The continuous monitoring of rainfall: A technical discussion

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Abstract

The problem of lost data using clockwork recording, syphon-type rain-gauges is discussed prior to a description of the hardware and software used in a micro-processor controlled, solid state memory device developed at Rhodes University for use with a tipping bucket raingauge. The two types of continuous rainfall monitoring system are compared with respect to ease and reliability of operation, hardware reliability, gauge visiting frequency, data recovery, data resolution and cost. The Rhodes memory device-tipping bucket combination is shown to have a large number of advantages and is clearly a very suitable system for use in hydrological research networks.

Introduction

There are two major sources of error in the estimation of areal average rainfall amounts that have been widely referred to and discussed in the hydrological literature. These are, firstly, the ability of a raingauge to accurately measure the amount of precipitation falling at a point (Rodda, 1967; Green, 1970; Neff, 1977; De Villiers, 1980) and secondly, the extrapolation of one or more point rainfall measurements to estimate the amount falling over a wide area (Rodda, 1962; Unwin, 1969; Schulze, 1976; Thorpe, Rose and Simpson, 1979). The first problem has prompted a number of comparisons of different raingauge types and siting principles and the results have been expressed both qualitatively as well as quantitatively. Attempts to solve the second problem have varied from the use of simple averages through to quite sophisticated statistical and mathematical mapping techniques such as polynomial surface fitting.

While there can be no doubt that these are real problems and will both remain a potential source of error in many hydrological analyses, there is a further problem which is less frequently referred to in the hydrological literature, that is the question of data recording procedure and the reduction of instrument failure time and consequent loss of data. In the case of a continuously recording raingauge which can yield high resolution data about short period rainfall intensities, the ability of a gauge to measure point rainfall accurately and the subsequent extrapolation to areal estimates become redundant considerations if the recording device fails and no data are collected. Similarly, it is necessary that the design of the gauge and recording device be adequate to supply information at the level of resolution required by the hydrological analysis for which the rainfall data are intended. Both the time resolution (determined by the clock device) and the depth of rainfall resolution (determined by the gauge orifice and measuring technique) are important.

In the South African context, many of the continuous recording gauges used by the state departments, municipalities and research institutions are of the syphon type using a clockwork operated rotating drum loaded with a paper chart to record the data. This type of a gauge is used in the research network of the Ecca catchments operated by the Hydrological Research Unit (HRU) of the Geography Department at Rhodes University (Roberts, 1978). Within the main Ecca catchment (80 km^2) the HRU has maintained 10 such gauges since 1975, using a weekly chart changing procedure, but unfortunately the records are incomplete due to a number of different kinds of instrument failure (Table 1). For 1981 and 1982 a total of 653 (out of 7300) station-days, (i.e. 730 days of record for 10 stations) contained missing data and while not all of these represent complete days of instrument failure, there could exist other station-days of failure as complete charts (7 days) with no rainfall are never processed and so cannot be identified as having lost data. While no attempt has been made to apportion the missing data into different reasons for failure, Table 1 summarises the type of failure that can occur and the procedures followed at the HRU to minimize their occurrence. There are clearly a number of ways in which failure can occur, several of them related to operator error. Apart from failure during recording, other errors can occur at the chart processing stage when the graphical data are converted into numerical values. Regardless of whether charts are processed manually or semi-automatically using a computer based digitizing system, errors are difficult to avoid and can only be minimized by using a time-consuming checking routine.

TABLE 1
TYPICAL CAUSES OF LOSS OF DATA IN SYPHON-TYPE RAIN-GAUGES

Failure	Remedial measure
Damaged float or float guide	Early identification of problem from charts and replacement of damaged part
Blocked syphon mechanism	Common problem relieved by regular cleaning and polishing
Damaged fibre tip pen	Regular inspection and replacement
Empty ink reservoir	Operator error relieved by strict chart chaning procedure
Ink blotching	Use correct ink and keep charts dry during changing
Poor adjustment of clockwork mechanism	Regular checking of trace timing and adjustment of problem clocks
Clockwork mechanism failure	Keep spare clocks and use a regulare servicing procedure to prevent complete failure.
Clock not wound up or overwound	Operator error
Blocked inlet filter	Regular cleaning

Other operator errors are possible such as failure to record the time of chart placement, incorrect securing of the chart to the drum, etc.

When functioning correctly, the syphon-type gauge will record even very small increments of rainfall (given sufficient trace resolution), while a tipping bucket gauge can never record with a resolution of better than the volume required to tip one bucket. However, modern gauges of this type have buckets representing 0,2 mm of rainfall, which is an acceptable resolution for almost every hydrological analysis. Autographic tipping bucket gauges represent the most popular alternative to the syphon-type gauge. With a less complicated rainfall collecting mechanism they should be less liable to mechanical failure. They are commonly used with a battery powered clock and a stripchart mechanism which should also be more reliable than a clockwork motor. However, these systems can be as much as 20 % more expensive than a typical syphon gauge system. With the development of microprocessor technology a large number of hydrological network operators are turning towards electronic solid-state data logging. As far as rainfall is concerned, the tipping bucket mechanism lends itself more readily to use with electronic, microprocessor controlled, memory devices than do other raingauge types.

A microprocessor controlled, solid state memory raingauge

If these gauges are to be successful in replacing mechanical recording gauges, they should be more reliable and allow data to be retrieved at a level of resolution that is satisfactory for detailed analysis of rainfall intensities. A further requirement should be that any extra cost is more than offset by the improved data quality. The following two sections of this technical note briefly describe the hardware and data storage technique used in a raingauge system developed by the Electronic Services Group of the Department of Physics at Rhodes University for the use of the HRU in both semi-arid and sub-humid catchments. Some comparisons are made in the discussion between the system described here and the design features commonly found in alternative electronic systems commercially available during 1982.

Hardware

The logging unit was designed to log data from a tipping bucket rain-gauge. The gauge channels rain falling into the mouth of its funnel into a pivoting bucket which tips over and empties itself when full. When the bucket tips, a magnet attached to it's base passes over a reed switch which then momentarily closes, alerting the data logger.

The data logging unit consists of a MC146805E2 microprocessor, 4096 BYTES of static CMOS RAM memory, a 27C16 CMOS EPROM, a MM58174 CMOS REALTIME-CLOCK and various support logic. The choice of CMOS digital logic ensures an extremely low power consumption by the data logger. The MC146805E2 single chip microcomputer has a useful power-saving "STOP" mode which stops all internal operations, drastically reducing power consumption. With the microcomputer in it's STOP mode, power consumption is of the order of a few hundred microamperes only, while in the "RUN" mode the logger power consumption is increased to approximately 30 mA.

The power supply is via four "C" size NICAD rechargeable cells with a capacity of 2 A/h. Since the data operates for the most time in it's STOP mode, the RUN/STOP duty cycle is extremely low and the batteries have sufficient capacity to operate the logger for up to three months without recharging.

The rainfall data are stored in RAM memory in a partially compressed format, the high portion of each byte containing a time count in minutes and the lower half of the byte containing the tip count. As each half of each byte can represent a maximum count of fifteen, this format sets a limit to the maximum time or tip count which may be represented by each byte of data.

Data logging is initiated by the first bucket tip during rainfall. At the first tip the DATE and TIME are stored in memory. Rainfall data are stored after this and logging continues until no tip occurs during any ten minute period, at which time it is assumed that rainfall has stopped. At this point a blank (zero) byte is stored to mark the end of that rainfall event in memory. During rainfall the real time clock provides timing pulses at one minute intervals so that the logger may accurately time the rainfall event. The software is considered in more detail in the next section.

To recover the data the logger is connected to a host computer which interrogates it and stores the data directly onto floppy disc for later processing. Communications between logger and host computer is by TTL level (5 V) serial format at 1200 bits per second. When the logger is connected to a host computer it communicates interactively with the operator, allowing him to check and set the time and date information in the real time clock, and to read the data from the logger into the host.

The data are not erased after reading, allowing multiple reads in case data from a previous read are lost. The data contained within the logger's memory are overwritten only once they have been read and the logger is once again connected to a raingauge and rainfall occurs.

The electronics and battery supply is entirely packaged within a single aluminium die-cast box with a six pin connector providing the interface to the rain-gauge, host computer and battery charger. The nicad cells are soldered together via connecting straps to obviate momentary disconnection of the power supply by mechanical shock during mishandling, thereby causing loss of collected data, a problem encountered with early prototype units.

The batteries are usually charged once a month for about two hours, the charging being via a constant current source providing approximately 250 mA as recommended by the cell manufacturer.

Software

The data logging system has been designed to maximise the measuring resolution during periods of high intensity rainfall and to minimize the amount of memory space that is used. The logging system is summarized in flow diagram form in Figure 1 where it can be seen that the logging period for low intensity rainfall (12 mm/h) is 10 min. Should 10 or more tips (2 mm) be experienced before a 10 min period expires then the data are written at the next integer minute or if a total of 15 tips have been accumulated then the time written is the nearest whole number of minutes less than the actual time accumulated and the remaining fraction of minutes is carried into the next period. For very intense rainfall periods (> 180 mm/h) 15 tips will be measured before the time count reaches 1 min in which case (0,15) is written, the tip counter reset and the additional number of tips accumulated up to the end of the 1 min period. The data pair (1, no of tips) is then written to memory. Finally, if no tips are registered in any 10 min period then a zero is stored and the memory "switched off" until the next tip. The only conditions where this system is rather wasteful of memory space is during prolonged light rainfall with an intensity of less than 1,2 mm/h (< 1 tip every 10 min). Under these conditions the real time month, day, hour and minute information is written out about every 20 – 30 min.

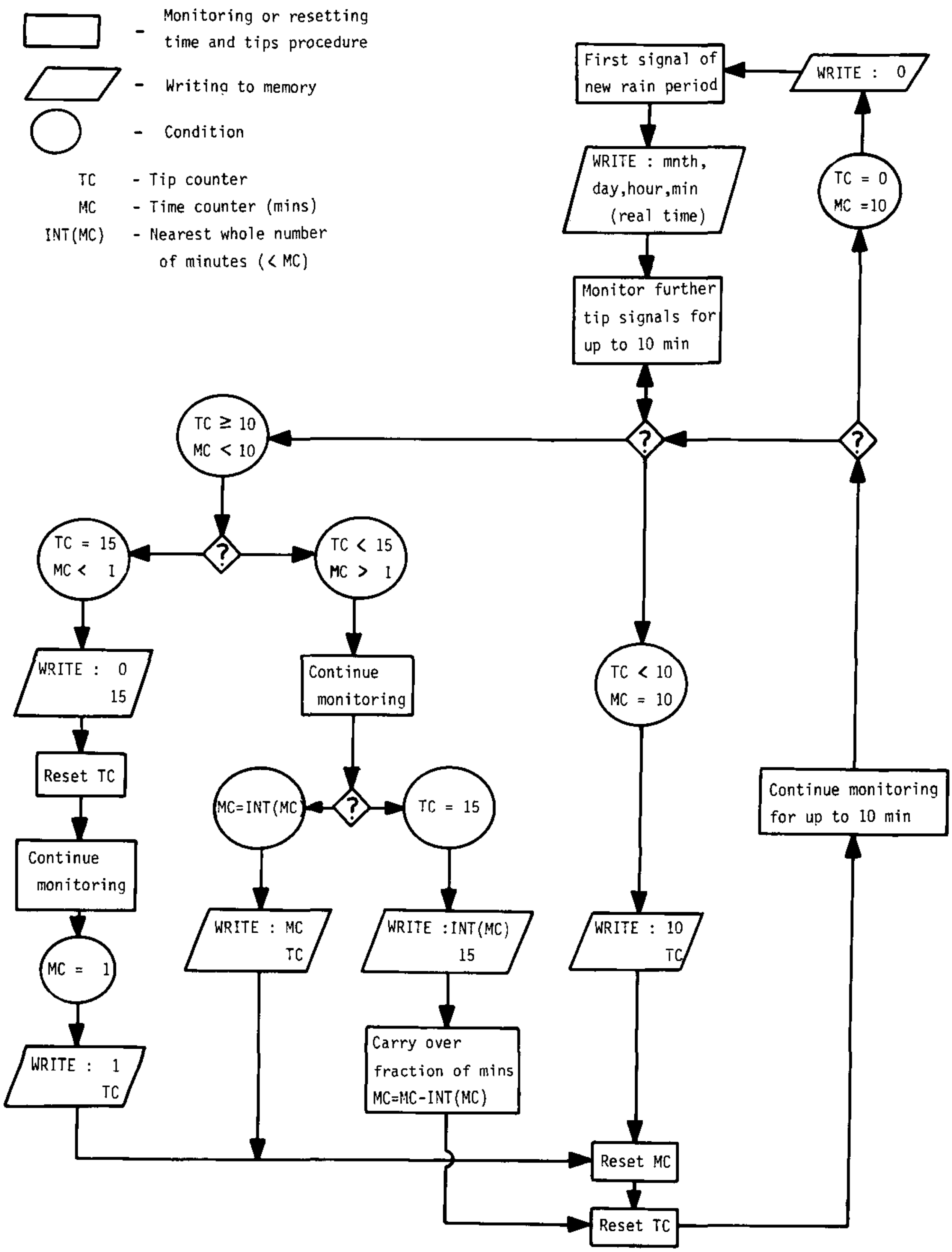

Figure 1
Flow diagram to represent the software for the electronic data logging rain-gauge.

An example of the memory space required is provided by the data logged during the period 5 July to 5 August 1983 in the Southern Cape. Apart from several short periods of rainfall the main block of data covered the storm of 24 to 28 July during which time the rainfall was more or less continuous. The intensity varied from very light falls to a maximum recorded intensity of 0,6 mm/min (over 4 min). In all 360 pairs of information (time count, tip count) were stored and the real time reference was written 70 times resulting in about 650 bytes (out of a maximum of 4 096) of storage space being used. An analysis of a number of years of daily rainfall records for the Southern Cape suggests that the maximum storage would never be exceeded if the logging boxes were changed every month and that under most circumstances the boxes could be left out for at least 3 months.

At Rhodes University the data are extracted using a microcomputer and program written in ASSEMBLER and temporarily stored on floppy disc. Further processing, to reduce the data to break-point rainfall increments, is carried out on the microcomputer using a BASIC program. The format of the output is then compatible with an established suite of programs used to process rainfall data obtained from digitizing syphon gauge charts. The final stages of processing and storage are carried out on the Rhodes CDC CYBER 825 main frame computer, facilitated by a link between the two systems.

Discussion

The discussion is centred around a comparison of the electronic data recording, tipping bucket gauge system with a typical mechanical recording syphon gauge. These are probably the two most common types of continuous rain-gauge systems in use at present and in making a comparison the following factors are considered.

Ease and reliability of operation

The procedure for changing the data logging boxes is much simpler and less prone to operator error than chart changing. In the Rhodes system, the real time clock setting is checked via the microcomputer each time the data is retrieved, the batteries recharged and the box plugged into the gauge in the field. The data stored can be read as often as desired, meaning that should a fault occur in the computer during reading, no data are lost, as it can be re-read again later. Once data have been read once, a flag is set automatically, such that new data overwrites the old. If this flag is not set (i.e. if the old data has not been read yet) then the new data are stored at the end of the old data. In this case data are only lost if the old and new sets combined exceed the memory space. This whole operating procedure compares very well with the process of clock winding, chart replacement and on/off date and time registration that has to be followed with a clockwork gauge.

Hardware reliability

The mechanism of a tipping gauge is far simpler than that of a syphon gauge with less components that are liable to fail. With respect to the logging devices, there is perhaps insufficient experience of the electronic loggers to categorically state that they are more reliable than chart recorders. However, the concept of 'infant mortality' is well known and accepted within the field of electronics. This refers to the fact that the components are unlikely to fail after an initial 'burn in' period, except through mishandling.

Four electronic raingauges (involving the use of eight logging boxes) have been tested by the HRU at Rhodes University during 1983. Two were installed in Grahamstown and the semi-arid Ecca research catchment in January and two in the Outeniqua mountains in the Southern Cape during May. Some early failures occured when the four NICAD batteries became momentarily disconnected during postal transit, causing an interruption in the power supply and a complete loss of data. The problem was rapidly identified and solved by using a battery pack consisting of four batteries permanently linked. Following this improvement, no loss of data has occurred and by the end of 1983 the Grahamstown gauge had returned a complete 12 month record while only one month had been missed (due to battery disconnection) from the Ecca gauge. Both the Southern Cape gauges have been working successfully since August. It is extremely rare indeed for any of the syphon gauges to remain in operation for six months without at least some lost data or small hardware failure, regardless of regular servicing. Assuming that the logging boxes are not subjected to very rough treatment there is every reason to believe that they will continue working for a long time, even in the harsh environment of the semi-arid Ecca catchment were temperatures range between 0°C and 40°C and where lightning discharges are common in summer.

Frequency of gauge visits

One common criticism of electronic loggers is that a failure usually results in the total loss of data for the period between memory changes. This situation could obviously be serious in view of the much longer changing period than the usual week for paper charts. However, the improved reliability of the electronic loggers should more than compensate for this and although more time is required to effect a true evaluation, the authors are confident that less data will be lost using the Rhodes system, changed on a monthly basis, than syphon-type gauges. If each gauge failed once a year then the amount of data lost would still be less than the amount lost during 1981-82 for the 10 syphon gauges in the Ecca catchment.

For a remote station the longer period between visits is a distinct advantage. The period can also be varied such that during a dry season when few rainfall events occur the memory can be changed even less frequently (although at a greater risk of some loss).

Ease of data recovery

One of the greatest advantages of the electronic recording gauges is the fact that processing of data and their incorporation into any permanent data bank is much less time consuming as well as less prone to operator error. The data can be automatically processed in full by a suite of computer programs and the often tedious and error prone chart digitizing stage is eliminated.

Data resolution

A single tip, in commonly available gauges, represents 0,2 mm of rainfall, thus with a 10 min logging period, the lowest intensity that can be identified is 1,2 mm/h. Any rain falling at a lower intensity is reduced, during logging, to a series of 10 min periods with 1,2 mm/h intensity separated by zero rainfall periods. For intensities between 1,2 mm/h and 12 mm/h the time resolution remains at 10 min, but for greater intensities the resolution increases until at 180 mm/h it is 1 min. For a typical syphon gauge chart, where one trace represents one day and one syphon 10 mm, the theoretical time resolution can vary between 1 min and 3 min and the rainfall depth resolution between 0,03 mm and 0,09 mm depending upon the trace line thickness. For weekly charts and 25 mm syphon ranges these figures become 8 min to 20 min and 0,08 mm to 0,2 mm respectively. While some of these figures appear to be superior to the tipping-bucket gauge, in practice these theoretical resolutions are rarely achieved due to clock errors, non-vertical syphon traces and operator digitizing errors amongst others. It is therefore considered that the tipping bucket gauge and electronic logging system used at Rhodes, returns data that are of an adequate resolution at medium to low intesities and a highly competitive resolution at high intensities. Should a higher resolution than 10 min be required for medium to low intensities then this can be achieved by a relatively straightforward change in the microprocessor program, although a given storm will then occupy more memory and changing visits may have to be more frequent.

Costs

Table 2 gives a breakdown of comparative costs for a 10 gauge network using typical syphon gauges or solid state memory-tipping buket gauges and it is clear that savings can be made using the latter system. No account has been taken of the computer hardware required to extract the data from the electronic memories as it is assumed that the syphon gauge charts are processed using a digitizer and micro-computer and that the only additional hardware required would be a relatively inexpensive serial interface board.

It has not been possible to carry out a thorough comparison of the Rhodes system with other available solid state loggers. However, the Rhodes logger was designed to avoid some of the disadvantages that the authors identified in the commercially available alternatives. A number of these disadvantages came to light during informal discussions with other hydrologists and scientists (Cousens, 1982). While it is not the purpose of this paper to criticise any specific system that was available in 1982, none were identified that either had a satisfactory reputation or that met the HRU requirements at a price competitive with chart recording raingauges.

TABLE 2
COMPARATIVE COSTS FOR A 10 GAUGE NETWORK

Typical syphon gauge		Solid state recording gauge	
Gauge complete	R 1 200	R 360 R 470*1	Tipping bucket gauge Two data logging boxes
		R 830	
10 units	R12 000	R8 300	10 units
2 spare clocks to allow regular servicing*2	R275	R 470	2 spare logging boxes for emergency breakdowns*3
4 spare pens in case of failure*2	R15		
TOTALS	R12 290	R8 770	

Notes: *1 Non-commercial price based upon component cost and time for assembly (Sept. 1982)
*2 Requirements based upon HRU experience
*3 Assumes less than one month turn around for repair of failed boxes

The final part of this discussion compares some of the advantages of the Rhodes system with typical features of alternative system:

- The interface to a host computer is built into the logger box thus avoiding the extra expense of a separate interface unit.
- A realtime clock is built in, thus obviating the necessity to manually record time during installation. Many alternative loggers rely upon a registration procedure before logging can begin. The Rhodes logger is merely plugged in, which avoids operator error at a very crucial stage in the data collection procedure.
- Owing to the use of CMOS electronic components, which have very low power requirements, the logger has a self-contained power source. Many of the alternatives require a rather bulky external power source.
- The logger uses CMOS RAM memory which does not need to be erased before collecting new data. Commonly used EPROM memories require either ultraviolet or electronic erasure involving the cost of the erasing device as well as a potential source of damage due to mishandling.
- The software has been designed to be very economical in terms of memory space by effectively closing down during periods of no rainfall. This can be compared with other systems that often log continually at regular intervals, or at best extend the logging interval to 2 h during dry periods. Most commercially available systems are quoted as having memory capacities of up to one month. The memory of the Rhodes logger is easily sufficient to record an extremely wet month in a humid region, and in more intermittent rainfall regimes, could well last for three months.

Conclusions

It is clear that electronic recording gauge systems can be superior to mechanical syphon gauges in almost every respect. This paper has described the design of one such system and attempted to show that it has advantages over others for use in a gauge network established to yield continuous rainfall data of research quality and resolution. The logger box is a self-contained device which can be used with any tipping bucket raingauge. It has the great advantage of an extremely simple operation procedure and is at least as reliable as any other rainfall logging device currently available.

It is an economic impossibility to immediately replace all old syphon gauges, in an established network, with new electronic gauges. It is therefore imperative that data received from the two gauge types can be made compatible at an early stage in the processing system and subsequently processed and stored together. It is then possible to use eletronic gauges to either replace defunct syphon gauges or to extend the network when required without causing a break in a long record and with no disturbance to the final data storage technique.

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