AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523
BIBLIOGRAPHIC INPUT SHEET

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0158

1. SUBJECT CLASSIFICATION	A. PRIMARY: Agriculture	AP10-0000-0000
	B. SECONDARY: Water resources and management	

2. TITLE AND SUBTITLE
A computer automated system for hydrologic data acquisition and anlyses

3. AUTHOR(S)
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4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1970	13p.	ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS
Ariz.

8. SUPPLEMENTARY NOTES (Sponsoring Organization, Publishers, Availability)

9. ABSTRACT

10. CONTROL NUMBER	11. PRICE OF DOCUMENT
PN-RAA-107	

12. DESCRIPTORS	13. PROJECT NUMBER
Computer programs Data Information systems	14. CONTRACT NUMBER: CSD-2457 211(d)
	15. TYPE OF DOCUMENT

AID 590-1 (4-74)

A COMPUTER AUTOMATED SYSTEM FOR HYDROLOGIC DATA ACQUISITION AND ANALYSES

J. L. Thames and R. M. Tinlin

ABSTRACT

An interfaced hydrologic data acquisition-processing system has been installed at the University of Arizona. A forested mountain watershed and a desert watershed area within a 50 kilometer radius of the campus are instrumented for measuring a variety of hydrologic and climatic variables. Measurement data are both multiplexed over the Bell Telephone system and transmitted by radio to a campus laboratory. Measurements on the desert watershed may be programmed in any sequence and sampling rate varied from seconds to 24-hour intervals automatically or according to the rate at which input signals may change. Operation of the system is automated from a central laboratory by a small computer. Reference information, preliminary data reduction programs, and control data may be entered into the system. All output is recorded on magnetic tape but may also be displayed on strip charts or teleprinter. The facility is used in an ecological research program and provides input-output data for research in synthetizing the hydrologic behavior of watersheds. It also offers a unique means of teaching principles of hydrologic processes, methods of data acquisition and procedures in hydrologic analyses.

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INTRODUCTION

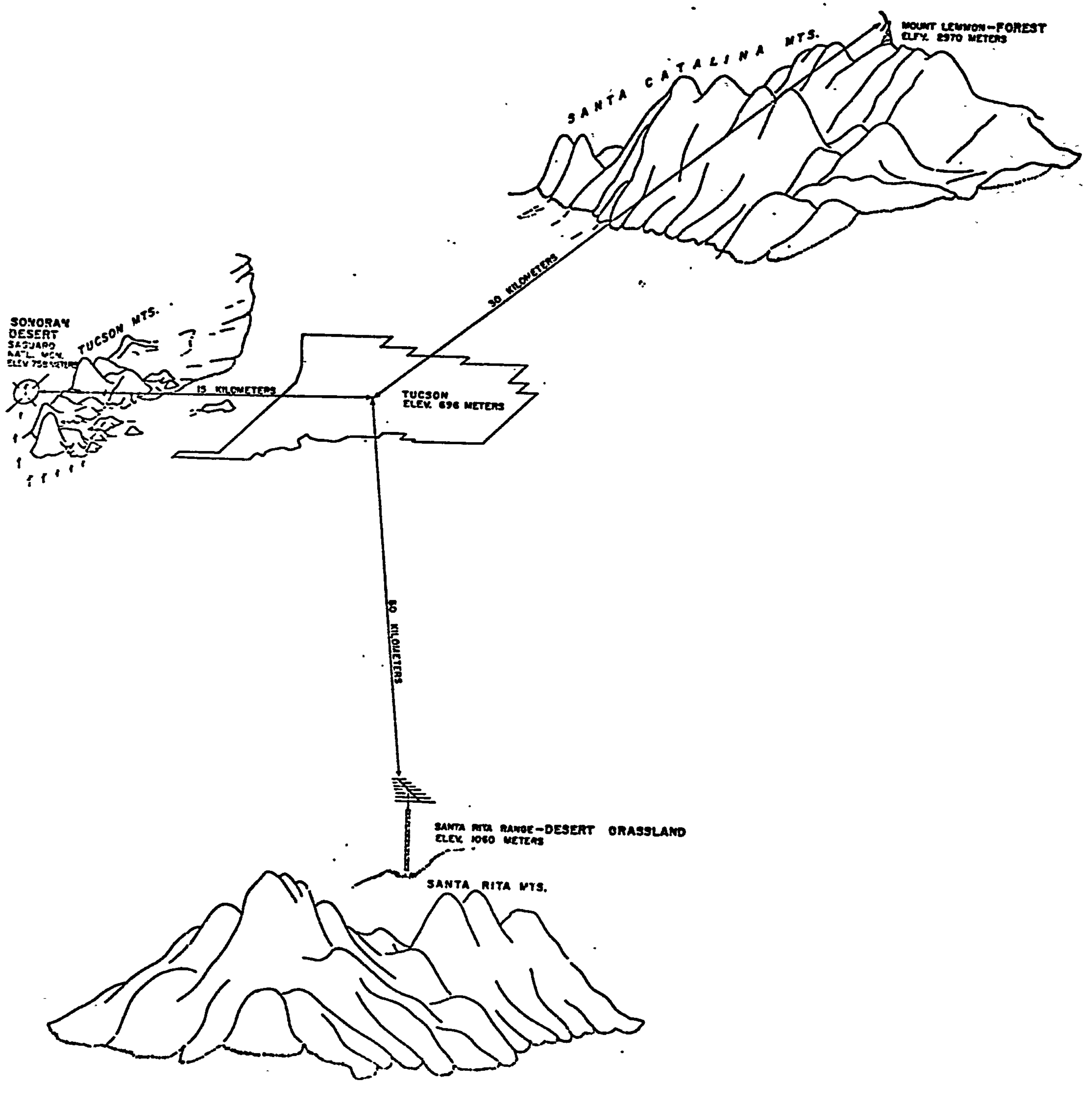
Deserts of the United States support one of the most rapidly increasing population segments of the nation. The associated sprawl of compacted urban areas and the changing use patterns of wildlands will emphasize environmental pressures on the "fragile" desert ecology in the future, particularly when more water becomes ava lable through technological advances in desalinization, weather modification and watershed management practices.

To sustain desirable aspects of this growth a thorough knowledge of the hydrological and ecological processes characterizing deserts is essential. Land managers must have a wider understanding and more technical training than ever before. Research results must be synthesized into predictive models to serve as guides for optimizing resource management and urban planning strategies.

This paper describes a data acquisition facility being developed for hydrological and ecological research and training, operated jointly by the College of Earth Sciences and the Department of Watershed Management, in the College of Agriculture, at the University of Arizona.

THE FACILITY

The complete facility will include a forested mountain watershed, a desert grassland watershed and a Sonoran desert watershed (see figure 1). At present, two modes of telemetry are used to transmit a variety of hydrological and meteorological data from the forest and desert grassland watersheds to a central control station on campus. The Sonoran desert watershed will be added to the facility with a hard wire telemetry link early in 1971.


SANTA CATALINA MTS.
MOUNT LEMMON—FOREST
ELEV. 2970 METERS
30 KILOMETERS
SONORAN
DESERT
SAGUARO
NAT'L. MON.
TUCSON MTS.
15 KILOMETERS
TUCSON
ELEV. 696 METERS
80 KILOMETERS
SANTA RITA RANGE—DESERT GRASSLAND
ELEV. 1060 METERS
SANTA RITA MTS.

The central station contains a small computer for on-line data processing and recording. It affords control of the data taking process - varying the sample rate in relation to input changes, real time, etc. Magnetic tape permanently records the data.

Three major functions of the facility provide: 1) meteorological-hydrological input for an ecological research effort of the Desert Biome[1/]; 2) quality control in the collection of input-output data needed for developing and testing synthetic hydrologic models of watersheds; and 3) a unique laboratory for student instruction in watershed hydrology.

TELEMETRY AND DATA ACQUISITION SYSTEMS

The facility tests hydrologic data acquisition schemes and provides a variety of instrumentation for student instruction. One of the two systems in operation is a simple impulse duration type. Data are transmitted by tone pulses of durations proportional to variations in the measured quantities and are converted at the central station into analog form. The other, a system developed by the Leach Corporation, is a state of the art, remote control digital data acquisition system.

PULSE DURATION SYSTEM:

An electro-mechanical transmitter, the principal element of this system converts variations in a measured quantity to a proportional time interval (figure 2). The conversion is made by a follower which rides a continuously rotating cam and keys a mercury switch. The position of the follower on the cam, set by an electrical or mechanical link to the sensor, determines the duration of the pulse. A 13-second pulse corresponds to maximum deflection of a sensor, and a 3 second pulse to zero. Thus, measurement data are carried within a 3 to 13 second time interval for each 15-second cam cycle.

1/ International Biological Program, Research Design Plan for Analysis of Structive and Function of Desert Ecosystems, David W. Goodall, Director, Utah State University, 1969.

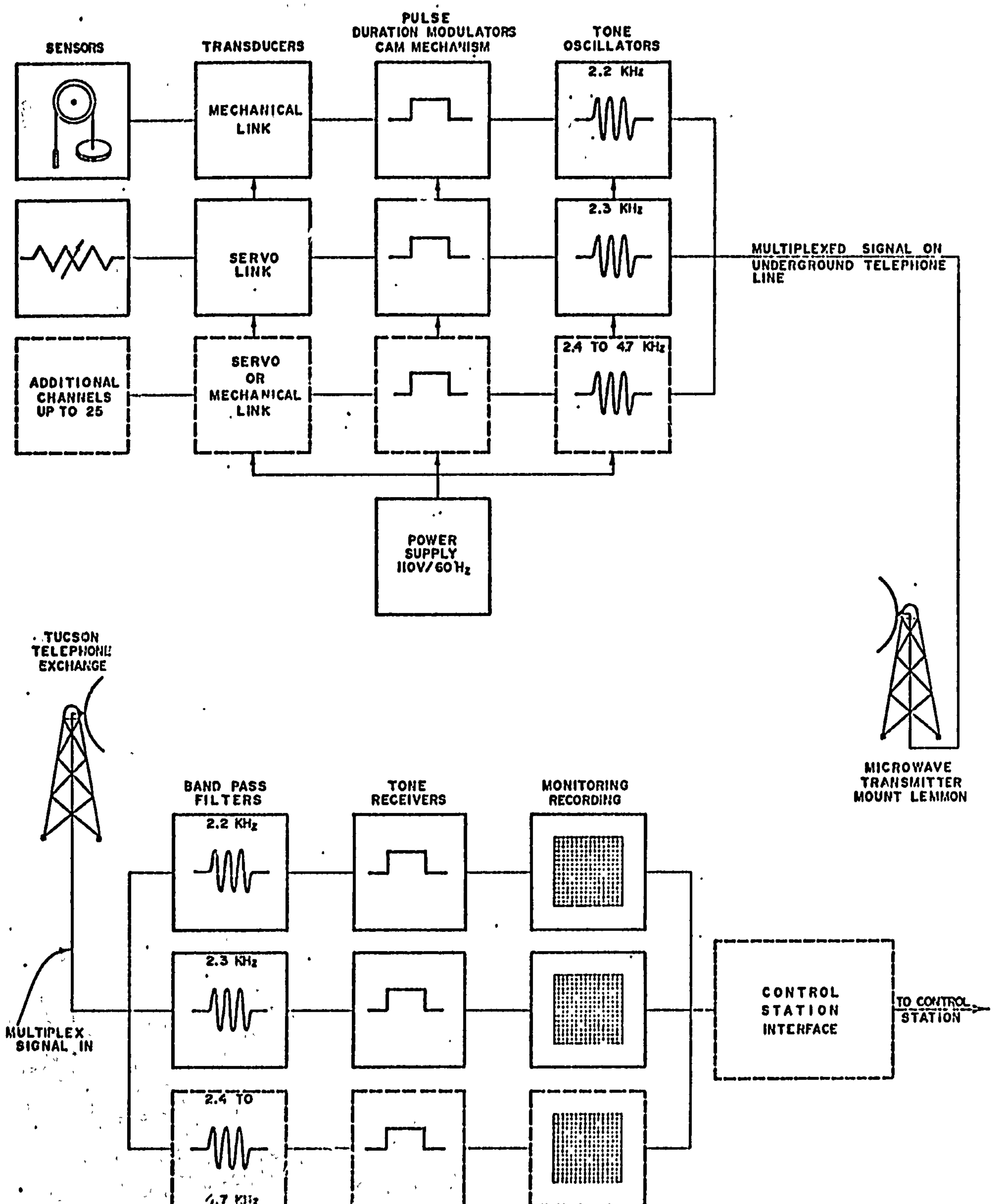


Figure 2. Pulse Duration System

Time modulated pulses from the transmitters key corresponding tone oscillators. The resulting modulated tones are multiplexed through an underground telephone cable to a microwave transmitter on the watershed summit. Multiplex data are transmitted to the Tucson telephone exchange and are sent via a leased line to the central station. The system has a capacity of 24 channels imposed by the audio frequency spectrum of the commercial telephone facility. Individual channels are separated by 100 Hz.

At the central station, the signal is demodulated to direct current pulses by band pass filters and tone receivers. Time durations of pulses correspond to amplitudes of the original sensor output. Direct current pulses position retransmitting slide wires and, for selected variables, operate analog recorders for visual monitoring. The re-transmitting slide wires are read by a magnetic tape data logger. But the system is also being interfaced with the control station of the digital system.

DIGITAL SYSTEM

This system consists at present of a control station at Tucson and a remote station at the Santa Rita desert grassland site. Both digital pulse and analog type sensors are used at the remote station (see figure 3). The digital pulse sensors are typical contact closure devices, such as a tipping bucket rain gage. Signals from analog sensors are conditioned and multiplexed into a 10-bit, ramp type, analog to digital converter. The digitized output of the converter is applied via the data bus into the memory.

The memory is a 32-word, 16-bit core plane with control logic. A pulse from either type of sensor enters into the memory via the data bus. The basic function of the memory permits digital pulse data to be stored between interrogation cycles. At the beginning of an interrogation cycle, the analog data are written into memory and a sequential output of all data begun.

As data are being sequenced out of memory a parity bit is assigned. Parity checking determines if data have been correctly transmitted and received. The number of bits in a data word are totaled, and if an even number of bits is present, then a parity bit is added to make the total odd. If an error occurs in the transmission of data (as might happen during an electrical storm), the error is detected and the data flagged.

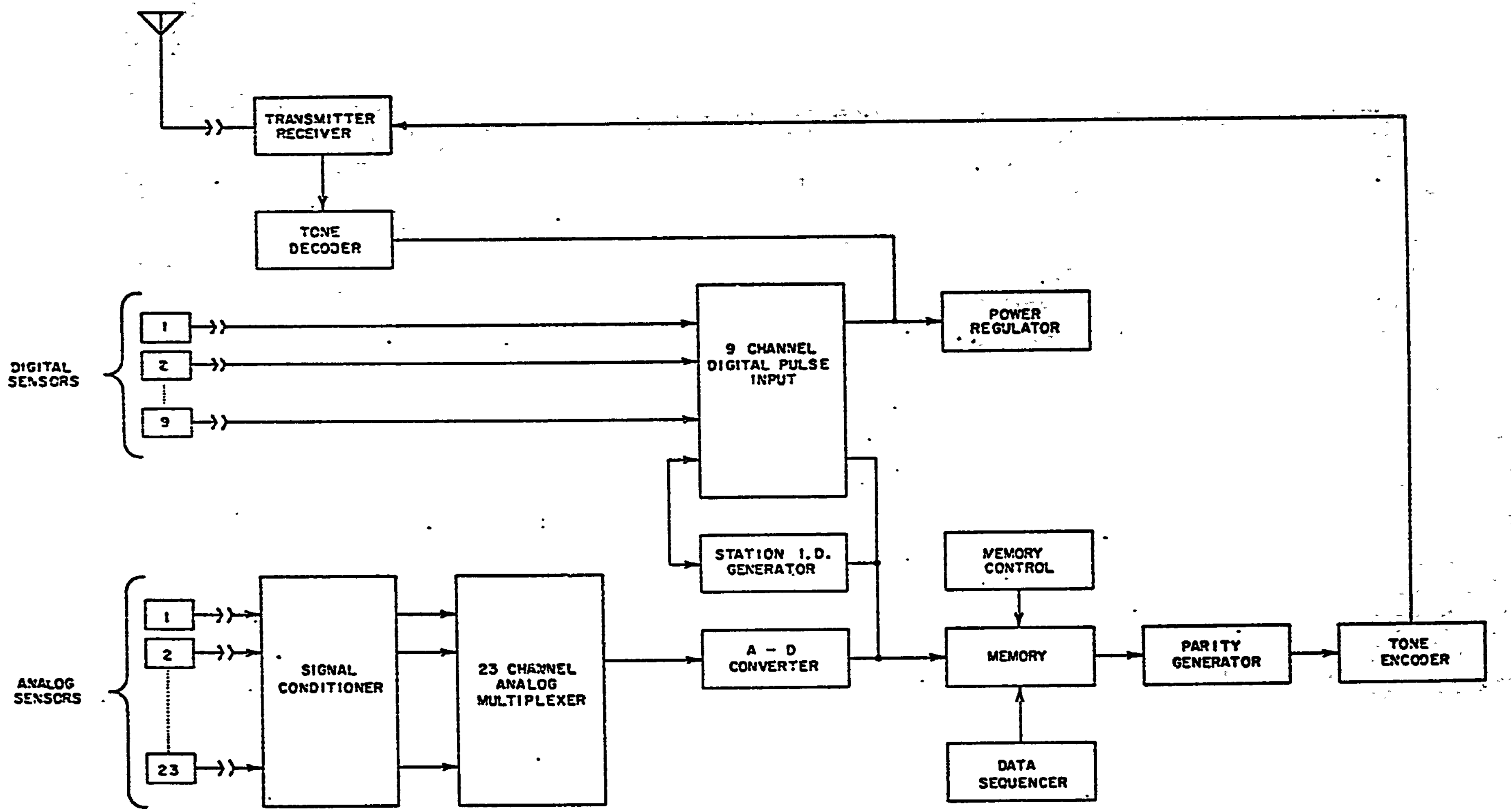


Figure 3. Digital System, Remote Station

Interrogation of the remote stations is initiated by a signal generated at the control station and received by the tone decoder which then initiates a sampling and reporting cycle. Output from the memory, applied to the tone encoder, modulates the transmitter carrier for data transfer to the control station.

The control station, heart of the Leach System, generates remote station addresses, checks them as well as incoming data for validity, and logs all information. The equipment consists of a teleprinter and an equipment rack in which are mounted 1) crystal controlled digital clock, 2) radio communication link transceiver, 3) read/write magnetic tape deck, 4) 8K 16 bit computer, and 5) high speed paper tape reader.

The clock displays real time in hours, minutes and seconds and is monitored by the computer. When a selected time interval has elapsed, pulses are generated by the clock and an interrogation cycle is begun. The time interval between interrogation cycles is adjustable by operator entry either directly through the teleprinter keyboard or through the tape recorder with paper tape. A code may also be entered manually into the teleprinter to initiate a manual request for data from either all stations in sequence or from a selected station.

An interrogation cycle begins with the computer outputting to the transceiver an 8 bit address word, the addressed remote station responds and transmits the accumulated data back to the control station, the received data is checked for the correct station address, correct number of bits in the record and correct parity. If these are positive, the data are then converted into engineering terms before they are logged, e.g., wind direction in degrees, wind velocity in miles per hour, and temperature in degrees, etc. The control station then interrogates the next station. Read out is normally made every six minutes and transcribed on magnetic tape. The teleprinter displays the data every hour except during storms when the sampling and display frequency is stepped up to two minutes.

Magnetic tape at the control station provides the optimum raw data storage medium for the facility. It records all data as they are acquired and recalls historic data at will for new or additional analyses without restricting system capability. The small computer performs many of the analyses required by the project. For complex problems such as those associated with computer modeling the tape is used directly on the 6400 CDC computer.

COMPARISON OF THE TWO SYSTEMS

The pulse-duration system has been in operation for two years, the digital system for only a few months. For this reason and because of differences in their basic function, direct comparison cannot be made.

Essentially, the pulse-duration system is a telemetry system for transmitting data from the field and recording it in the laboratory. Expensive interfacing with the central computer is being improvised to make it a more complete data acquisition system. Even so, it will lack the flexibility of the digital system.

Interestingly, costs of field stations and telemetry links are similar for both systems. The field station components of the digital system are contained in compact, light weight, water tight units which may be buried underground. Electronics are solid state for reliability and have low power consumption. The system, normally in a stand-by condition, consumes little power because it is activated only when it receives an interrogation command.

The pulse duration field installation operates continuously and requires 110V/60 Hz power which presents a serious problem for isolated instruments. Because the system is used near a mountain summit, above ground power lines are impractical for winter conditions, and the buried lines in use pick up induced power surges whenever lightning strikes the watershed. This problem has not been overcome.

Field transmitters of the pulse-duration system, though ruggedly constructed, are exposed above ground. The mechanical mechanism wears under continuous use and requires excessive maintenance, however, repairs are not difficult to make. The solid state components of the digital system have thus far been trouble free, but in case of breakdown, the services of a skilled technician are required.

ECOLOGICAL FUNCTION

A major goal of the Desert Biome program is to develop predictive models of the transfer of energy and matter among the components of desert ecosystems. A large number of desert sites in Western United States are involved in the overall program. The desert grassland, and Sonoran desert are the primary sites in Arizona.

Knowledge of the energy and water balance is essential to the program. Accordingly, the Santa Rita site is instrumented as shown in Table 1. A similar installation will replace a standard weather station at the Saguaro site in 1971. A less sophisticated set of instruments has been in operation on the forested watershed for two years.

Table 1. - Meteorological and Soil Measurements, Desert Grassland Site

Distance from Soil Surface (meters)	Measurement
+ 16	Water vapor, temperature, wind speed
+ 8	Water vapor, temperature, wind speed, wind direction
+ 4	Water vapor, temperature, wind speed, radiation
+ 1	Precipitation (one recording gage per 100 acres)
0	Soil surface temperature (radiometer)
-.05 -.10 -.25 -.50 - 1.00 - 2.00	Soil moisture, soil temperature, soil water potential and spatially replicated according to the inability of of soil characteristics.

To estimate the energy balance, meteorological variables are continuously measured above the vegetation canopy at a single station on the study area. Supplemental measurements are obtained for short periods at other locations over the areas. Hopefully, these measurements augmented with data on the surface roughness of the vegetation can be extrapolated downward into the vegetation layer.

The meteorological data required are: (a) profiles of wind, temperature and moistur and (b) stress, roughness and heat flux in the surface boundary layer. Because there are alternative approached to obtaining these quantities as well as preferences by individual investigators for specific sensing instruments, both digital and analog, among the wide array available, and extremely adaptable data acquisition system is required.

The water balance on the ecological sites is being assessed by two methods; direct measurement and hydrologic simulation. Direct measurements are made of major inputs and outputs including precipitation, stream flow, channel transmission loss and soil moisture.

Spatial estimates of precipitation in the southern desert of the United States are made difficult by convection storms which characteristically occur in cells not much larger than 1 kilometer in diameter. Tipping bucket raingages, monitored by the digita system, and supplemented with standard gages are proving adequate. The tipping bucket gage is well suited to the project. It requires little service, minimizes disturbance on the study areas, and can be installed at considerable distance from the remote station with only a simple line connection.

Typical desert watersheds have low relief dry dense channel networks and intermittant stream flow. Channel transmission losses are high and difficult to evaluate. Presently stream flow is being measured at inlet and outlet points on two channels on the desert grassland watershed by four flumes equipped with telemetry. The network wil be expanded in the future.

Soil moisture, because of spatial variability is sampled directly. However, plans are in progress to test aerial infra-red scanning, supplemented with ground truth data on soil moisture and rainfall to obtain spatial estimates.

SIMULATION FUNCTION

Simulation modeling, one of the most popular tools of hydrology, produces a history of events baded on mathematical models representing real world situations. Frequently the accuracy of available data is the limiting criterion and establishes the simulation accuracy of a particular model. Data requirements for simulation must be guided by the model building process. For maximum efficiency the entire process of data collection, evaluation, conversion and storage, through the final analysis should be a single system. In this way transmission of data from one stage to the next and the effect of changing one part of the system or another, can be kept in the forefront. The facility described herein has this capability.

Because of the relatively high precipitation on desert mountains and because these areas make important contributions to the region, the forested mountain watershed is used primarily to provide input-output data for hydrologic modeling.

The hydrologic quantities measured and telemetered are surface runoff from 0.15 Hector plots replicated on the watershed, stream flow from the watershed, precipitation and snow density. Climatic variables monitored are solar radiation,humidity and air temperature.

INSTRUCTIONAL FUNCTION

Aside from its inherent research functions, the facility is a key part of a curricula being developed in watershed hydrology. Specific instructional uses give students: 1) A fundamental understanding of the interrelationships between variables in the hydrologic cycle by working first-hand in the laboratory with these quantities as they change in space and time on natural watersheds, 2) Technical training by performing laboratory exercises in computer programming for data acquisition, reduction and analysis.

By means of high speed computation data may be collected, reduced and analyzed in any desired fashion almost immediately and in some cases while the hydrologic event is occurring. The student observes and works with hydrologic processes in the laboratory, at any time and under the most inclement conditions. With this versatility the gap between the publication of research results and their eventual incorporation into classroom instruction is lessened. The convenience of having a variety of data immediately at hand and ready for the computer, allows new developments in hydrologic techniques and research to be tested and demonstrated with the facility as they become pertinent. Teaching efficiency and educational effectiveness is increased by dealing with complex problems in a very practical but dramatic way.

The small computer provides an economical means of teaching the application of computer principles in hydrology, ranging from basics to the implementation of graduate research projects. Data reduction schemes, operational computer programs and laboratory exercises are about 75 percent complete at present. Because the facility is open-ended to allow additional or deletion of new developments its full potential will probably not be realized for some time. It will be tested in several courses during the fall semester of 1970 and will go into full time operation the following semester.

Acknowledgements: This project is partially supported by National Science Foundation Grant GB 15886 and by the Agency for International Development under an institutional grant to increase instructional competence in system analysis of watershed management.