
IRRIGATE	821	330	98	60
NEWSRELEASE	1596	2219	485	1587
WEATHER	2619	2643	1481	3894
TOTAL	11933	15859	10787	12458

A complete benefit to cost analysis for the services rendered by the near-real time weather-based products is beyond the scope of the work undertaken here. An example of the benefit of using WEATHER, ET or IRRIGATE in scheduling Nebraska center pivots is compared below to the cost of operating the network.

POTENTIAL BENEFIT TO COST FOR USING AWDN DATA
TO SCHEDULE CENTER PIVOTS IN NEBRASKA (1986 Economy)

$$\text{BENEFIT/COST} = \frac{\text{SAVINGS REALIZED DUE TO FEWER IRRIGATIONS}}{\text{COST OF OPERATING THE AWDN}}$$

$$= \frac{\text{cost/acre (pivot acreage) (cycles saved)}}{\text{(number stations) (operating cost)}}$$

$$= \frac{\$6\text{/acre (2,888,000 acres) (cycles saved)}}{35\ (\$1100)}$$

Cycles Saved*	Benefit/Cost
1	450/1
2	900/1
3	1350/1

*Function of growing season weather

It is apparent from this example that the cost of operating AWDN is minor compared to the benefits that can be derived. Other products of the work undertaken here include the reports and presentations prepared in an effort to transfer this technology into the public sector. A listing of this activity is given in Appendix 12. In addition to the publications mentioned, there are many theses and dissertations completed and in progress that are using the data from the AWDN.

V. CONCLUSIONS AND RECOMMENDATIONS

It is concluded for this study that there is a major role for near-real time weather data to play in today's agricultural production on the High

Plains. It would appear that a significant user audience will develop when timely products dealing with phenology (crops and pests), crop water use, livestock production and crop status (drought and yield) are made available.

It is recommended that the National Climate Program Office promote the use of Automated Weather Data Networks in other regions. Development of products that utilize the near-real time data, assessment of user needs and integration with existing climate networks and archives must also be supported. The economic and sociologic character of a region will dictate the number of near-real time stations needed and the use to which the resulting data is put. However, data collection and quality control may vary little from region to region so it is suggested that a large savings could be realized by transferring the existing AWDN system to other regions.

VI. REFERENCES

Booysen, J. 1987. A crop specific drought index for wheat. Ph.D. Dissertation in progress.

Boyer, J. S. 1982. Plant productivity and environment. Science 218:443-448.

Goodin, W. R., G. J. McRae and J. H. Seinfeld. 1979. A comparison of interpolation methods for sparse data: Application to wind and concentration fields. J. Appl. Meteorol. 18:761-771.

Hubbard, K. G. 1987a (in press). Surface weather monitoring and the development of drought and other climate information delivery systems. The International Drought Symposium Workshop. Lincoln, NE.

Hubbard, K. G., L. Navarro and J. Schmidt. 1987b (in preparation). Calibration of pyranometers for use in an Automated Weather Data Network. J. Clim. and Appl. Meteorol.

Hubbard K. G., N. J. Rosenberg and D. C. Nielsen. 1983. An automated weather data network in support of agricultural operations. J. Water Resources Planning and Management. 109:213-222.

Hubbard, K. G. and N. L. Klocke. 1986. Climate and irrigation in Nebraska. Preprint Volume of the Conference on Climate and Water Management - A Critical Era. Amer. Meteor. Soc., Boston, Mass. pp. 33-35.

Hubbard, K. G., N. J. Rosenberg, D. A. Wilhite, S. J. Meyer, J. J. Schmidt and J. R. Hines. 1985. An assessment of near real time users of information from the Automated Weather Data Network. CAMaC Progress Report 85-4. 20 pp.

Johnson, G. T. 1982. Climatological interpolation functions for mesoscale winds. J. Appl. Meteorol. 21:1130-1136.

Lee, D. M. 1979. Australian drought watch system. In: M. T. Hinchey (ed.), Botswana Drought Symposium, pp. 173-187. Clark University Press.

Meyer, S. J., K. G. Hubbard, N. J. Rosenberg and D. A. Wilhite. 1986. Improving Nebraska's near-real time weather-based products through user interaction. CAMaC Progress Report 86-4. 239 pp.

Meyer, S. J., K. G. Hubbard and D. A. Wilhite. 1987a. (submitted). The effect of random and systematic errors in the variables used to estimate potential evapotranspiration by the Penman method.

Meyer, S. J., K. G. Hubbard and D. A. Wilhite. 1987b. (in preparation) Improving projected potential evapotranspiration estimates using National Weather Service forecasts.

Nairizi, S. and J. R. Rydzewski. 1977. Effects of dated soil moisture stress on crop water yields. Exp. Agric. 13:51-59.

NAS. 1986. The National Climate Program; Early Achievements and future directions. National Academy Press. 55 pp.

Palmer, W. C. 1965. Meteorological drought. U.S. Department of Commerce, Weather Bureau, Research Paper No. 45.

Penman, H. L. 1948. Natural evaporation from open water, bare soil and grass. Proc. Roy. Soc. Amer. 193:120-145.

Perring, T. M., T. O. Holtzer, J. L. Toole, J. M. Norman and G. L. Myers. 1984. Influences of temperature and humidity on pre-adult development of the Banks grass mite. Environ. Entomol. 13:338-343.

Rosenberg, N. J. 1974. Microclimate: The Biological Environment. John Wiley & Sons, New York. pp. 187-188.

Rosenberg, N. J., K. G. Hubbard, J. M. Norman, R. J. Supalla, T. L. Thompson, D. C. Nielsen, D. Rempe, W. E. Spurgeon, and J. R. Hines. 1983. A demonstration and evaluation of the Use of Climate Information to Support Irrigation Scheduling and Other Agricultural Operations. CAMaC Progress Report 83-1. 125 pp.

Sagar, R. 1987. An approach to defining the spider mite environment in a corn canopy. Masters Thesis in progress.

Thornthwaite, C. W. 1948. An approach toward a rational classification of Climate. Geography Rev. 38:55-94.

Toole, J. L., J. M. Norman, T. O. Holtzer and T. M. Perring. 1984. Simulating Banks grass mite population dynamics as a subsystem of a crop canopy-microenvironment model. Environ. Entomol. 13:329-337.

Wilhite, D. A. 1983. Government response to drought in the U.S. with particular reference to the Great Plains. J. Clim. and Appl. Meteorol. 22:40-50.

Appendix 1. Project Objectives 1980-1982

Under the direction of CAMaC researchers the University of Nebraska undertook a demonstration project in 1981 to use climate data in near-real time. The objectives of this project (entitled "A Demonstration of the Use of Climate Information to Support Irrigation Scheduling and Other Agricultural Operations") were:

1. To test a prototype information system providing current weather data, archived-climate data and soils data to support irrigation scheduling services provided to Nebraska farmers by the AGNET system (note: AGNET is a user-friendly information system that now offers more than 200 software packages as well as market news and reports).

2. To test the same information system in support of other agricultural operations in Nebraska and other Great Plains states for which improved climate information support is potentially of value.

3. To plan and carry out engineering and economic evaluations that:

    a. measure the sensitivity of information products and recommendations to the kinds of data provided by the prototype system;

    b. estimate costs and potential benefits of irrigation scheduling services with and without improved climate information, in terms of water saved, energy conserved and crop yields achieved as a basis for a decision on whether or not to install an operational system;

    c. assess potential for water and energy conservation in Nebraska through improved irrigation scheduling and, possibly, for the Great Plains region.

Appendix 2. Project Objectives 1983-1986

1. To demonstrate regional cooperation in Nebraska, South Dakota and Wyoming by:

   a. collecting and exchanging near-real time weather and climate information;

   b. integrating the AWDN and AFOS data into summaries and products as needed to prepare advisories on current weather-related agricultural problems;

   c. evaluating the costs and benefits of a regional weather and climate information network for coping with climate adversity.

2. To develop improved quantitative measures of drought severity and crop-specific indices for identifying regional impacts of drought.

3. To demonstrate regional cooperation in Nebraska, South Dakota, Wyoming, Kansas and Colorado by expanding the collection and exchange of near-real time weather and climate information to two additional cooperating states.

Appendix 3. Automated Weather Data Network: Station Placement

The stations in the automated weather data network are placed at intervals of about 50 miles to represent the macroclimate of the state or, in other words, the climate of large areas of the state.

Stations at this spacing can certainly be expected to give relatively large differences in readings even when experiencing the same air mass because they represent areas that are very different in character. Stations in a large valley would be expected to have lower average wind speed, higher humidity, and so forth, than stations outside the valley. Even so, stations at this spacing will be statistically correlated. This fact should allow someone working midway between two stations to (with some experience) use one or both of the nearby stations with constant adjustment factors.

When possible, stations are placed in a rural environment to establish a reference for the surrounding area. Stations are generally located at some distance from isolated irrigated fields because the microclimate in such fields will vary considerably with the specific irrigation schedule. Hopefully, measurements from the stations reflect the average characteristics of air in a given vicinity and can be used as a reference point for irrigators, dryland farmers, ranchers and businessmen alike.

The stations in the network are located so as to avoid measurement of microclimate. For this reason, stations are placed over grass, using the assumption that microclimatic features of the underlying surface disappear at about 4 times the surface height (our sensors are 5 to 6 times the height). The grass surface is mowed from time to time to ensure that it does not exceed 12 inches in height. Microclimates that exist because of tall trees, buildings or nearby terrain features are also avoided. Stations are located a distance away from such features equivalent to 6 to 10 times their height. A fetch of this length is assumed to be sufficient, although greater fetch is desirable. Sites that represent mesoclimates (i.e., small valleys, depressions and tops of hills) are also avoided.

Reference stations will be helpful to researchers who will one day want to apply their results to wide areas and who typically make weather measurements in or above a specific field of interest. To arrive at the best applications, the total environment must be considered. The microclimate is important because it is the local environment of the crop, insect, and so forth. The microclimate inside a field does vary with variations in the macroclimate, making it important as well. Of primary importance, however, is the fact that on a large scale it is only practical to measure the macroclimate; therefore, the majority of climate networks are measuring macroscale features of the climate.

Appendix 4. Weather Stations in AWDN

	#	Name	Elevation (m)	Latitude (N)	Longitude (W)	Start-up (mo/day/yr)	Ending Date (mo/day/yr)
255369	1	Mead	366	41 08	96 30	5/19/81	
251229	2	Brule	1029	41 03	101 55	5/21/81	1/12/87
251599	3	Champion	1029	40 23	101 43	5/20/81	
255319	4	McCook	792	40 14	100 35	5/21/81	
252319	5	Dickens	945	41 00	100 56	5/21/81	
250369	6	Arthur	1097	41 39	101 31	2/13/82	
259209	7	West Point	442	41 49	96 49	5/15/82	
257519	8	Sandhills Ag Lab	975	41 37	100 49	6/02/82	11/11/85
257899	9	South Central	552	40 32	98 09	7/14/82	
256019	10	North East	445	42 23	96 59	7/16/82	
256489	11	Panhandle	1244	41 51	103 41	8/21/82	
256079	12	North Platte	922	41 04	100 45	9/15/82	
253479	13	Gudmundsen's	1049	42 24	101 26	10/05/82	
257839	14	Sidney	1317	41 14	103 00	12/01/82	
254699	15	Lincoln-Havelock	351	40 50	96 40	5/05/83	
257249	16	Roger's Farm	347	40 49	96 41	6/04/83	11/12/86
256339	17	Ord	625	41 36	98 57	7/10/83	
050119	18	Akron, CO	1384	40 09	103 09	10/13/83	
391079	19	Brookings, SD	500	44 19	96 46	7/08/83	
393229	20	Gettysburg, SD	568	44 59	100 17	8/29/83	
397049	21	Redfield, SD	395	44 53	98 23	7/12/83	
253399	22	Grant	975	40 51	101 40	5/22/84	
250059	23	Ainsworth	765	42 33	99 52	6/04/84	
253299	24	Gibbon	625	40 42	99 00	12/04/84	
253359	25	Gordon	1109	42 48	102 10	10/18/84	
257849	26	Silverthorn	1302	41 32	102 47	9/01/84	
254459	27	Kingsley Dam	1008	41 13	101 39	11/01/84	
391619	28	Chamberlain,SD	427	43 48	99 20	12/11/84	
391129	29	Buffalo Gap, SD	981	43 30	103 19	11/14/84	6/26/86
256299	30	ONeill, NE	670	42 28	98 39	7/17/85	
144959	31	Manhattan, KS	320	39 12	96 35	1/01 85	
147399	32	Silver Lake, KS	271	39 06	95 50	3/28/85	
146139	33	Ottawa, KS	277	38 37	95 17	3/28/85	
146249	34	Parsons, KS	277	37 22	95 17	3/28/85	
143599	35	Hesston, KS	412	38 08	97 24	3/28/85	
147169	36	Sandyland, KS	564	37 56	98 46	3/28/85	
142979	37	Garden City, KS	866	37 59	100 49	3/28/85	
147239	38	Tribune, KS	1101	38 28	101 46	3/28/85	
141689	39	Colby, KS	966	39 23	101 04	3/28/85	
143529	40	Hays, KS	610	38 52	99 20	3/28/85	
147259	41	Scandia, KS	451	39 47	97 47	3/28/85	
487239	42	Pine Bluffs, WY	1554	41 11	104 06	4/01/85	
489619	43	Wheatland, WY	1417	42 05	104 57	4/01/85	
257529	44	Sandhills #2	975	41 37	100 49	7/15/85	3/25/87
144969	45	Manhattan #2	320	39 11	96 36	7/15/85	11/13/86
257119	46	Rising City	375	41 12	97 20	7/27/85	
394869	47	Lemmon, SD	792	45 56	102 10	9/19/85	6/19/86
258449	48	Tarnov	472	41 35	97 34	6/04/86	
130209	49	Ames #1	305	42 02	93 45	7/01/86	
130219	50	Ames #2	305	42 02	93 45	8/01/86	

255368	51	Mead Turf Farm	366	41 08	96 30	8/01/86
252109	52	UNSTA Curtis	784	40 38	100 31	8/05/86
254669	53	Lexington	731	40 47	99 45	8/05/86
251569	54	Central City	517	41 07	98 00	8/15/86
258049	55	Lincoln IANR	383	40 46	96 39	9/17/86
250259	56	Arapahoe Prairie	1097	41 22	101 40	2/02/87

Appendix 5. Program for CR21 at the Mead Agricultural Meteorology Laboratory

Input Table:

Param. No.	Entry	Description	Units
	*4		
11:	2	Pyranometer Program	
12:	XXX	Multiplier (M) (calibrated)	W/m^2
13:	XX	offset (o)	
21:	7	Soil Temperature, Grass-10 cm.	°C
22:	1	M	
23:	0	o	
31:	7	Soil Temperature, Mulch-10 cm.	°C
32:	1	M	
33:	0	o	
41:	7	Air Temperature (1.5 m)	°C
42:	1	M	
43:	0	o	
51:	8	Relative Humidity (1.5 m)	%
52:	1	M	
53:	0	o	
61	7	Soil Temperature, Bare-10 cm.	°C
62:	1	M	
63:	0	o	
71:	3	Wind Vane (3 m)	
72:	360	M (calibrated near 360°)	deg.
73:	0	o (calibrated near 0)	

Param. No.	Entry	Description	Units
81:	6	Anemometer (3 m)	
82:	.0133	M (calibrated near .0133)	m/sec.
83:	.447	o (calibrated near .447)	
91:	6	Raingage	
92:	1	M	mm
93:	0	o	

Output Table #1:

Param. No.	Entry	Description	Units
	*1		
03:	60	Store hourly	
11:	51	Average Air Temperature, hourly	°C
12:	4	channel	
13:	0	---	
21:	51	Average Relative Humidity, hourly	%
22:	5	channel	
23:	0	---	
31:	51	Average Soil Temperature, bare-10 cm	°C
32:	6	channel	
33:	0	---	
41:	56	Wind Vectors (4 outputs)	
42:	8	channel of anemometer	
43:	7	channel of wind vane	
51:	51	Average Solar Radiation, hourly	W/m^2
52:	1	channel	
53:	0	---	
61:	52	Total Rainfall, hourly	mm
62:	9	channel	
63:	0	---	
71:	51	Average Soil Temperature, grass-10 cm	°C
72:	2	channel	
73:	0	---	

Param. No.	Entry	Description	Units
81:	51	Average Soil Temperature, mulch-10 cm	°C
82:	3	channel	
83:	0	---	

Output Table #2:

Param. No.	Entry	Description	Units
	*2		
03:	1440	Store daily	
11:	53	Maximum Air Temperature, Daily	°C
12:	4	channel	
13:	0	---	
21:	54	Minimum Air Temperature, Daily	°C
22:	4	channel	
23:	0	---	
31:	53	Windspeed Maximum and Time	m/s
32:	8	channel	HH:MM
33:	1	do time	
41:	71	Average Vapor Pressure, Daily	kPa
42:	4	channel Ta	
43:	5	channel RH	
51:	0	Average Vapor Pressure Deficit	kPa
52:	3	---	
53:	0	---	
61:	52	Total Rainfall, 24 hrs.	mm
62:	9	channel	
63:	0	---	
71:	50	Sample Battery Voltage	mV
72:	0	channel	
73:	0	---	

Appendix 6. Program for CR21X at Lincoln, NE, Horticultural Field Site

Input for Table 1:

Param. No.	Entry	Description
	*1	Enter Input Table 1
1:	60	Update Interval (sec.)
1:P	11	Pgm. for 107 Probes (air and soil)
1	4	Repetitions
2	1	Input Channel
3	1	Excite Channel
4	1	Input Storage Location
5	1	Multiplier
6	0	Offset
2:P	12	Pgm. for 207 R.H. Probe
1	1	Repetitions
2	5	Input Channel
3	1	Excite Channel
4	1	Input Location for First Temp. Compensation
5	5	Input Location for First R.H.
6	1	Multiplier
7	0	Offset
3:P	4	Pgm. for Wind Vane
1	1	Repetitions
2	5	Range Code
3	9	Input Channel
4	2	Excite Channel
5	5	Delay in 1/100 Sec.

Param. No.	Entry	Description
6	1000	Excite in mV
7	6	Input Storage Location
8	.7176	Multiplier (unique to instrument, see note 1)
9	0	Offset
4:P	1	Pgm. for Pyranometer
1	1	Reps.
2	2	Range Code
3	11	Channel of First Measurement
4	7	Input Location of First Measurement
5	XXX	Multiplier (unique to instrument, see note 2)
6	XX	Offset (unique, zero if new)
5:P	3	Pgm. for Anemometer (pulse)
1	1	Repetitions
2	17	Input Channel
3	2	Configuration (switch closure)
4	8	Input Storage Location
5	.0133	Multiplier for 60 Sec. Interval (see note 3)
6	.477	Offset (.477 for new)

Note 1 - Wind vane must be calibrated with CR21X by operator.

Note 2 - LI-COR provides a calibration constant, C, which must be altered to obtain a multiplier which will yield average watts per meter square: m = 10,000/C [W/m^2] (i.e., if C = 58.1 mA/1000 W/m^2 then: m = 10,000/58.1 = 172.1 W/m^2).

Note 3 - Anemometer multiplier for 60-second interval in meter/sec. is = .7980 ÷ 60 = .0133 (when new).

Param. No.	Entry	Description
6:P	3	Pgm. for Raingage (pulse)
1	1	Repetitions
2	18	Input Channel
3	2	Configuration
4	9	Input Storage Location
5	1	Multiplier (=1 For Raingages with 1 tip/mm)
6	0	Offset
7:P	92	Pgm. Control (if time)
1	0	60 Min. Interval
2	60	Time Interval (min.)
3	10	Command
8:P	77	Output Processing (Record Time)
	100	Store Julian
9:P	77	(Record Time)
	10	Hour - min.
10:P	71	Output Processing (Average) - Air Temp.
1	1	Repetitions
2	1	Input Location
11:P	71	R.H.
1	1	
2	5	
12:P	71	Soil Temp.
1	1	
2	2	

Param. No.	Entry	Description
13:P	76	Output Processing - Wind Vector
1	1	
2	0	
3	8	
4	6	
14:P	71	Pyranometer (Average)
1	1	
2	7	
15:P	72	Rain Gage (Total)
1	1	
2	9	
16:P	71	Air #2, Soil #2, Temperatures (Average)
1	2	
2	3	

To set CR21X Clock:

Param.	Entry	Description
	*5	Display current time
05:	XX	Enter year
05:	XXXX	Enter Julian day
05:	HH:MM	Enter hours:minutes

PROGRAM FOR CR21X

Input for Table 2:

Param. No.	Entry	Description
	*2	
1:	60	Execution Interval of 60 Sec.
1:P	92	Pgm. Control (If time)
1	0	Time into Interval
2	1440	Time Interval (Min.)
3	10	Command
2:P	73	Output Max. Air Temp. #1
1	1	Reps.
2	00	No Time of Max.
3	1	Input Location of Air Temp.
3:P	74	Output Min. Air Temp. #1
1	1	Reps.
2	00	No. Time of Min.
3	1	Input Location
4:P	73	Output Max. Wind Speed and Time
1	1	Reps.
2	10	Time of Max. (HHMM)
3	8	Input Location of Anemometer
5:P	56	Calculate Sat. Vapor Press.
1	1	Input Location of Air Temp.
2	11	Input Destination of ES
6:P	36	Processing: Z = RH * ES

Param. No.	Entry	Description
1	5	Loc. of RH
2	11	Loc. of ES
3	12	Destination Loc. of Z
7:P	30	Load Fixed Data
1	100	Fixed Data, F
2	13	Destination Loc. of F
8:P	38	EA= Z/F (EA = Vapor Pressure, kPa)
1	12	Loc. of Z
2	13	Loc. of F
3	14	Destination Loc. of E
9:P	35	ED = ES-EA (ED = Vapor Pressure Deficit, kPa)
1	11	Loc. of ES
2	14	Loc. of EA
3	15	Destination of ED
10:P	71	Output Average EA and ED
1	2	Repetitions
2	14	Starting Input Location
11:P	10	Read Battery Voltage
1	16	Input Location
12:P	70	Sample Battery
1	1	Reps.
2	16	Input Loc.

CR21X Channel Configuration

Channel

1. **Air Temperature** #1
2. **Soil Temperature** #1 (Bare Soil-10 cm. depth)
3. **Air Temperature** #2 (1000' Away)
4. **Soil Temperature** #2 (Turf-10 cm. depth)
5. **Relative Humidity**
6. (for additional relative humidity)
7.
8.
9. **Wind Vane**
10.
11. **Pyranometer**
12. (for additional pyranometer)
13. (for P.A.R. probe)
14.
15.
16.
17. **Anemometer**
18. **Rain Gage**
19.
20.

Appendix 7. AWDN Variable Codes-Revised 10-22-1986
(This is a List of Variab.cod file)

Code Number	Description	Units
100	Average Air Temperature (1.5m)	Celsius
109	Sample Air Temperature	Celsius
110	Maximum Air Temperature (1.5m)	Celsius
111	Minimum Air Temperature (1.5m)	Celsius
120	Maximum Air Temperature (1.5m)	Farenheit
121	Minimum Air Temperature (1.5m)	Farenheit
122	12-hour Min. Air Temp. (1.5m)	Farenheit
130	Time of Maximum (110 or 120)	HHMM
131	Time of Minimum (111 or 121)	HHMM
140	Average Air Temperature (2 cm)	Celsius
141	Maximum Air Temperature (2 cm)	"
142	Minimum Air Temperature (2 cm)	"
150	Average Air Temperature (3 cm)	"
151	Maximum Air Temperature (3 cm)	"
152	Minimum Air Temperature (3 cm)	"
200	Average Relative Humidity (1.5m)	%
201	Average Relative Humidity #2 (1.5m)	%
209	Sample Relative Humidity (1.5m)	%
219	Maximum Humidity (1.5m)	%
220	Minimum Humidity (1.5m)	%
229	Time of Maximum Humidity	HHMM
230	Time of Minimum Humidity	HHMM
300	Average Soil Temperature (10cm)	Celsius
301	Average Soil Temperature (5cm)	Celsius
302	Sample Soil Temperature (5cm)	Celsius
303	Sample Soil Temperature (20cm)	Celsius
304	Sample Soil Temperature (50cm)	Celsius
305	Sample Soil Temperature (100cm)	Celsius
306	Sample Soil Temperature (180cm)	Celsius
309	Sample Soil Temperature (10cm)	Celsius
319	Maximum Soil Temperature (10cm)	Celsius
320	Minimum Soil Temperature (10cm)	Celsius
329	Maximum Soil Temperature (5cm)	Celsius
330	Minimum Soil Temperature (5cm)	Celsius
339	Time of Max Soil Temp (10cm,319)	HHMM
340	Time of Min Soil Temp (10cm,320)	HHMM
350	Average Soil Temp under grass(10cm)	Celsius
351	Average Soil Temp under grass(2.5cm)	Celsius
352	Maximum Soil Temp under grass(2.5cm)	"
353	Minimum Soil Temp under grass(2.5cm)	"
360	Average Soil Temp under mulch(10cm)	Celsius
370	Average Air Temp above grass (5cm)	"
371	Maximum Air Temp above grass (5cm)	"
372	Minimum Air Temp above grass (5cm)	"
380	Average Soil Temp under corn (75cm)	"
400	Average Wind Speed (3m)	m/s
500	Wind Vector Magnitude (3m)	m/s

509	Maximum Wind Speed (3m)	m/s
510	Time of Maximum Wind Speed	Minutes past midnight
519	Maximum Wind Speed (10m)	m/s
520	Time of Maximum Wind Speed	HHMM
600	Wind Vector Direction (3m)	degrees from North
609	Wind Average Direction (3m)	Degrees
700	Vector Standard Deviation (3m)	degrees
800	Total Radiation (2m)	Watts/m**2
801	Total Radiation #2 (2m)	Watts/m**2
809	Total Radiation (2m)	Langleys
900	Total Precipitation	mm
901	Total Precipitation	inches
920	Snow Depth	inches
930	Total Precipitation 24 hrs	mm
1000	Shadow Band Radiation (2m)	Watts/m**2
1100	PAR-Photosyn. Active Radiation (2m)	uE/m**2
1101	Photosyn. Irrad	Watts/m**2
1200	Infra-Red Eq. Temperature (corn)	Celsius
1300	Average Vapor Pressure	Kilopascal
1301	Vapor Pressure Deficit	Kilopascal
1800	Net Radiometer	W/m**2
1900	Eppley Downward	W/m**2
1901	Eppley Upward	W/m**2
2000	Everest Nadir	C
2030	Everest-thirty degrees	C
2040	Everest-corn-70 degrees	C
2041	"	"
2042	"	"
2043	"	"
3000	Pyrgeometer (up)	W/m**2
3005	Pyrgeometer's temperature	C
3010	Pyrgeometer (down)	W/m**2

Appendix 8. Station Information File (SIF) for Mead

```
*************************************************************
*                                                           *
*                STATION SPECIFICATIONS                     *
*                     f:s01 .SIF                            *
*                                                           *
*************************************************************
```

STATION NAME:	MEAD
STATE NAME:	NEBRASKA
LATITUDE:	41.08
LONGITUDE:	96.30
ELEVATION (M):	366.00
STATION #:	5369
STATE #:	25
AGNET STATION #:	1
DATA LOGGER CLOCK ERROR (MINS.):	0
TIME ZONE DIFFERENCE (MINS.):	0
DATA EXCLUSION WINDOW (MINS.):	14400

```
*************************************************************
*                                                           *
*              STATION TIME SPECIFICATIONS                  *
*                                                           *
*************************************************************
```

	YEAR	CALENDAR DAY	HOUR	MINUTE
STATION START-UP TIME	1981	139	0	0
STATION ENDING TIME	2000	200	0	0
QUALITY CONTROL MARKER	1987	106	0	0
AGNET MARKER	1987	106	0	0
LAST DATE RECEIVED MARKER	1987	106	0	0

```
*************************************************************
*                                                           *
*                 LOGGER OUTPUT TABLES                      *
*                                                           *
*************************************************************
```

OUTPUT TABLE #	AGNET CODE 0=NOT SEND 9999=EOF 1=SEND	TABLE ID FROM LOGGER	TABLE SAMPLING (MINUTES) INTERVAL	LOCATION OF CALENDER DAY 0=LAST TIME IN TABLE	LOCATION OF IN TABLE HR/MIN	TIME AFTER MIDNIGHT OF FIRST (MINUTES) TABLE
1	1	1	60	2	3	0
2	1	2	1440	0	0	0

```
*********************************************************
*                                                       *
*               VARIABLE OUTPUT TABLES                  *
*                                                       *
*********************************************************
```

VAR-IABLE TABLE #	TABLE ID FROM LOGGER	LOCATION OF VARIABLE IN TABLE	ID NUMBER OF VARIABLE	FLAGS "M"=MISSING " "=GOOD	LOCATION OF VARIABLE IN RECORDS TO AGNET	TOP LINE OF LABEL	BOTTOM LINE OF LABEL
1	1	4	100	" "	1	"AIR TEMP"	" C "
2	1	5	200	" "	2	"REL HUM "	" % "
3	1	6	300	" "	3	"SOIL TMP"	" C "
4	1	7	400	" "	4	"WIND SP "	" M/SEC "
5	1	8	500	" "	5	"WIND VEC"	" M/SEC "
6	1	9	600	" "	6	"VECT DIR"	" "
7	1	10	700	" "	7	"VECT SD "	" "
8	1	11	800	" "	8	" RAD "	" W/M2 "
9	1	12	900	" "	9	" PRECIP "	" MM "
10	2	2	110	" "	1	"MAX TEMP"	" C "
11	2	3	111	" "	2	"MIN TEMP"	" C "
12	2	4	509	" "	0	"MAX WIND"	" SPEED "
13	2	5	510	" "	0	" TIME "	" OF MAX "
14	2	6	1300	"M"	0	"AV VAPOR"	"PRESSURE"
15	2	7	1301	"M"	0	"VAP PRES"	"DEFICIT "
16	2	8	900	" "	0	" PRECIP "	" MM "

Appendix 9. Station Information File (SIF) for Lincoln, NE

```
*************************************************************
*                                                           *
*                 STATION SPECIFICATIONS                    *
*                       f:s55 .SIF                          *
*                                                           *
*************************************************************
```

STATION NAME:	LINCOLN IANR
STATE NAME:	NEBRASKA
LATITUDE:	40.46
LONGITUDE:	96.39
ELEVATION (M):	383.00
STATION #:	4809
STATE #:	25
AGNET STATION #:	55
DATA LOGGER CLOCK ERROR (MINS.):	0
TIME ZONE DIFFERENCE (MINS.):	0
DATA EXCLUSION WINDOW (MINS.):	28800

```
*************************************************************
*                                                           *
*               STATION TIME SPECIFICATIONS                 *
*                                                           *
*************************************************************
```

	YEAR	CALENDAR DAY	HOUR	MINUTE
STATION START-UP TIME	1986	239	0	0
STATION ENDING TIME	2000	200	0	0
QUALITY CONTROL MARKER	1987	106	5	0
AGNET MARKER	1987	106	5	0
LAST DATE RECEIVED MARKER	1987	106	5	0

```
*************************************************************
*                                                           *
*                  LOGGER OUTPUT TABLES                     *
*                                                           *
*************************************************************
```

OUTPUT TABLE #	AGNET CODE 0=NOT SEND 9999=EOF 1=SEND	TABLE ID FROM LOGGER	TABLE SAMPLING (MINUTES) INTERVAL	LOCATION OF CALENDER DAY 0=LAST TIME IN TABLE	LOCATION OF IN TABLE HR/MIN	TIME AFTER MIDNIGHT OF FIRST (MINUTES) TABLE
1	0	107	60	2	3	0
2	0	201	1440	0	0	0

VARIABLE OUTPUT TABLES

VARIABLE TABLE #	TABLE ID FROM LOGGER	LOCATION OF VARIABLE IN TABLE	ID NUMBER OF VARIABLE	FLAGS "M"=MISSING " "=GOOD	LOCATION OF VARIABLE IN RECORDS TO AGNET	TOP LINE OF LABEL	BOTTOM LINE OF LABEL
1	107	4	100	" "	1	"AIR TEMP"	" C "
2	107	5	200	" "	2	"REL HUM "	" % "
3	107	6	300	" "	3	"SOIL TMP"	" C "
4	107	7	400	" "	4	"WIND SP "	" M/SEC "
5	107	8	500	" "	5	"WIND VEC"	" M/SEC "
6	107	9	600	" "	6	"VECT DIR"	" "
7	107	10	700	" "	7	"VECT SD "	" "
8	107	11	800	" "	8	" RAD "	" W/M2 "
9	107	12	900	" "	9	" PRECIP "	" MM "
10	107	13	140	" "	0	"AIR "	"TEMP2 "
11	107	14	150	"M"	0	"AIR "	"TEMP3 "
12	201	2	110	""	1	" MAX "	" TEMP "
13	201	3	111	""	2	" MIN "	" TEMP "
14	201	4	509	" "	0	" MAX "	" WIND "
15	201	5	510	" "	0	" TIME "	" OF MAX "
16	201	6	1300	" "	0	"AV VAPOR"	"PRESSURE"
17	201	7	1301	" "	0	"VAP PRES"	"DEFICIT "
18	201	8	900	" "	0	"TOT PREC"	" MM "
19	201	9	141	" "	0	"MAX AIR "	"TEMP2 "
20	201	10	142	" "	0	"MIN AIR "	"TEMP2 "
21	201	11	151	"M"	0	"MAX AIR "	"TEMP3 "
22	201	12	152	"M"	0	"MIN AIR "	"TEMP3 "
23	107	15	350	"M"	0	"SOIL TEM"	"TURF 10C"

Appendix 10. **A listing of AWDN data codes, the code of comparative data, upper and lower limits and procedure numbers used to perform quality control on the data respectively.**

CODE	COMP.	HI	LOW	PROCEDURE NOS.		
100		40.	-30.	5		
109		40.	-30.	5		
110	111	40.	-20.	57		
111		30.	-30.	5		
120	122	110.	5.	57		
121	120	80.	-20.	58		
122	120	80.	-20.	58		
130		2400.	0.	5		
131		2400.	0.	5		
200		100.	0.			1112
201		100.	0.			1112
209		100.	0.			1112
219	220	100.	0.	7		1112
220		100.	0.			1112
229		2400.	0.	5		
230		2400.	0.	5		
300		40.	-20.	5		
301		40.	-20.	5		
302		40.	-20.	5		
303		40.	-20.	5		
304		40.	-20.	5		
305		40.	-20.	5		
306		40.	-20.	5		
309		40.	-20.	5		
319	320	40.	-20.	57		
320		40.	-20.	5		
329	330	40.	-20.	57		
330		40.	-20.	5		
339		2400.	0.	5		
340		2400.	0.	5		
350		40.	-20.	5		
360		40.	-20.	5		
400		25.	0.	419		
500		25.	0.	419		
509		90.	0.	419		
510		2400.	0.	5		
519		100.	0.	419		
520		2400.	0.	5		
600		360.	0.	4		
609		360.	0.	4		
700		100.	0.	51		
800		1999.	0.	215	10	
801		1999.	0.	215	10	
809		1499.	0.	215	10	
900		150.	0.	651		
901		4.	0.	651		
920		11.	0.	651		
1000		1299.	0.	21	10	
1100		9999.	0.	21	10	

1101	9999.	0.	21	10
1200	40.	0.	5	
1300	99.	0.	51	
1301	99.	-99.	51	

Appendix 11. Quality control procedures used by AWDN computer programs.

Procedure No.	Procedure Name	Definition
01	SETNEG	Sets negative values of a variable to zero, e.g. solar radiation data.
02	SUNTIM	Checks solar radiation output against sunrise and sunset times to identify any problems with the data logger time.
03 04 05 10	HILO	Checks values agains an upper and lower limit and performs functions based upon the procedure no. 03 Alerts technician-no data change 04 Sets data to threshold value and changes data flag to 'E' 05 Values exceeding thresholds are set to zero and the data flag to 'M' 10 Values outside threshold are set to nearest threshold and no changes to flags.
06	FLAGME	During periods of missing precipitation the values are set to zero and the flags to 'E'
07	MAXMIN	Checks a value agains comparitive values from a related sensor and flags the value when: 07 Value .LE. Comparitive value 08 Value .GE. Comparitive value
09	NOCHNG	Counts the number of consecutive values that are constant and reports the value to the technician when a preselected number of occurrences has been detected
11	UPSET	Sets a value to the upper threshold when it is exceeded e.g. RH>100
12	DNEST	Sets a value to the lower threshold when it is found to be less than that threshold and sets the flag to 'M'.

Appendix 12. Summary of Publications and Presentations

Information transfer and education of the public about new technology is a vital role of the university. A listing of publications and presentations related to this project follows:

Publications

Hubbard, K. G., N. J. Rosenberg and D. C. Nielsen. 1983. Automated weather data network for agriculture. Journal of Water Resources Planning and Management 109:213-222.

CAMaC Progress Report 83-1. 1983. A demonstration and evaluation of the use of climate information to support irrigation scheduling and other agricultural operations. University of Nebraska.

Millard, P. 1984. The changing direction of weather information, in "Farming with Pride." Pride Company, Inc. Glen Haven, WI. Winter Quarter.

CAMaC Progress Report 85-4. 1985. An assessment of near-real time users of information from the automated weather data network. University of Nebraska.

Hubbard, K. G., and N. L. Klocke. 1986. Climate and irrigation in Nebraska. Preprint Volume of the conference on Climate and Water Management - A Critical Era. Amer. Meteorol. Soc. 33-35.

Hubbard, K. G. 1986. Nebraska cattle and crop producers find weather impacts polarizing in 1985. Preprint Volume of the Conference on the Human Consequences of 1985's Climate. Amer. Meteorol. Soc. 208-222.

CAMaC Progress Report 86-4. 1986. Improving Nebraska's near-real time weather-based products through user interaction. University of Nebraska.

Hubbard, K. G. 1986. Surface weather monitoring and the development of drought and other climate information delivery systems. The International Drought Symposium and Workshop. Lincoln, NE.

Hubbard, K. G., D. A. Wilhite and D. A. Wood. 1986. An AWDN brochure. University of Nebraska.

Presentations

Hubbard, K. G. Use of automated weather stations in irrigation scheduling. Irrigation Scheduling Workshop. University of Nebraska, Lincoln, NE. March, 1982.

Nebraska Educational Television. IANR update. April, 1982.

Hubbard, K. G., N. J. Rosenberg and D. C. Nielsen. Automated weather data network for agriculture. Workshop on Managing Our Limited Water Resources. American Society of Civil Engineers, Lincoln, NE. May, 1982.

Weekly meetings of Nebraska's Agricultural Climate Situation Committee. Summer, 1981-1987.

Hubbard, K. G. Automated weather stations and crop water use. Irrigation Short Course. University of Nebraska, Lincoln, NE. January, 1983.

Rosenberg, N. J. Ag Meteorology by the Year 2001. Ag 2001 Planning Committee. University of Nebraska, Lincoln, NE. February, 1983.

Hubbard, K. G. Climate data collection and management: The Nebraska AWDN and AGNET. Cooperative Climate Service Conference. National Climate Program Office. Tallahassee, FL. March, 1983.

Hubbard, K. G. Developing a near-real time automated weather data network. 16th Conference on Agriculture and Forest Meteorology. Amer. Meteorol. Soc. Fort Collins, CO. April, 1983.

Hubbard, K. G. A summary of the 1982-83 El Niño and other weather topics for Nebraska. Meeting of the Advisory Committee for Mead Research Facility. January, 1984.

Hubbard, K. G. A new weather tool: AWDN. Meeting of Nebraska Legislators. Lincoln, NE. January, 1984.

Hubbard, K. G. Use of Weather data for agriculture. Big Byron Open House. Ogallala, NE. January, 1984.

Hubbard, K. G. and A. Weiss. Using weather data in research. North Platte District Seminar. February, 1984.

Rosenberg, N. J. and K. G. Hubbard. AWDN for Nebraska. University of Nebraska Regents Meeting. February, 1984.

Schutz, W. How to use the computer to achieve best results in agriculture. Arabian productivity advances using computer and computer graphics. Riyadh, Saudia Arabia. February, 1984.

Hubbard, K. G. Development of AWDN. US/China Project 3 Planning Meeting. Phoenix, AZ. March, 1984.

Hubbard, K. G. An automated weather data network for agriculture. Seminar at University of Arizona. Tucson, AZ. March, 1984.

Hubbard, K. G. and N. J. Rosenberg. Nebraska's automated weather data network Part I: Near-real time weather data collection. Workshop on crop simulation. Lincoln, NE. March, 1984.

Thompson, T. L. Nebraska's automated weather data network Part II: Managing the weather database. Workshop on crop simulation. Lincoln, NE. March, 1984.

Thompson, T. L., G. Meyer, J. Gilley, D. Martin and K. G. Hubbard. Nebraska's automated weather data network Part III: Agricultural applications. Workshop on crop simulation. Lincoln, NE. March, 1984.

Rosenberg, N. J. and K. G. Hubbard. An automated weather data network. Seminar at the University of Wyoming. Laramie, WY. March, 1984.

Hill, H. L. and K. G. Hubbard. Agricultural uses of weather and climate information in Nebraska: Nebraska automated weather data network and AGNET. Workshop on Weather Information Packages for Use in On-Farm Operations. Chico, CA. May, 1984.

Hubbard, K. G. Challenges to meteorologists and climatologists doing research in the late 1980's and 1990's. Workshop on weather and climate needs for agriculture in the 1990's. Kansas City, MO. October, 1984.

Hubbard K. G., D. A. Wilhite, N. J. Rosenberg and S. J. Meyer. A regional automated weather data collection network for near-real time agricultural applications. 76th Annual meeting of the Amer. Soc. of Agric. Engin. Las Vegas, NV. November, 1984.

Wilhite, D. A., K. G. Hubbard, and S. J. Meyer. Application of near-real time weather data in agricultural decision making. Amer. Soc. Civil Engin. San Francisco, CA. October, 1984.

Hubbard, K. G. A regional automated weather data network: Applications of data. Seminar at Kansas State University. November, 1984.

Hubbard, K. G. The use of computers in weather data collection. Microcomputer workshop. Kearney, NE. November, 1984.

Hubbard, K. G. Nebraska's State Climatology Program. Amer. Meteorol. Soc. Chapter Meeting. Omaha, NE. October, 1984.

Rosenberg, N. J. and K. G. Hubbard. Near-real time users of information from the automated weather data network. International Symposium in memory of Dr. Franz Sauberer. Vienna, Austria. 1984.

Hubbard, K. G. An automated weather data network for agriculture. North Central Computer Institute Data Acquisition Workshop. Chicago, IL. January, 1985.

Nebraska vs. Colorado College Football Game. Half-time feature. October, 1985.

Hubbard, K. G. Nebraska's automated weather data network. Weather Network Symposium. Oklahoma State University. Stillwater, OK. November, 1985.

Hubbard, K. G. Demonstration of the utility of near-real time climate information. Summer meeting of the Amer. Soc. of Agric. Engin. East Lansing, MI. June, 1985.

Meyer, S. J., K. G. Hubbard and D. A. Wilhite. Improving Nebraska's near-real time weather products through user interaction. 17th Conference on Agricultural and Forest Meteorology. Amer. Meteorol. Soc. Scottsdale, AZ. May, 1985.

Hubbard, K. G. Research related to near-real time weather data. University of Nebraska Chancellor's Council. Lincoln, NE. September, 1985.

Nebraska vs. Michigan College Bowl Game. Half-time feature. January, 1986.

Hubbard, K. G. Advances in automated weather data collection. Regional Entomology Survey Meeting. Lincoln, NE. January, 1986.

Hubbard, K. G. Regional soil moisture monitoring. National Climate Program Office Seminar. NOAA. April, 1986.

Hubbard, K. G. and J. Booysen. A drought index for wheat. Annual Meeting of the Amer. Soc. of Agron. New Orleans, LA. November, 1986.

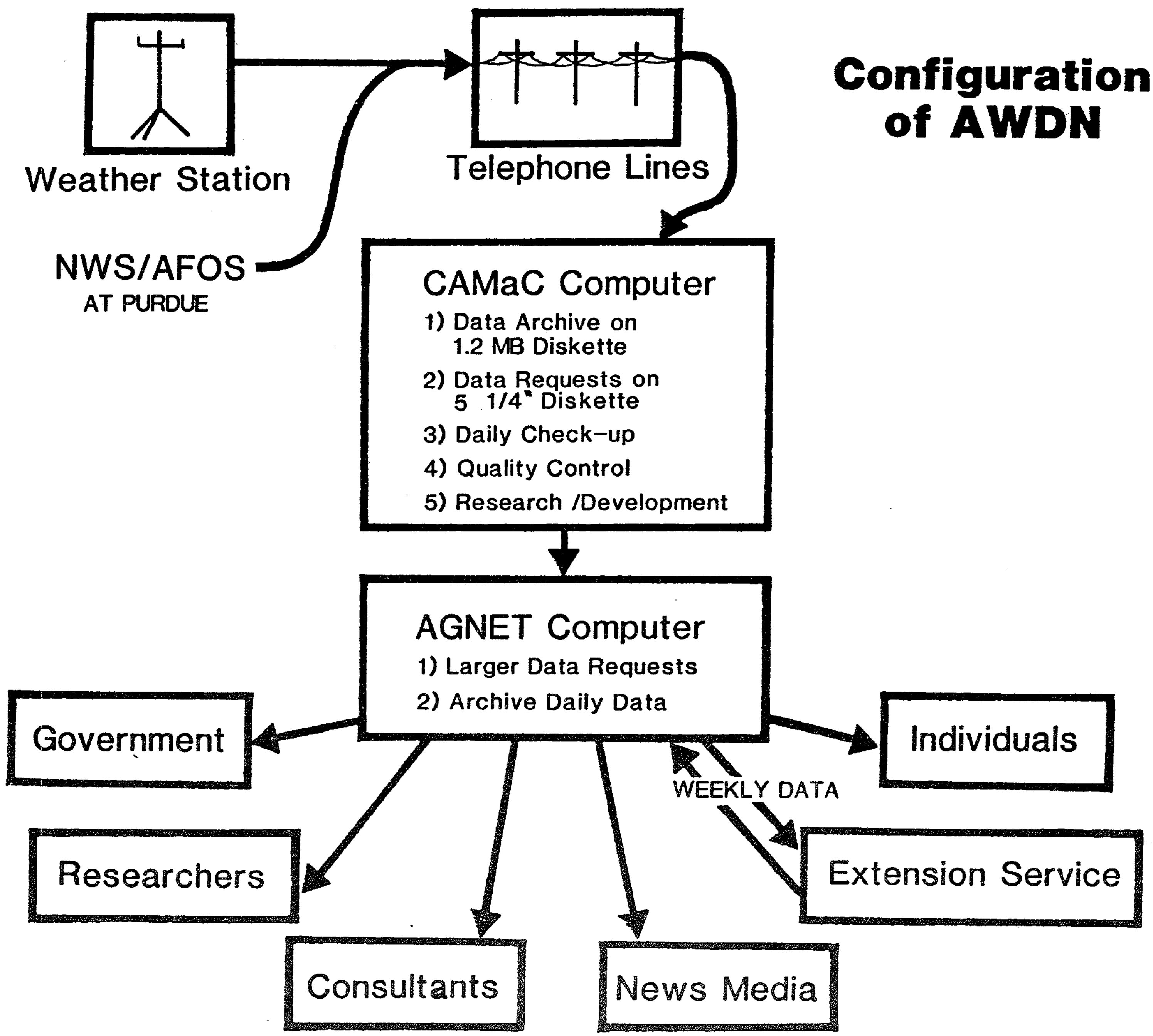

Figure 1. Linkages within the Automated Weather Data Network.

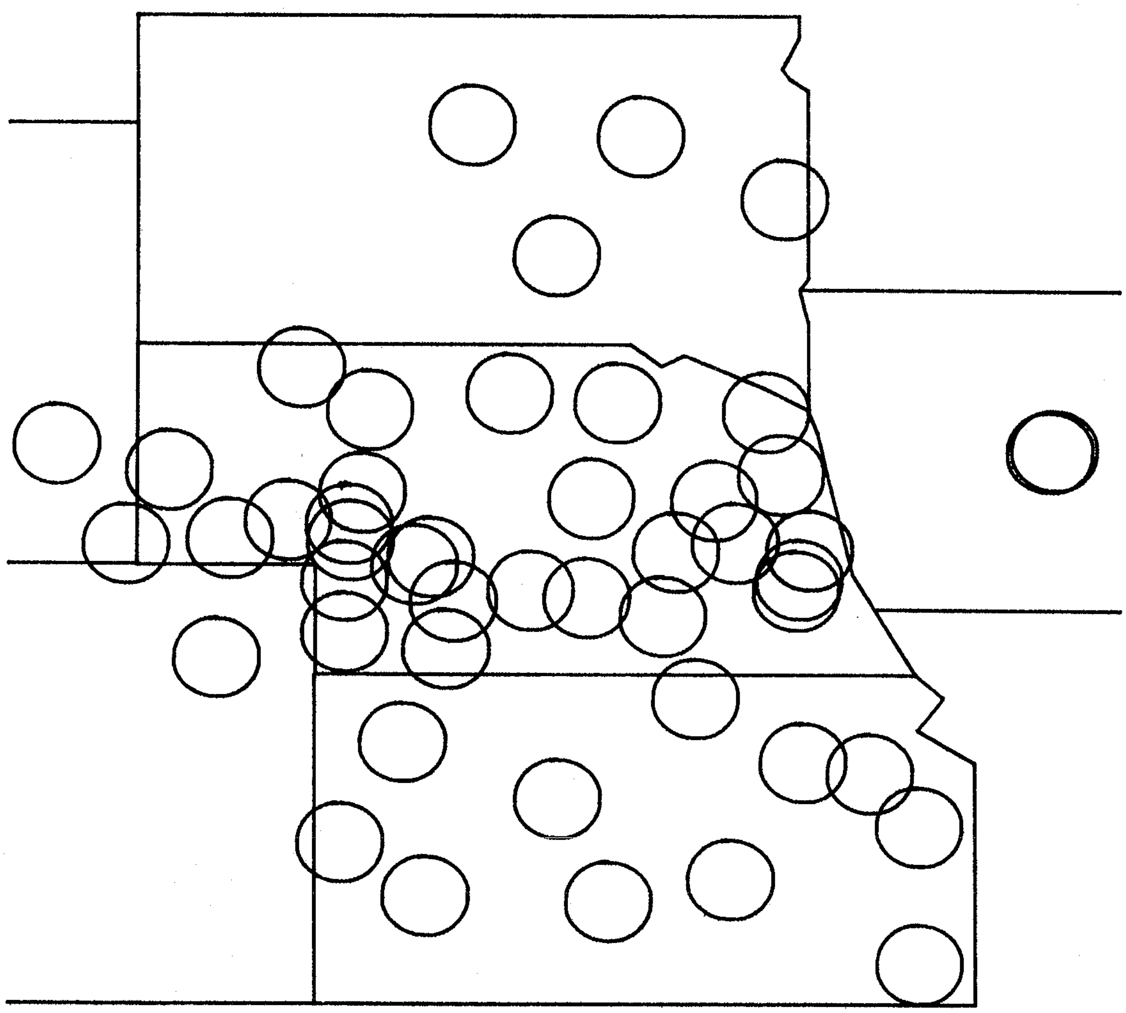

Figure 2. Distribution of AWDN stations as of May, 1987.

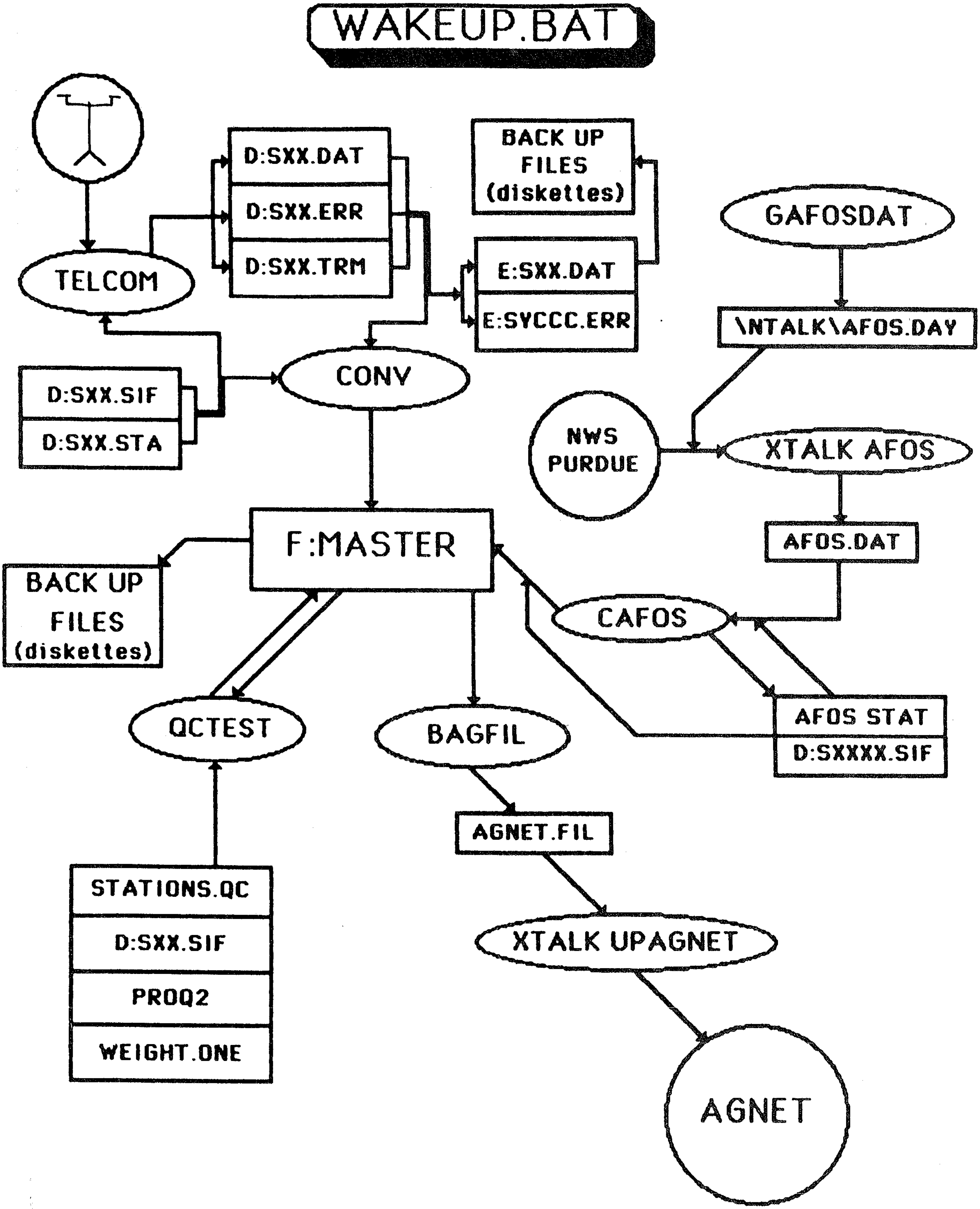

Figure 3. Generalized flow diagram for AWDN computer programs and data files.