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THE UNIVERSITY OF NEW SOUTH WALES

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Manly Vale N.S.W. Australia

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by

Chin Hong Cheah

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Supplementary Notes

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Abstract

A field monitoring station with telemetric capabilities was established to collect rainfall and runoff data of a roof catchment located in the UNSW Water Research Laboratory at Manly Vale. The data collection system enables hydrologic information such as rainfall depths and runoff volumes to be obtained during rainfall storm events. Roof runoff quality samples were also collected and analysed. Collected data was transmitted in real time via General Packet Radio Service (GPRS) to an Internet server for storage. Detailed description of the telemetry system is provided in this report. Based on the data transmission success rate, the reliability of the system during the monitoring period was determined to be 99.95%. Benefits of incorporating such a system were evident and discussed herein. Operation of the field station can be monitored without having to be present at the site. This new approach in collecting hydrologic data will be valuable for practical applications at remote locations and also minimising interruption during data collection exercises.

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1. INTRODUCTION

The conventional approach in collecting hydrologic data from a field monitoring station is to store the gathered information in a data logger located on-site. The data is then retrieved during a site visit before evaluation can be made or manipulation of the data can be carried out. Various operational drawbacks stem from this approach. These include the need for frequent site visits to ensure ongoing reliability of the station and the lack of operator control over the station from remote locations. Fortunately, these problems can now be overcome with the installation of a telemetry system, whereby collected data are transmitted to a central location either wirelessly or through a land line. The availability of such state-of-the-art technology hence provides opportunities for improvement in the field data collection exercise.

In response to the scarcity of information pertinent to stormwater contamination originating from roof catchments (Chang *et al.* 2004), a research project has been developed to investigate the quantity and quality of roof runoff in an Australian urban environment. Differences exist in runoff quality from a road to that from a roof as shown by Wong (2005). Recent emphases on adopting Water Sensitive Urban Design (WSUD) approaches for urban stormwater management also highlight the importance of understanding runoff and the associated pollutant transport processes from the many types of impervious surfaces in an urban environment.

Thus, the project objectives are as follows:

- To incorporate a GPRS telemetry system into a field monitoring station
- To determine the runoff quantity and quality from a roof catchment during various storm events.

Chapter 2 of this report provides a brief background to the project, outlining the importance of the study and its objectives. Site selection and installation of the field monitoring station are described in Chapter 3. Chapter 4 describes the data monitoring and retrieval processes, highlighting the application of the telemetry system. Preliminary results derived from the field exercise are then provided in Chapter 5. Chapter 6 provides recommendations for future improvements of the system. Monitoring will be undertaken throughout 2007. The need for further upgrades to the telemetry system will be assessed during this period.

2. BACKGROUND

2.1 Stormwater Runoff from Roof Surfaces

Runoff from roof surfaces has often been overlooked as a contributor to stormwater pollution even though it is an important transport pathway for pollutants that are washed from the atmosphere into the ground and subsequently groundwater. Various compounds contained in roofing materials may also be leached into the runoff during a storm event, exacerbated by the acidic nature of rainwater (Chang *et al.* 2004). Few studies have been conducted to investigate these processes occurring on different roof catchments, more so in the Australian context. Stormwater models that provide more reliable and accurate predictions for a roof catchment can only be formulated once the runoff processes are adequately characterised. Suitable treatment measures can only be implemented to manage roof runoff contamination once its nature and prevalence are understood.

The recently published Australian Runoff Quality (ARQ) reported that concentrations of contaminants such as lead, copper and cadmium in runoff from roof surfaces are significantly lower than in runoff from road surfaces (Wong, 2005). Samples taken from roofs generally exhibit metal concentrations which are a few orders of magnitude lower than those from road catchments. This is largely due to the fact that vehicles are the main contaminant sources of road surfaces (Ball, 2002) whereas pollutants on roofs originate primarily from atmospheric deposition and rainwater (Mason *et al.* 1999). Nonetheless, consideration of results from various studies indicates that the quality of roof runoff should be a concern, be it failing to meet drinking water quality standards (Thomas and Greene, 1993; Yaziz *et al.* 1989) or exceeding the maximum acceptable values for wastewater (Malmqvist, 1983; Quek and Förster, 1993; Zobrist *et al.* 2000). Therefore, it is of interest to investigate the quantity and quality of runoff from a typical urban roof catchment.

2.2 Field Data Collection

In order to better understand the runoff processes occurring on the roof surfaces, hydrologic measurements are required. The data obtained from these measurements may serve as direct input into simulation models for design, analysis and decision making. The sequence of steps conventionally followed for field data monitoring as proposed by Chow *et al.* (1988) is shown in Figure 2.1 and discussed as follows:

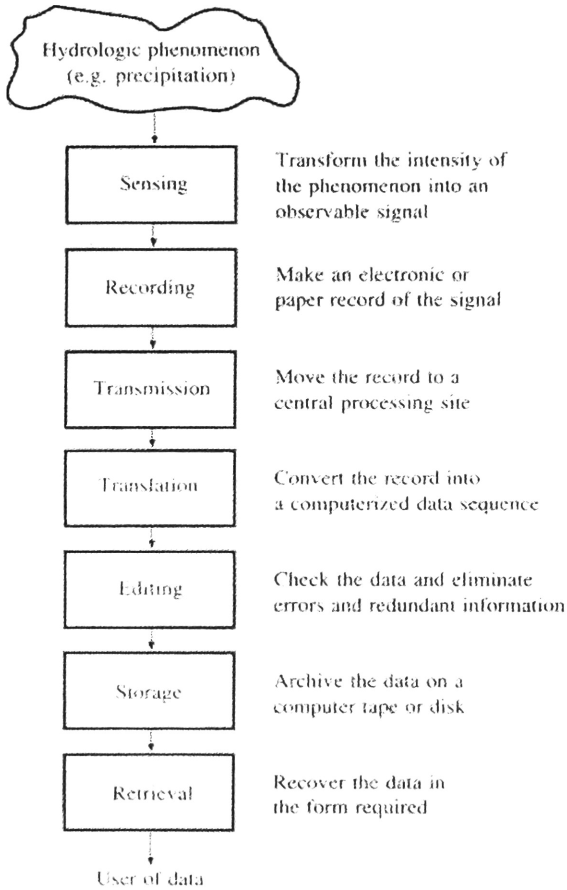

Figure 2.1: Hydrologic measurement sequence (After Chow *et al.* 1988)

Sensing

The level or intensity of the phenomenon is first transformed into an observable signal using a sensor. The sensors may be direct or indirect. A direct sensor measures the phenomenon itself, for example, rainfall depth is measured in a rain gauge. On the other hand, an indirect sensor measures a variable related to the phenomenon, for example, temperature is measured in a mercury thermometer by noting the change in length of a column of mercury. Many hydrological variables are measured indirectly including stream flow, temperature, humidity and radiation.

Recording

The signal produced by the sensor is then preserved by a recorder. This can be performed manually by an observer taking readings off the sensor and tabulating them for future reference, or automatically using a device which accepts the signal from the sensor and stores it on paper charts or in an electronic memory.

Transmission

Transmission is the transfer of recorded data from a remote monitoring site to a central location. This may be done manually by visiting the site and procuring the data, or it may be done automatically through real-time transmission utilizing radio networks, satellites, telephone lines, or through wireless telephony. For the latter case, the recorder has the data electronically stored and sends them back to the central location immediately or upon polling by a central computer. This is a valuable approach for providing continuous access to remote monitoring sites which are difficult to reach.

Translation

The original record in field instrument form is then converted into a computerized record for permanent electronic storage during the translation process.

Editing

The next step is checking the records translated into the computer to correct errors which might have occurred during any of the previous steps. Common errors include mistakes in the automatic timing of recorded measurements and information lost in transmission and translation, which can be filled in by directly analysing the record made on-site.

Storage

The edited records are stored in a computerized data archive, which is generally indexed by location and sequenced by the time of measurement.

Retrieval

Finally, the data can be retrieved by users for further analysis through accessing the computer database.

Advances in the fields of electronics and computer technology have enabled the development of faster, more accurate and reliable hydrologic measurement devices, data loggers, storage media, data transmission methods and analysis capabilities. Data can be gathered and disseminated more reliably and timely. The introduction of new hydrologic measurement devices has by and large removed the need to go through the *Translation* process, as records of data are kept in digital format. Moreover, the availability of telemetry systems further reduced the time taken for the *Transmission* of data, if not conducted in real time. These improvements are enough to increase the reliability of the hydrologic measurements made and improve the efficiency of the entire data collection process.

3. INSTALLATION OF FIELD MONITORING STATION

3.1 Site Selection

In selecting a suitable site for installing the field equipment and meeting the project objectives, a number of locations located in the vicinity of WRL were examined. Among the important aspects that were taken into consideration were:

Accessibility and Security

The location of the monitoring station must be conveniently accessible so that installation, inspection and maintenance of the equipment can be carried out with ease. Furthermore, runoff samples from the roof catchment can be gathered after a storm event and delivered to the laboratory in the shortest possible time frame. In spite of this, it would be preferable that the site be situated away from the public eye in order to reduce the likelihood of vandalism and potential theft of the installed equipment. This is a major factor given the high cost of procuring the equipment.

Interference with the Public and Need for Site Alterations

Another issue to be considered is the need for site alterations and whether the installation of the monitoring station would pose inconvenience to the public or local community. In choosing a site which is readily available without the need for major modifications, a lot of the complications involving local council approvals and permission from the community can be avoided. Minimal site alterations would also consequently reduce the set up costs.

Site Characteristics

For this study it was decided that the roof catchment adopted for the study should be representative of roofs found in urban areas. The surface should be free from excessive organic materials or growths so that runoff would not be impeded and determination of the pollutant loads affected.

3.2 Location and Catchment Details

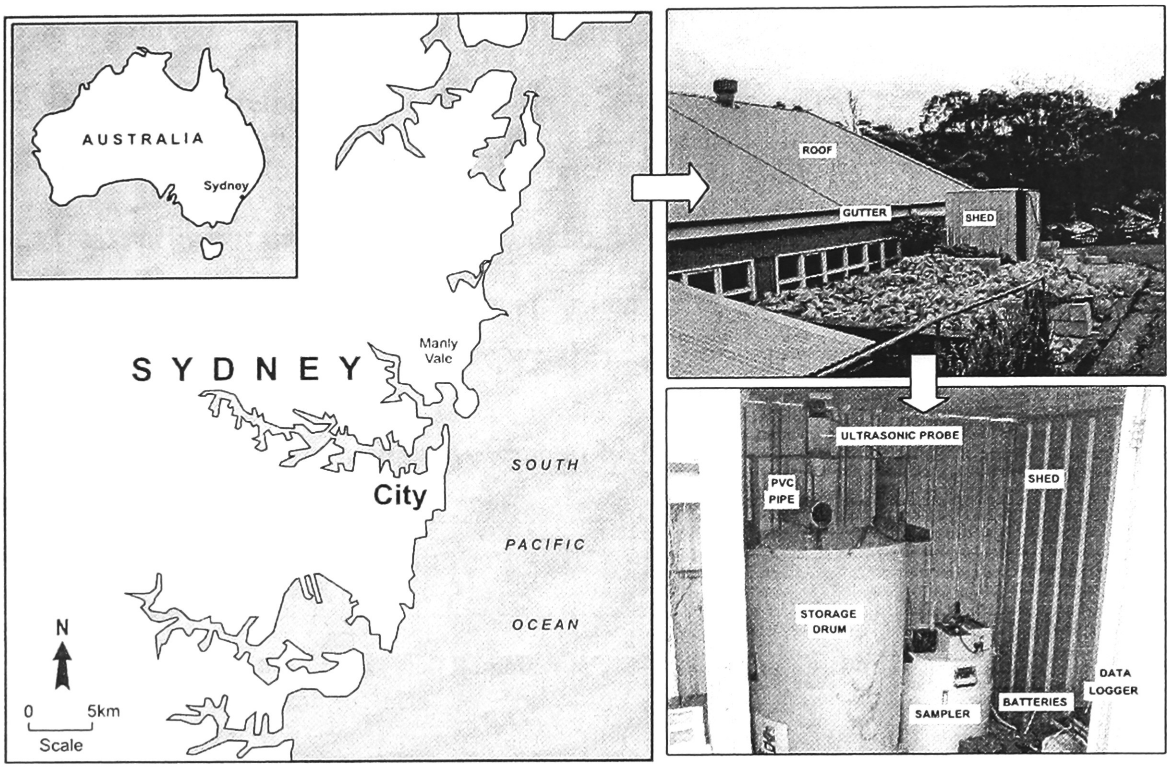

Figure 3.1: Location map of roof catchment

The site selected is a roof catchment located at the UNSW Water Research Laboratory, Manly Vale. This roof catchment has a typical urban roof drainage system and therefore is suitable for extrapolation of the study results to other roof catchments. The catchment consists of a 51 m^2 roof made of Colorbond® corrugated corrosion-resistant steel draining into an adjacent copper gutter, which is connected to a downpipe. The roof section has an inclination of 26° facing north-west, with no obstruction posed by nearby trees or buildings. The surface is relatively new (reroofed in 2004) and clean, without presence of any organic material that may influence the water quality results. One of the main reasons that this site was chosen is due to its accessibility and close proximity to the laboratory facilities. In addition, the area has restricted public access and virtually no interference with the public. Also, minimal site alterations were needed when the field monitoring station was installed adjacent to the site. A location map of the catchment is shown in Figure 3.1.

3.3 Field Instrumentation

In order to fulfil the requirements of the study, a system of monitoring equipment had to be assembled. It was desirable that the monitoring system:

- Incorporate telemetry capabilities
- Be able to monitor rainfall and flow rates coming off the roof catchment
- Take sufficient runoff samples throughout each storm event
- Be fully automated without manual assistance at the onset of a rainfall event due to the unpredictable nature of the weather.

Hence a robust and comprehensive system had to be designed and installed adjacent to the selected roof catchment.

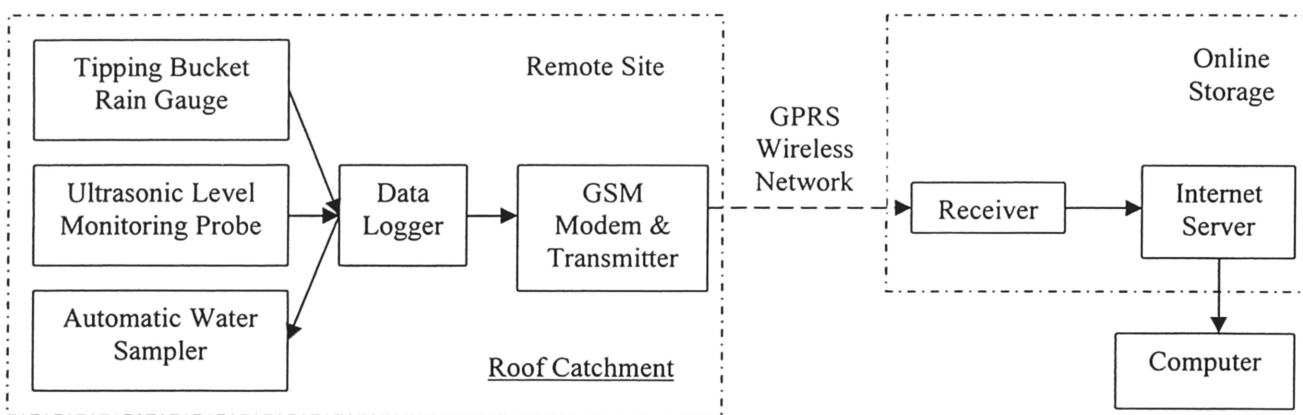

Figure 3.2: Schematic of setup of the field monitoring station and telemetry system

Shown in Figure 3.2 is a schematic diagram of the equipment installed and used at the monitoring station. The arrows indicate the direction of the information flow. A physical schematic diagram is shown as Figure A.8 in the Appendix. Key components of the system for monitoring roof runoff are described in subsequent sections with the manufacturer's specifications included in Appendix Section A.9. All equipment were calibrated prior to installation and maintained on a regular basis (at least once every fortnight) during deployment at the site.

3.3.1 Tipping Bucket Rain Gauge

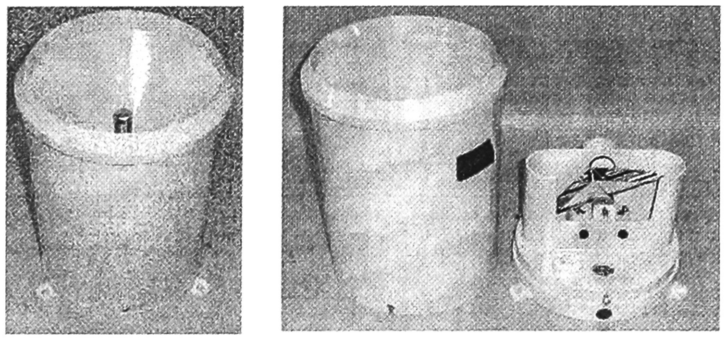

Figure 3.3: Tipping bucket rain gauge

A tipping bucket rain gauge (see Figure 3.3) was installed about 12 m from the roof catchment. A receiver of 200 mm diameter collects the rainfall which is strained by a metal gauze before being passed to the tipping bucket measuring system. Tips of the bucket occur when 0.2 mm of precipitation is received with each tip activating a reed switch closure which is in turn detected by the data logger. This is recorded as a count through the digital input channel. This channel is scanned at 17 ms intervals, equivalent to 60Hz. An additional standard rain gauge was used as a check against the values recorded by this tipping bucket rain gauge.

The rain gauge is located away from the sloping roof catchment. It is placed at a level surface and elevated at a distance of more than 2 m above the ground so that the effects of raindrops splashing can be avoided (WMO, 1983). It is connected to the data logger via a cable protected by an artificial speed hump as it goes across the surface of the road. The collector of the rain gauge is also clear of large obstructions such as buildings and vegetations, with a clear cone angle of 30° for overhead objects. All of these were done to ensure the rainfall measurements are representative of the actual rain falling on that given area. Cleaning of the collector was also carried out on a frequent basis. An illustration can be found in Figure A.9 of the Appendix.

3.3.2 Ultrasonic Level Monitoring Probe

An ultrasonic level monitor (see Figure 3.4) was used to measure the water level in the storage drum. This device operates by emitting a series of ultrasonic pulses from the transducer, with each pulse being reflected as an echo from the water surface and sensed by the transducer again. Internal filtering is then applied to discriminate the true echoes from the false ones. The time taken for the pulse to travel to the water surface and back is converted into mA (milliamp) output signal (with a range of 4 mA to 20 mA), corresponding to the distance between the ultrasonic sensor and the water surface. The unit is temperature compensated and requires a 0.25 m ‘blanking’ zone in front of the sensor. Hence, it is elevated at least 0.25 m from the expected highest water level in the drum. This unit is powered by a 24V DC power supply.

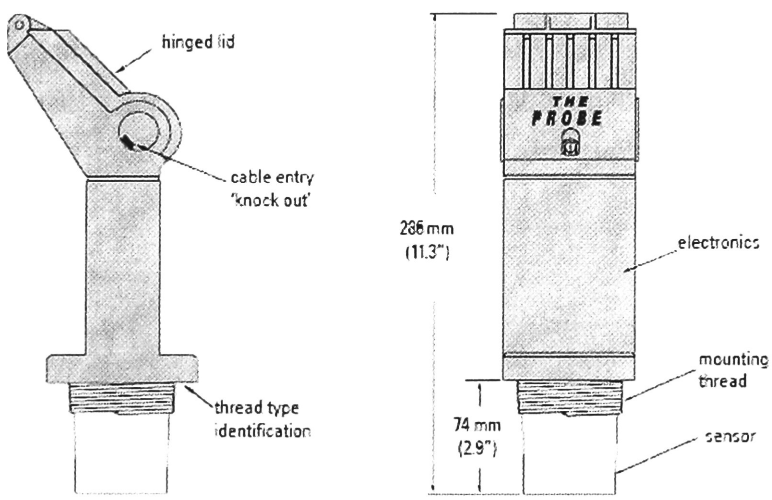

Figure 3.4: Level monitoring probe (After SMPI, 2003)

Calibration of the mA output was carried out so that the output span is proportional to the water level. In other words, the lowest water level in the drum (datum) will produce a 4 mA output whereas at the highest water level it will produce a 20 mA output. The whole calibration process was conducted as per SMPI (2003). The output signals were then stored in the data logger before being converted into water levels during the data processing stage. This is described in detail in Appendix Section A.7.

3.3.3 Automatic Water Quality Sampler

An automatic water quality sampler (see Figure 3.5) known as the Waste Watcher was used to obtain the roof runoff samples. It is configured in a master-slave relationship, whereby the sampler operates as a slave to the data logger. Once a predetermined rise in water level is recorded in the drum, the data logger would initialise and electronically pulse the sampler to begin operation.

Sampling of the runoff can be performed either by:

- Flow proportional sampling; or
- Time event sampling.

As it was intended that the pollutograph for the whole storm event has to be determined, time event sampling would be more appropriate as samples would more likely be collected for the whole hydrograph, including the rising limb, the peak and the recession curve. As a result, the temporal pattern of pollutant concentrations and loading may be monitored and this will also facilitate the determination of the event mean concentration. Given the small size of the roof catchment, the quick catchment response time and also the rainfall patterns recorded in this region, a sampling interval of two minutes was selected. As the sampler is able to collect a maximum of 24 discrete samples for each event, storm events with duration of less than 50 minutes can be sampled adequately.

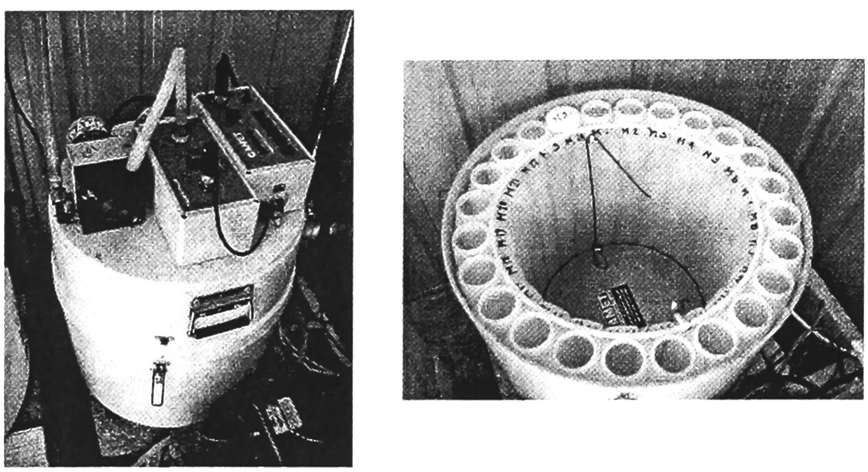

Figure 3.5: Automatic water quality sampler

In order to conserve battery power, the sampler is operated in "low power float mode". Hence, the sampler would obtain samples only when its controller receives a "wake up" signal from the data logger. The operation will cease when the external float switch opens during a sample run and starts again after another switch closure. This then provides the option of sampling from more than one rainfall storm event.

Trial runs were introduced to determine the pump running time for sample collection. In order to fill up the one litre sample bottle, a run time of 12 seconds was found to be enough. Also, the pipe connection between the sampler intake point and sample bottles was shortened so that the flow travel time can be reduced, therefore minimising power consumption. In addition to that, metallic fittings were removed to avoid possible contamination.

Runoff was sampled at the bottom end of the sloping PVC pipe just before the drop into the drum so that the instantaneous concentration of contaminants at the time of sampling can be determined. This is vital in working out the temporal variation of the contaminant concentrations during the duration of the storm event. As sampling was carried out prior to water level determination, errors were introduced. They will be accounted for in the volume calculation.

3.3.4 Data Logger

The data logger used is a dataTaker DT80 (see Figure 3.6). It is a robust data logger with multiple digital and analog input channels, as well as a built-in display. The communication devices of the logger provide RS232, Ethernet, USB and USB memory stick ports together with modem dial-in and dial-out functions. It has an internal data storage capacity of 64MB with the option of overwriting the memory once it has reached the storage capacity. For this field exercise, the data logger is powered by a 240V AC power supply.

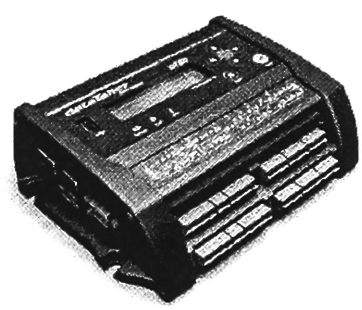

Figure 3.6: Data logger

In addition to logging and storing data, the data logger was used to initiate start-up, control and shut down of the main instruments such as the tipping bucket rain gauge, the ultrasonic probe and the automatic sampler during a storm event. Therefore the field monitoring station functions as a stand alone self contained modular unit. Data can be downloaded using the following methods:

- Directly from the logger via a combination of laptop and RS232 cable
- Using a USB memory stick
- From the Internet server where the data was transmitted via GPRS.

Configuration of the logger is performed using software referred to as DeTransfer.

3.3.4.1 DeTransfer and Data Logger Programming

DeTransfer is the software used to programme and operate the data logger by providing an interface between the logger and the laptop, via the RS232 port or USB. In order to prompt the logger to run an operating cycle, a programme containing textual commands was written and sent to the data logger through the "Send" window. The commands are then executed by the logger. Jobs (sets of commands) are generally stored in the internal file system of the logger along with the data they generate. Among the general categories of the commands include:

- *Channel definitions*: defining what measurements are to be taken, how they are to be acquired and how the measured values are to be presented
- *Schedule definitions*: defining when a setoff measurements are to be taken and where the results are to be stored
- *Job management commands*: allowing a set of schedule and channel definitions to be grouped into a single programme or "job", which can then be treated as a unit
- *Data management commands*: allowing logged data points and alarms to be retrieved, displayed or deleted
- *Configuration commands*: allowing various aspects of the logger operation to be adjusted to suit the project requirements.

A copy of the programme is included in this report in Appendix Section A.1.

Alternatively, data can be displayed in real time in the "Receive" window when the logger is connected to the laptop whilst being recorded in the internal memory of the logger.

3.3.4.2 Channels

Referring to Figure 3.7, two electronic data types can be acquired, digital and analog.

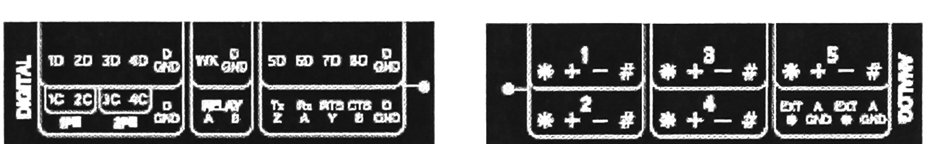

Figure 3.7: DT80 digital and analog terminals

Two inputs and one output connection were used in this field data collection exercise. For recording the number of tips generated by the tipping bucket rain gauge, a digital input channel was used. This channel was set as a counter and connected according to Figure 3.8.

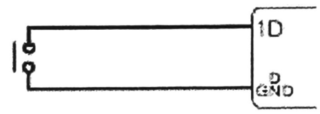

Figure 3.8: Connection of digital input channel

On the other hand, an analog input channel was used to record the 4-20 mA current output from the ultrasonic probe, as the current is proportional to the quantity being measured. Each analog input channel has an internal 100R shunt resistor connected between the "#" terminal and "AGND". A current loop measurement was adopted in this case whereby the logger measures the current across the internal shunt resistor and calculates the loop current. This is then scaled and returned as a percentage; 0% for a measured output of 4 mA and 100% for 20 mA. The loop is connected as shown in Figure 3.9.

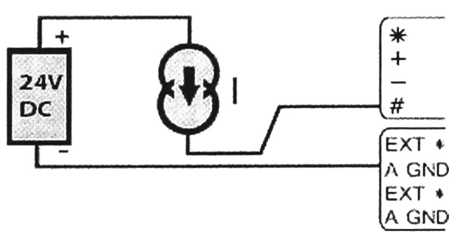

Figure 3.9: Connection of analog input channel

Lastly, a relay output channel was used to provide the switch closure to trigger the operation of the automatic water quality sampler. When the rise in the drum water level exceeds the predetermined value, the logger would initiate the sampler which in turn would start filling up the 1L sample bottles until an opened relay contact is detected. The connection is shown in Figure 3.10.

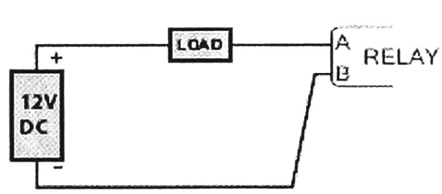

Figure 3.10: Connection of relay output channel

All of these connections complete the operating cycle of the system.

3.3.5 Storage Drum

A tapered circular drum was used to store the runoff coming off the roof catchment. It has a full storage capacity of about 224L with an outlet valve located at the bottom of the drum to discharge the water. The drum was also positioned in such a way that it is levelled to the ground, so that the water level would not be skewed.

Due to the limited storage capacity of the drum, only the first 4.4 mm of rainfall and runoff can be monitored and sampled. This is nonetheless found to be adequate in capturing the first flush that would occur during a storm event as results indicated that pollutant load from the roof catchment is supply limited with majority of the pollutants washed off within few minutes from the start of the storm event. The runoff volume collected in the storage drum can be determined using the method described in Appendix Section A.8.

3.4 GPRS Telemetry System

In this project, a telemetry system was established whereby real time data are transmitted from the monitoring station via a wireless modem over the GPRS (General Packet Radio Service) network and stored in a database located at a designated Internet server. GPRS is offered by mobile phone carriers and utilises the GSM (Global System for Mobile Communication) network that enables delivery of data directly from remote sites to a central database. This wireless communication service provides continuous connection to the Internet for GPRS capable devices and offers a cost-effective method of sending information.

3.4.1 Distinction from Other Telemetry Systems

Telemetry can be defined as a communication process by which measurements or data collected at remote places are transmitted to the receiving equipment for display, monitoring, and recording. The data transfer can be performed over different forms of media including telephone, computer network or via an optical link. The conventional telemetry system uses the telephone line for data transmission and acquisition. On the other hand, modern telemetry more commonly uses radio transmission and GSM technology for information transmission. One of the limitations of the earlier telemetry systems was the restriction of the subject to the confines of telephone lines. Wireless networking without the encumbrance and restriction of wires connecting the transmitter and receiver has catapulted the potential applications of telemetry solutions.

In using GPRS, data transfer is typically charged per megabyte of transferred data, while data communication via traditional circuit switching is billed per minute of connection time, independent of whether the system has been in an idle state. This has implications on the long term set up costs. GPRS is packet-switched, whereby multiple users can share the same transmission channel, only transmitting when they have data to send. This means that the total available bandwidth can be immediately dedicated to those users who are actually sending at any given moment, providing higher utilisation where users only send or receive data intermittently. The maximum speed of a GPRS connection is similar to a modem connection in an analog wire telephone network.

3.4.2 Benefits and Possible Issues

Following are some of the advantages observed by incorporating the GPRS telemetry system into our field monitoring station:

- *Convenience*: having the freedom of monitoring the station in any location with an Internet connection, thus allowing mobility and easy access to the recorded data without having to be present at the site.
- *Less restriction*: providing the option of installing the field monitoring system in any remote location without access to fixed land lines, hence less restriction in selecting a location as a monitoring site.
- *Reduce down time*: operation of the station can be monitored continuously through the Internet and any disruption in the data collection process will prompt immediate restoration efforts. Moreover, changes can be implemented immediately to the system to deal with unforeseen circumstances when required.
- *Cost effective*: service is charged for the transmission of data rather than the duration of connection.
- *Good coverage*: near ubiquitous network coverage, with 94.52% of the Australian population within the current coverage area as quoted by Vodafone Australia (2007).

It is expected that such a system would gain popularity in future field data collection exercise due to the benefits it has to offer and the economical feasibility in the long run. However, its reliability will be compromised whenever disruption occurs on the GSM mobile phone network or on any of the GPRS devices. These situations have yet to be encountered throughout the monitoring period. Another limitation of the system is the difficulty in estimating the data usage to date as this is not made known by the mobile phone carrier until the end of the billing month.

3.4.3 GSM Modem and Transmitter

The GSM/GPRS modem (see Figure 3.11) employed in this field exercise is capable of transmitting data, short messages (SMS) and fax messages via the GSM/GPRS mobile network. In this case, the data is transmitted from the data logger through the modem to an Internet server via the wireless GPRS network. A SIM card has to be inserted into the modem before it can operate on the GSM mobile phone network. The GPRS account may be supplied by any one of the carriers in Australia supporting GPRS. In order to set up a GPRS connection for the wireless modem, the Access Point Name (APN) has to be specified by the user. The modem in GPRS mode communicates over the Internet using standard Internet protocols. All modem settings are configured using software known as the Configuration Tool, which lets users configure the unit in a user friendly interface by programming the EEPROM (Electrical Erasable Program Read Only Memory). The settings will determine how the modem communicates with the server over the Internet. An overview of the setting is included in Appendix Section A.2.

Figure 3.11: GSM modem and transmitter

One of the advantages of using the GPRS network is that a reliable, uninterrupted stream of data can be obtained due to the availability of a continuous Internet connection. Data is constantly fed to the modem by the data logger via the RS232 cable before being transmitted to the online server where the information is updated and stored. In this project, setting up of the server and Internet interface is outsourced to Tony Kay Pty. Ltd. The modem is powered from the same power source as the logger; hence any disruption to the operation of the logger can be detected online with the cessation of data input.

3.5 Operational Logic

As discussed in Section 2.2, a sequence of hydrologic measurements is followed to gather data on the roof runoff process:

- *Sensing:* rainfall depths and drum water levels were determined using the tipping bucket rain gauge and ultrasonic probe
- *Recording:* the hydrologic data were stored in the data logger
- *Transmission:* recorded data were then transferred to the central database either through transmission over the GPRS wireless network or downloaded directly from the data logger during site visits
- *Translation:* the data files were converted into the correct format for storage
- *Editing:* the records were checked and compared with data from nearby monitoring stations
- *Storage:* edited records stored in the centralised data archive in a computer
- *Retrieval:* data were retrieved for subsequent analyses.

The operational logic of the equipment is shown in Figure 3.12.

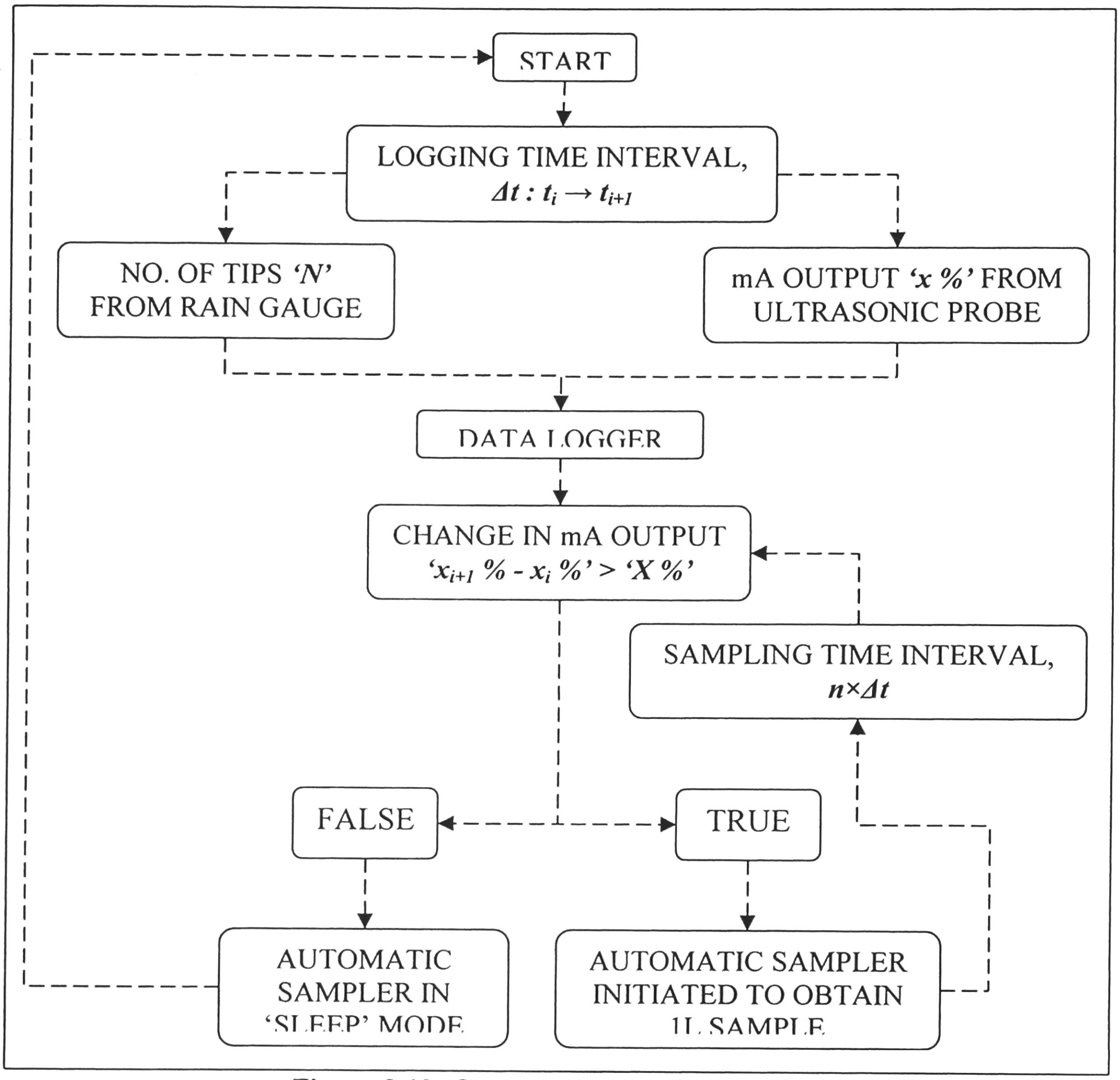

Figure 3.12: Operating cycle of equipment

The logging time interval of the monitoring system, Δt was set at 30 seconds. At the end of every time interval, the number of tips from the rain gauge and the mA output from the probe were recorded by the data logger. The logger then computes the change in mA output during the time interval and if the value exceeds *X%*, the automatic water quality sampler is triggered to obtain a runoff sample. This value is set as 0.4% after considering records from the initial storm events. The triggering criteria is based on the change in drum water level rather than the tips from the rain gauge as spatial variation of rainfall might occur and runoff may not be generated during the initial stages of the rainfall event. The whole cycle repeats until a false condition is encountered or when all 24 sample bottles have been filled up. After that, the sampler will return to "low power mode" while the logger continues to record data from the rain gauge and the ultrasonic probe. All data are continually transmitted through the modem via the GPRS network to an Internet server. Data can also be downloaded directly from the logger during the weekly site visits.

4. DATA MONITORING AND RETRIEVAL

4.1 Data Monitoring

Monitoring of the collected hydrologic data was performed in two ways:

- Frequent site visits
- Through the Internet in real-time mode.

This ongoing monitoring process ensures that the operation of the monitoring station is uninterrupted and continuous logging of the data is attained. Weekly site visits were made to inspect the equipment and to rectify problems that may have occurred. It must be noted, however, that this is often not possible for remote field monitoring stations and is subjected to the availability of the operator. Therefore, the focus was on utilising the established telemetry system that allows the collected data to be monitored online through the Internet. Any anomaly in the data indicates possible faults in the data collection system. The Internet site where the data is stored can be accessed as shown in Figure 4.1:

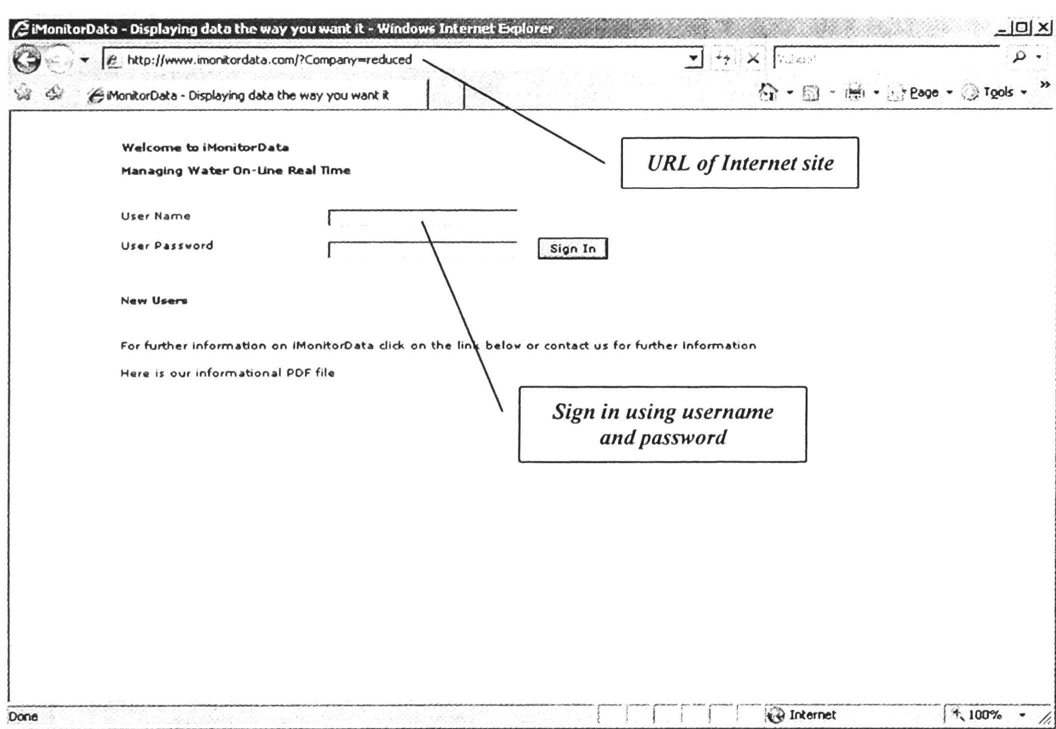

Figure 4.1: Internet login site where data is stored

A proper reporting format has to be defined before the data transmitted through the GPRS network can be displayed in the form of a graph or a table. Figure 4.2 shows the menu where this can be carried out.

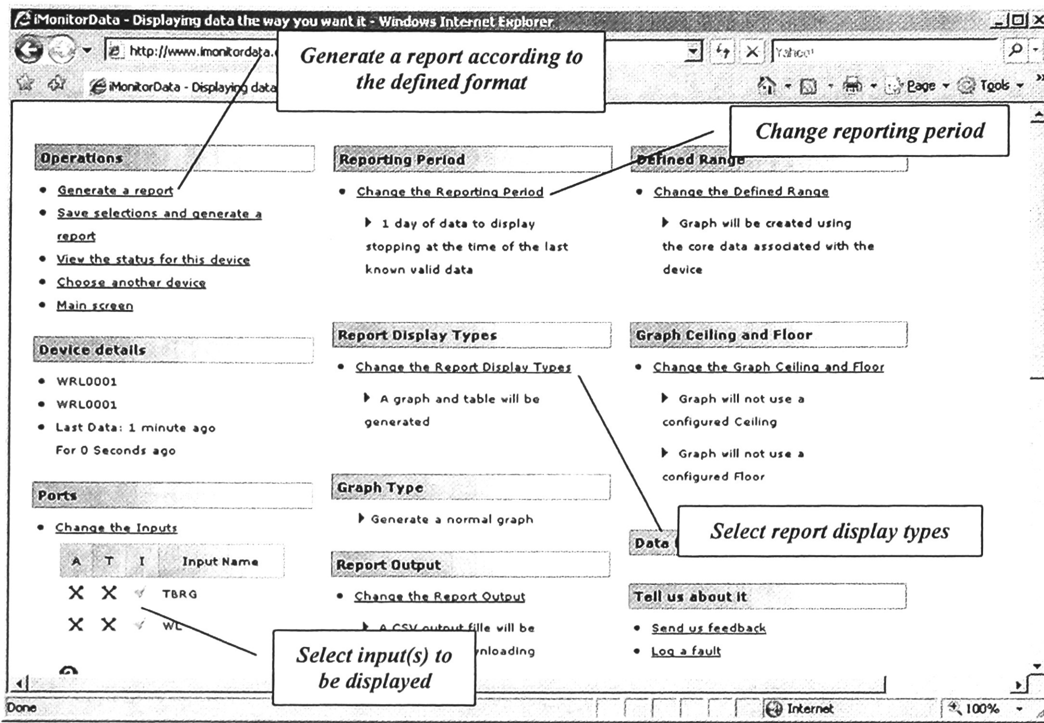

Figure 4.2: Defining data reporting format

The hydrologic data can then be shown in graph and table format (see Figure 4.3). Unlike the rainfall depths and drum water levels, the roof runoff quality is not monitored in real time.

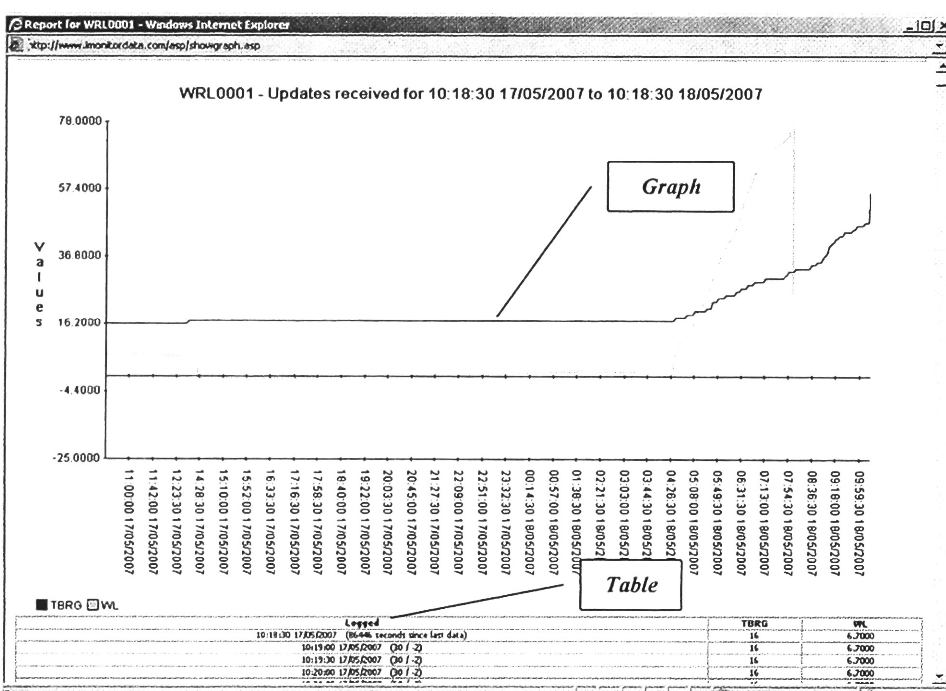

Figure 4.3: Data reported in both graph (top) and table (bottom) format

With this approach, the operator does not have to be on site to monitor the data from the logger.

4.2 Data Retrieval

During or after a storm event, the hydrologic data can be retrieved using two different options and they are discussed as follows:

4.2.1 Retrieving Data from Data Logger

The recorded data can be downloaded directly from the data logger during a site visit using either the combination of a laptop and RS232 cable or a USB key. The data file is found in the dataTaker binary data file format which can be exported to a spreadsheet for processing using software known as DeView (see Figure 4.4).

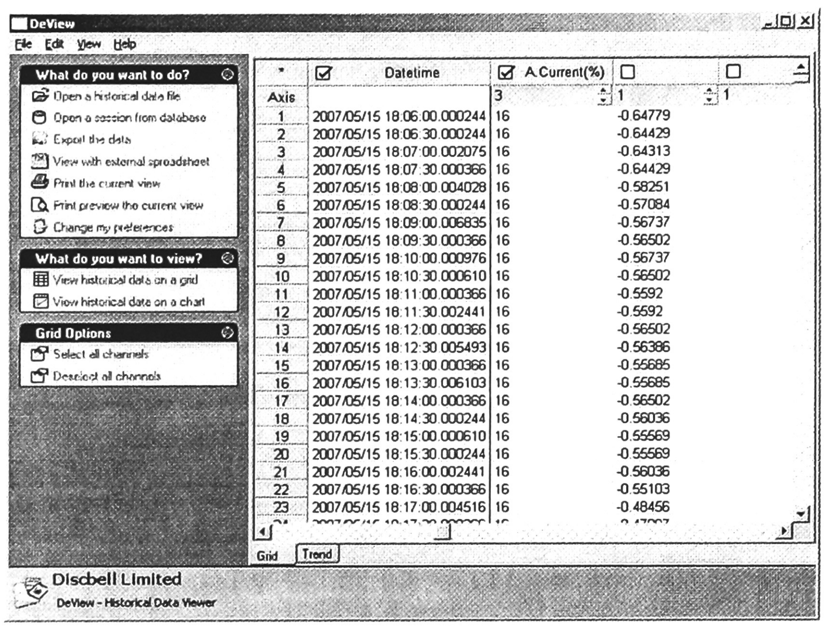

Figure 4.4: Viewing data in DeView

4.2.2 Retrieving Data from the Internet

The alternative method of accessing the data is by logging on to the Internet site (http://www.imonitordata.com/) as shown previously, where all data transmitted by the modem via the GPRS network are located at. Data can be monitored and downloaded at the same time in the following formats:

- HTML
- Text (Tab delimited)
- CSV (Comma delimited)

- Extended CSV (Comma delimited where dates and times are represented as Microsoft© compliant numbers allowing easy manipulation of data in Excel, Access or any other tool capable of using the supplied format).

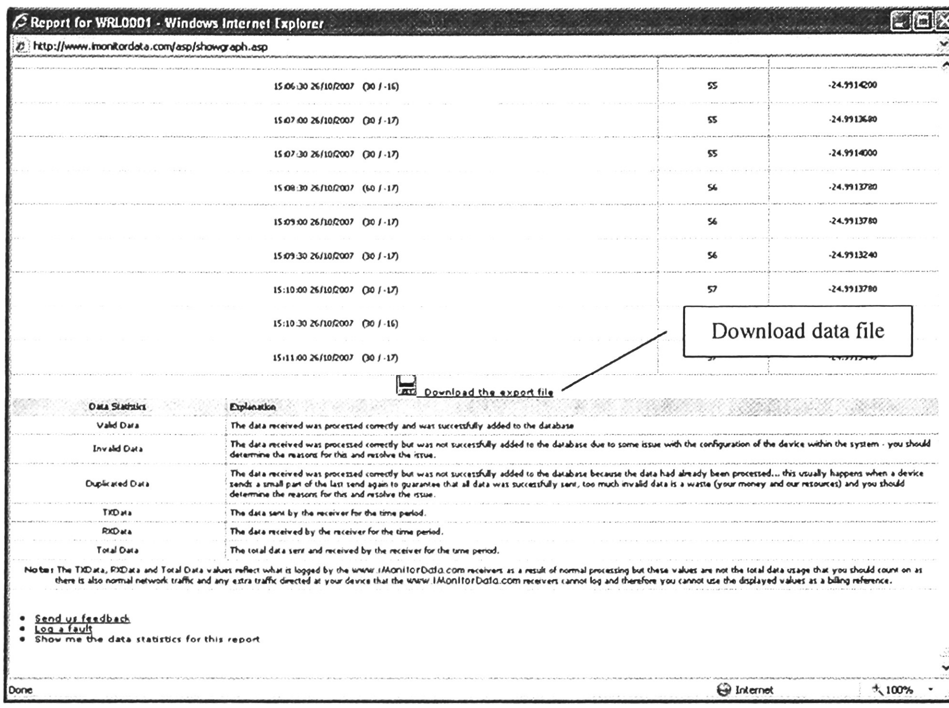

Figure 4.5: Downloading data file from the Internet site

All data can be exported to a spreadsheet for processing (see Figure 4.5). An alternative FTP site was also set up to store all data files and serves as a backup storage site. This is illustrated in Figure 4.6 and Figure 4.7.

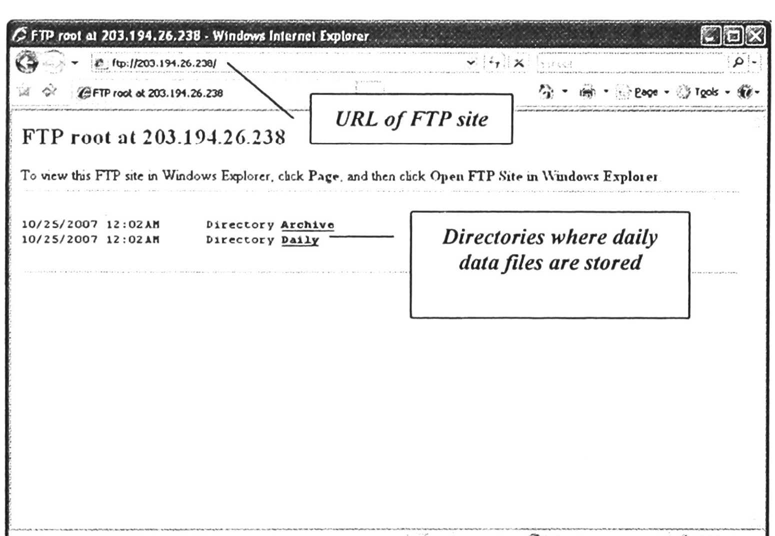

Figure 4.6: Downloading data file from the FTP site

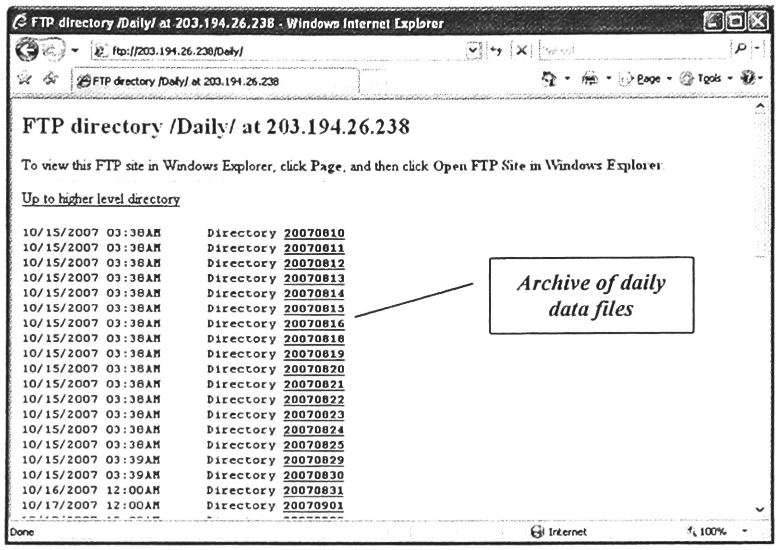

Figure 4.7: Directories in FTP site

4.3 Reliability of Telemetry System

Reliability of the GPRS telemetry system throughout the monitoring period was assessed by determining the data transmission success rate over the wireless network. According to Kay (2007), approximately 507563 lines of data have been successfully received at the receiver end, with 254 lines of data either missing or in error. Hence, the failure rate is about 0.05%. As the sampling interval of the logger was set at 30 seconds, this would amount to 1 or 2 lines of data lost per day. Therefore, it can be concluded that the system was highly reliable. The omission of data can be attributed to several reasons:

- Corruption of data records or data format, causing the receiver unable to retrieve or accept the data transmitted over the GPRS network
- Disruption to the GPRS network (rare)
- Issue with synchronising the data logger and the receiver, hence the occasional delay in the data set obtained by the receiver compared to the data set recorded by the logger.

Having consulted Hampson (2007) and Kay (2007), the following solutions were brought forward to address the aforementioned issues:

- Inclusion of a CRC (cyclic redundancy check) error checking mechanism in the system by rewriting the logger programme and changing the format of the data transmitted. This will allow the receiver to return a command to the modem and logger acknowledging whether the data has been successfully received or not. If not, the logger will be triggered to resend the data in the correct format.

- Reverting to an FTP transfer mechanism whereby a full error correcting protocol is inherently built in. This protocol actually uses TCP (Transmission Control Protocol) that includes error checking, ordered data transfer, retransmission of lost packets, discarding of duplicate packets and congestion flow control.
- Upgrading the firmware of the data logger to incorporate improvements in the data transmission protocols and power management areas.

These solutions were not implemented as they may result in other complications that may compromise the integrity of the current data collection system. Nevertheless, future installations of similar telemetric system should consider these alternatives.

5. EXEMPLARY RESULTS

5.1 Runoff Quantity

The monitoring period starts from early 2007. Many storm events have been recorded but runoff samples from only a selected few events have been collected. These rainfall events are typical of the many frequent storm events that occur in the Sydney region. Details of some of these events are presented in Table 5.1.

Table 5.1
Details of Runoff Sampling Events

Storm Event	Date	Sampling Time	No. of Samples	Rainfall Depth* (mm)	Runoff Volume* (L)	Antecedent Dry Period (Day)
A	7/02/07	19:01:00 - 19:13:30	5	1.6	82	5.4
B	24/02/07	20:18:30 - 20:55:00	10	3.2	166	11.6
C	4/03/07	23:13:00 - 23:29:00	9	4.6	230	4.3
D	8/03/07	21:00:30 - 21:46:00	10	3	159	3
E	12/03/07	20:17:00 - 20:27:00	6	3.6	182	3.9
F	7/06/07	3:36:00 - 4:31:00	8	4.6	229	8.1

*For sampling duration only.

All but one of the sampling events took place during night time. The antecedent dry period for the storm events (excluding events with less than 0.2 mm rainfall) ranges from 3 to 11 days.

Figure 5.1 shows the rainfall depths recorded with the corresponding hydrograph of a particular event. It can be seen that the field data collection system was behaving quite well as an increase in rainfall resulting in an immediate hydrograph peak, due to the short response time of the roof catchment.

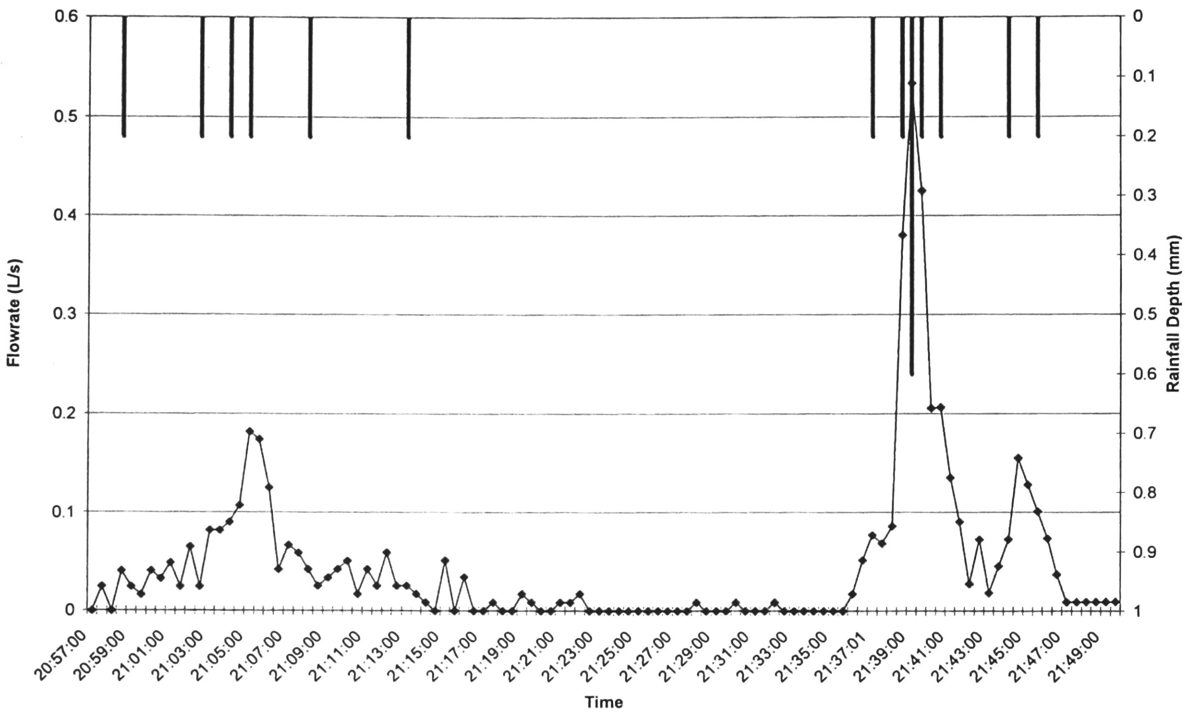

Figure 5.1: Rainfall depths and hydrograph for storm event D

5.2 Runoff Quality

5.2.1 Laboratory Analyses of Runoff Samples

After each storm event, the roof runoff samples were stored and subsequently taken to the University Analytical Laboratory of UNSW at Kensington for analyses. The parameters included are:

- pH
- Concentrations of trace metals both in dissolved and particulate form such as Cd, Cu, Fe, Mg, Mn, Ni, Pb, Zn
- Concentrations of suspended solids.

All pH measurements were made utilising a pH meter (accuracy of ±0.01pH) whereas the runoff samples were pre-treated and analysed for metals by the APHA (1998) standards, using the ICP/MS (Inductively Coupled Plasma/Mass Spectrometry) method. Blanks were included to ensure quality control.

5.2.2 Pollutographs

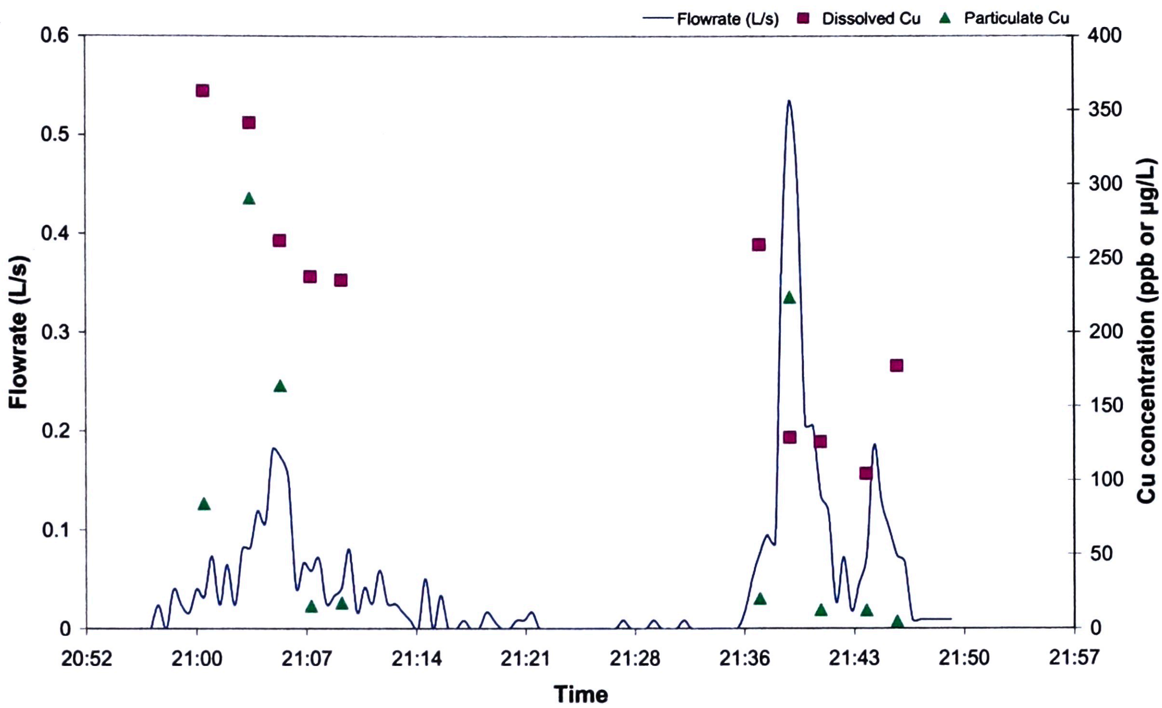

Figure 5.2: Pollutographs of copper for storm event D

The pollutographs and loadographs for each storm event can be plotted so that the temporal variation of the contaminant concentrations and loads can be examined. Pollutograph is a plot of pollutant concentration versus time whereas loadograph is a plot of pollutant mass flux verses time. Loadographs are determined by multiplying the concentrations of the contaminants with the flow rates. Examples are shown in Figure 5.2 and Figure 5.3.

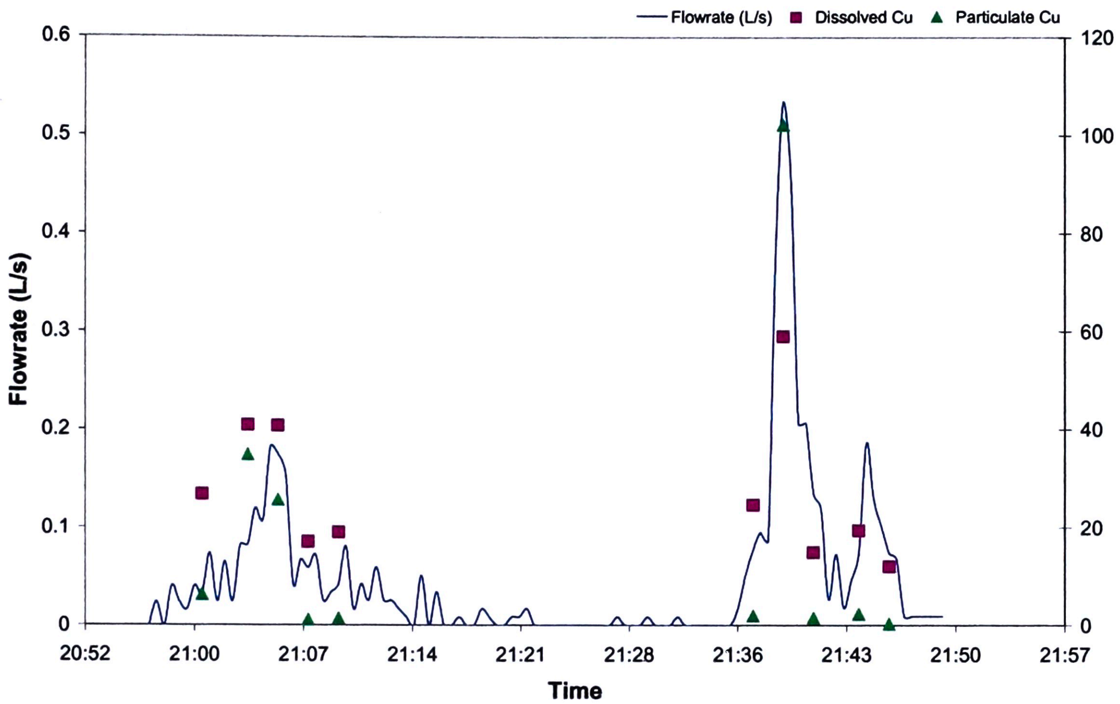

Figure 5.3: Loadographs of copper for storm event D

A general trend observed from the graphs is that the pollutant load transported downstream increases when the flow rate increases as runoff from the catchment entrains the constituents deposited on the catchment surface and transport them downstream during the storm event.

5.2.3 Event Mean Concentrations

The event mean concentration (EMC) is the total pollutant constituent mass divided by the volume of runoff. It can be expressed as:

$$EMC = \frac{M}{V} = \frac{\int C(t)Q(t)dt}{\int Q(t)dt} = \frac{\sum_{i=1}^{n} C(t)Q(t)\Delta t}{\sum_{i=1}^{n} Q(t)\Delta t} \qquad (1)$$

Where *C(t)* and *Q(t)* are the time variant constituent concentration and flow. As indicated in this mathematic expression for EMC, it is a flow weighted average. Consequently, when the EMC is multiplied by the runoff volume, the mass of pollutant constituent carried by the runoff can be estimated.

The event mean concentrations for the selected range of trace metals were determined for each storm event and are shown in Table 5.2.

Table 5.2
EMC (µg/L) of Metals in Roof Runoff for Different Storm Events

Storm Event		Cd	Cu	Fe	Mg	Mn	Ni	Pb	Zn	SS**
A	Particulate	0.03	224.59	2421.51	189.37	13.38	1.25	32.70	27.88	79.56
	Dissolved	0.13	731.56	37.25	757.43	19.20	0.55	3.93	101.01	
B	Particulate	0.01	68.23	212.47	46.52	2.02	1.97	12.21	5.53	19.09
	Dissolved	0.11	1529.81	13.82	130.16	4.20	0.66	18.98	66.13	
C	Particulate	0.03	523.08	233.49	49.23	3.35	2.59	13.66	10.30	18.11
	Dissolved	0.11	654.06	21.28	92.25	8.13	0.57	8.08	53.80	
D	Particulate	0.01	162.56	465.12	60.84	4.23	12.01	14.88	10.39	17.92
	Dissolved	<DL*	447.30	2.06	182.10	8.83	0.25	2.28	120.12	
E	Particulate	0.01	113.10	434.42	58.74	4.26	15.89	5.37	12.41	11.08
	Dissolved	<DL	33.79	<DL	365.07	1.14	<DL	<DL	33.00	
F	Particulate	0.02	91.29	506.68	104.35	8.31	1.77	8.79	19.95	19.74
	Dissolved	0.05	214.29	<DL	197.49	3.10	0.38	1.43	109.32	

*Below detection limit (<DL).
**Concentrations in mg/L.

Compared to values from road catchments, significantly higher copper concentrations were exhibited, with the source believed to be the copper gutter. Thus roofing materials are major sources of roof runoff contamination. Results show that contaminants such as iron, nickel and lead are mainly present in the particulate form whereas the rest are in soluble form. These results present certain management implications in treating stormwater runoff from roof catchments, as it is distinct from road runoffs where the particulate input is of more concern (Batley *et al.* 1994).

6. CONCLUSIONS AND RECOMMENDATIONS

A field data monitoring station has been installed in the UNSW Water Research Laboratory adjacent to a roof catchment to collect roof runoff quantity and quality data. Telemetry functions were added into the system and the installation details of the station were included herein. Benefits of adopting the latest GPRS technology into the field data collection have been shown. A success rate of 99.95% has been recorded in transmitting the collected data over the wireless network. Possible issues that may affect the reliability of the telemetry system are also discussed and solutions are provided. As field data is constantly relayed back to the central database and remotely monitored by the operator throughout the monitoring period, remedial actions were immediately introduced when problems arose and equipment malfunctions were able to be resolved in a matter of hours.

Enhancements to the communication system reported herein can be made by extending it to operation in a two-way mode between the operator and the monitoring system. Two-way communication over the wireless GPRS network would enable the operator to gain more control over the operation of the monitoring station. Direct feedback and corrective measures can be executed in the form of commands whenever abnormality of data is encountered. This will increase the reliability of the data collected during the exercise.

The project can be extended to more catchments so that a thorough investigation of the roof runoff quantity and quality can be carried out. This is made easy with the application of the GPRS system which allows simultaneous collection of data transmitted from multiple locations. Data can then be stored in the same designated location on the Internet.

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APPENDIX

A.1 Data Logger Programme

```
'==================================================================
' Site: WRL0001 (WRL Workshop Roof)
' Application: GPRS
' DataTaker: DT80
' Program written by Chin Hong, Cheah
' Date: 22/6/2007
' Version: 2.2
'==================================================================

H                          'Halt the DT80 before sending the program.

DELDATA*                   'Delete all data from the dataTaker.
DELALARMS*                 'Delete all alarms from the dataTaker.
DELJOB*                    'Delete all jobs from the dataTaker.

BEGIN"WRL0001"

CATTN                      'Clear the attention light.

'Set switches and parameters to output data in the CSV format,
/e          'Turns off Echo from the DT80.
/m          'Turns off Messages from the DT80.
/R          'Turns on data Returns from the DT80.
/t          'Turns off Time stamp in returned data.
/d          'Turns off Date stamp in returned data.
/h          'Turns off Fixed format mode. (DeLogger will turn this back on)
/n          'Turns off channel number in returned data.
/c          'Turns off Channel type in returned data e.g. TK
/u          'Turns off data units in returned data e.g. Deg C
/l          'Turns off the DT80 serial number in the returned data.
P22=44      'Sets Data delimiter character 44 = , (comma).
P24=13      'Sets Scan delimiter character 13 = CR (carriage return).
P32=8       'Sets number of significant digits to 8.
P41=0       'Sets time sub-second digit to 0.
```

```
'Add extra functions to the display
FUNCTION1="START" {GA}                          'Function 1 starts logging.
FUNCTION2="STOP" {HA}                           'Function 2 stops logging.
FUNCTION3="RA10S" {RA10S}                       '10 seconds logging speed.
FUNCTION4="RA30S" {RA30S}                       '30 seconds logging speed.
FUNCTION5="RA1S" {RA1S}                         '1 second logging speed.
FUNCTION6="SetSwitches" {/e/m/R/t/d/h/n/c/u/l P22 = 44 P24 = 13 P32 = 8 P41 = 0}
'Set switches and parameters from the display.
FUNCTION7="RUNJOB" {RUNJOB"WRL0001"}            'Runs the job.

1..2CV(W)=0                                     'Initialises Variables

RA("B:",ALARMS:OV:100KB,DATA:OV:1MB)30S LOGONA GA      'Schedule

$="#!,WRL0001"                                  'Prefix for GPRS
D                                               'Date
T                                               'Time

4C("TBRG")                                      'TBRG digital channel
4#L("Current")                                  'Probe analog channel
4#L(=1CV,W)                                     'Assign reading to variable
2CV(W)=1CV-2CV                                  'Compute difference
ALARM1(2CV("Pulse")>0.4)1RELAY {[1RELAY(R)]}    'Trigger sampler via relay
2CV(W)=1CV                                      'Assign value to variable

END
```

A.2 Modem Configuration

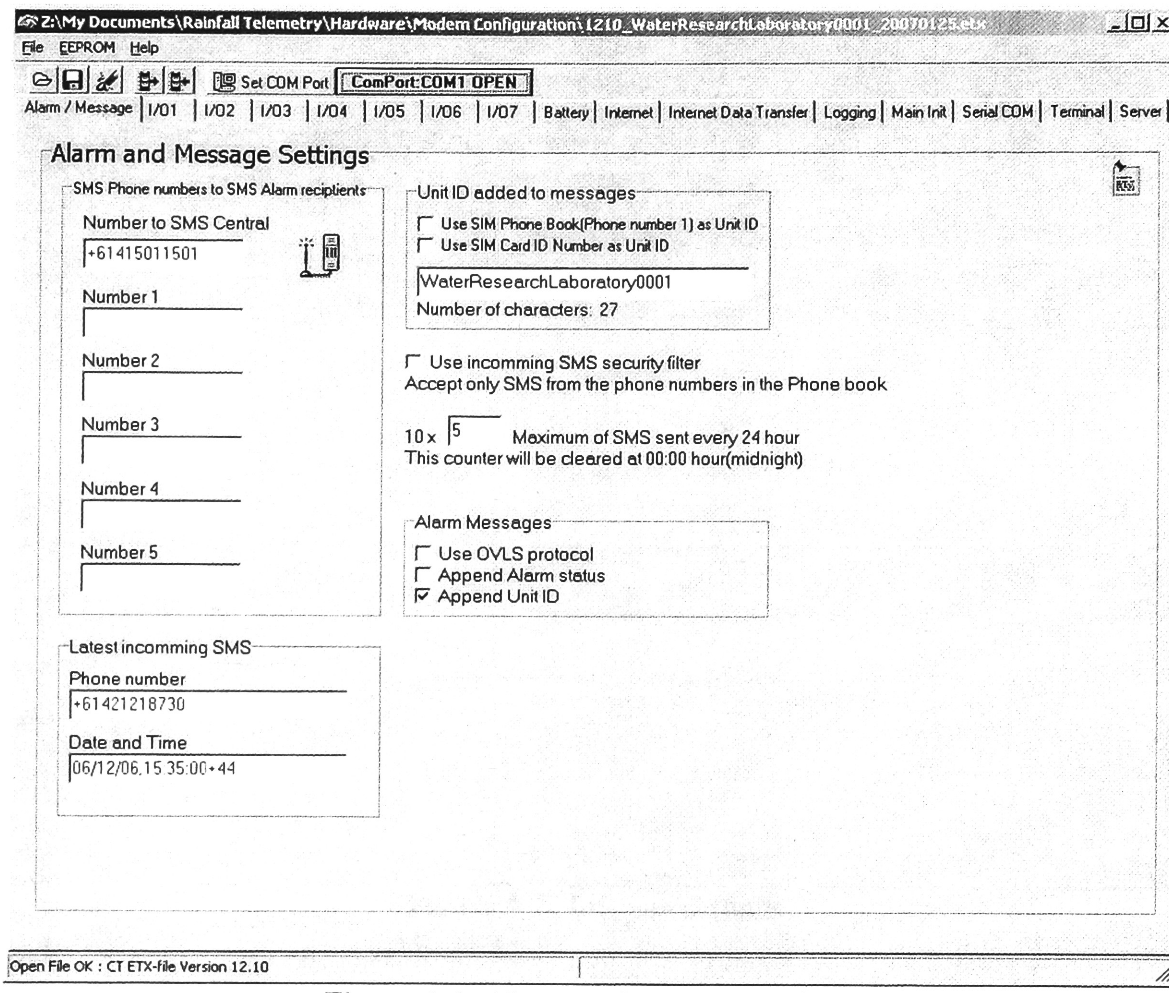

Figure A.1: Alarm and message settings

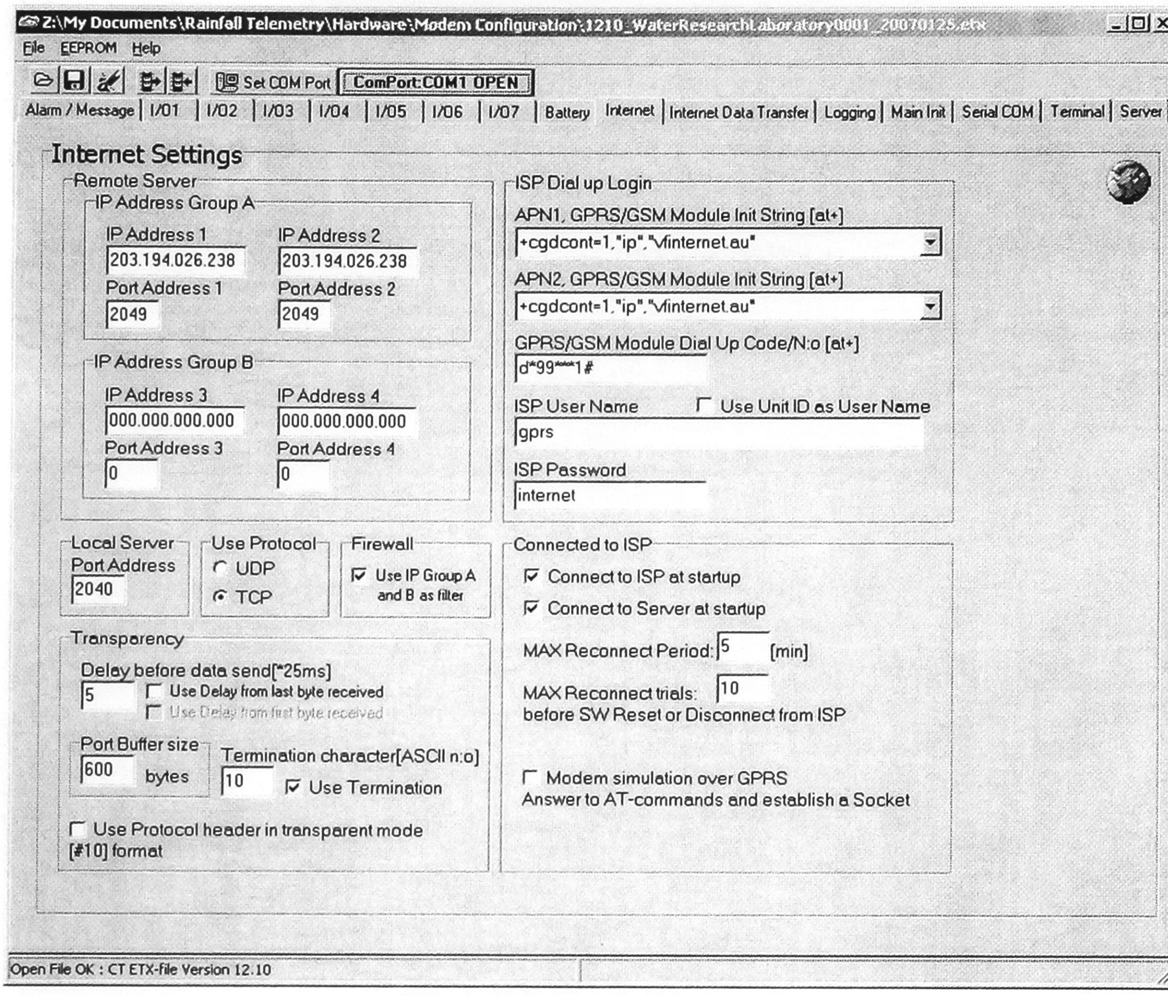

Figure A.2: Internet settings

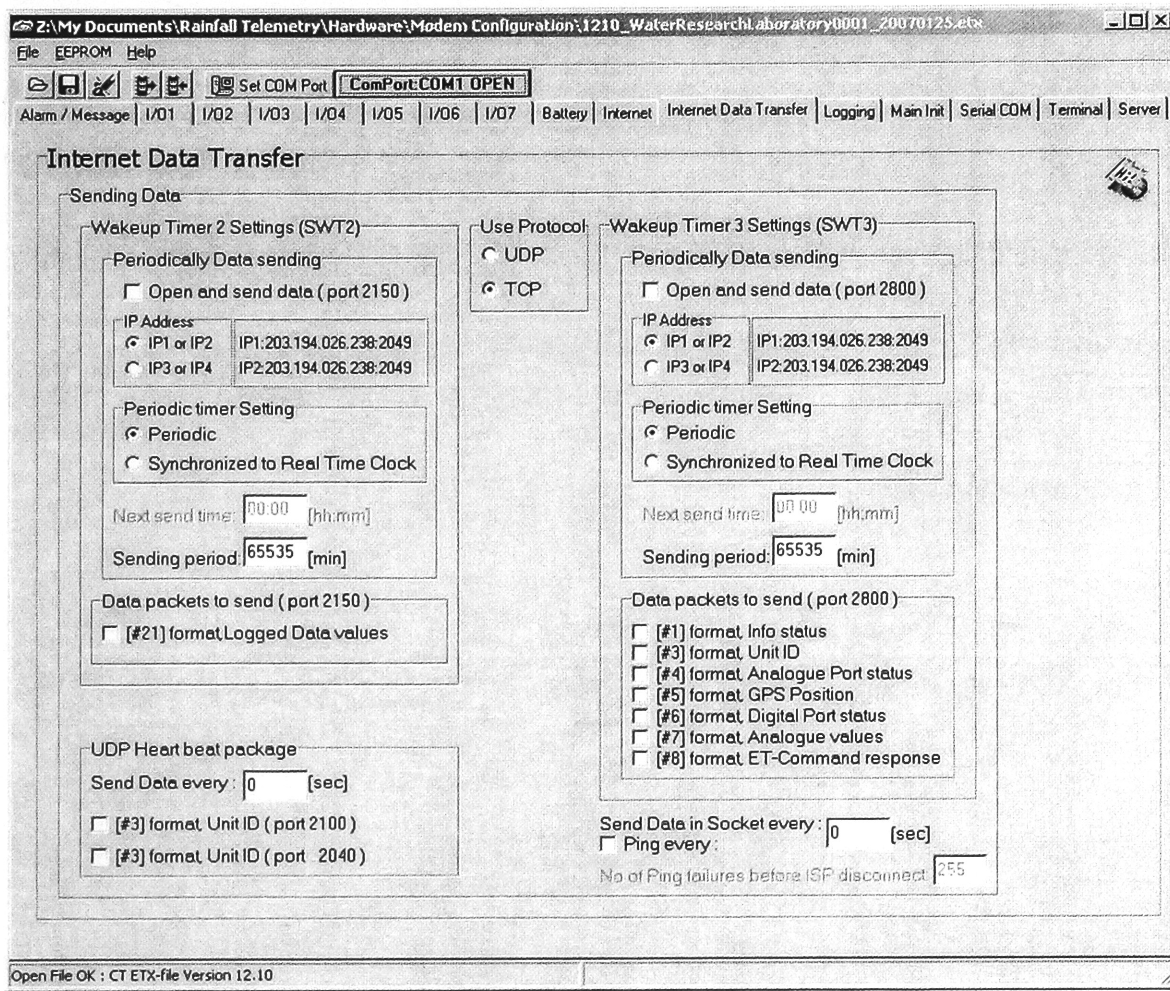

Figure A.3: Internet data transfer

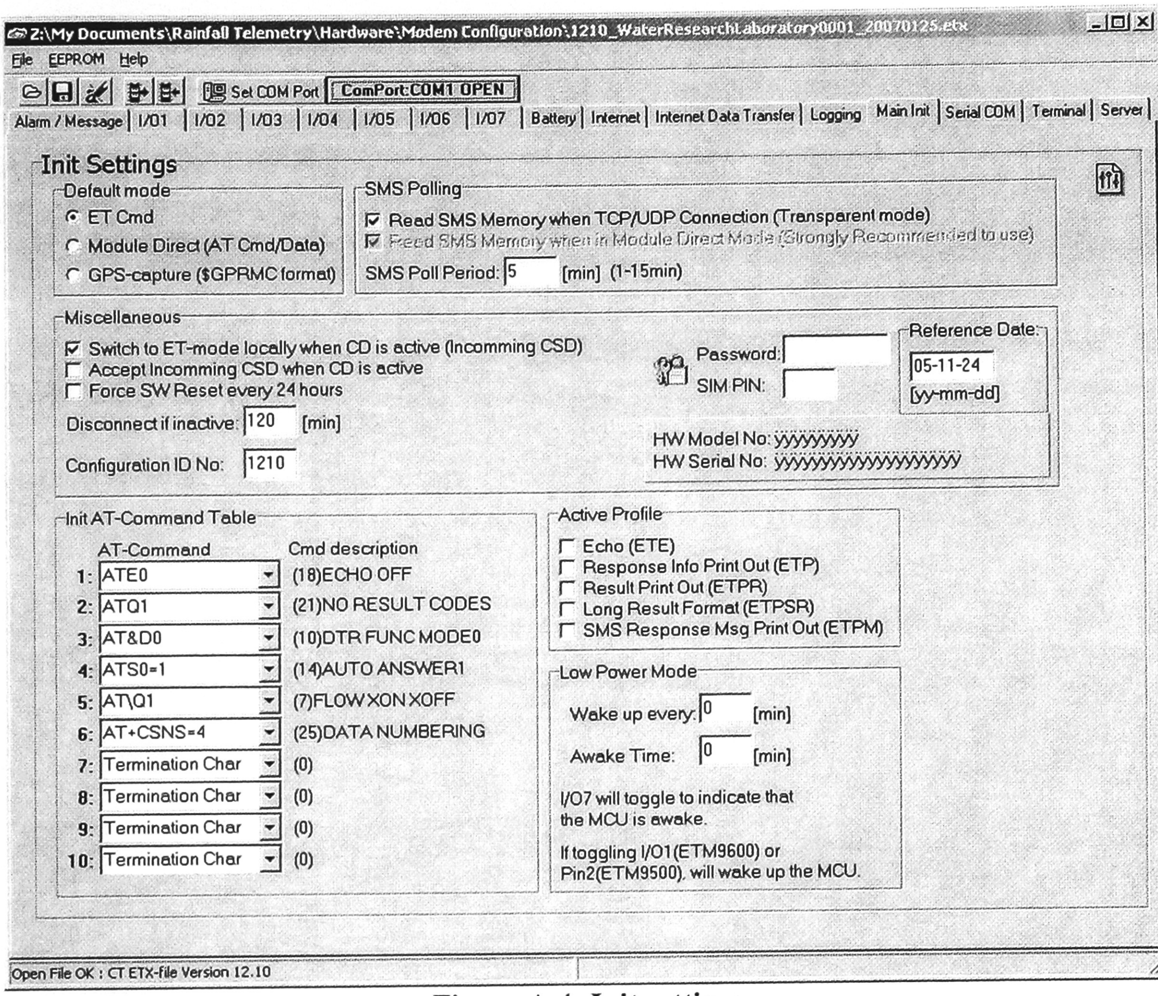

Figure A.4: Init settings

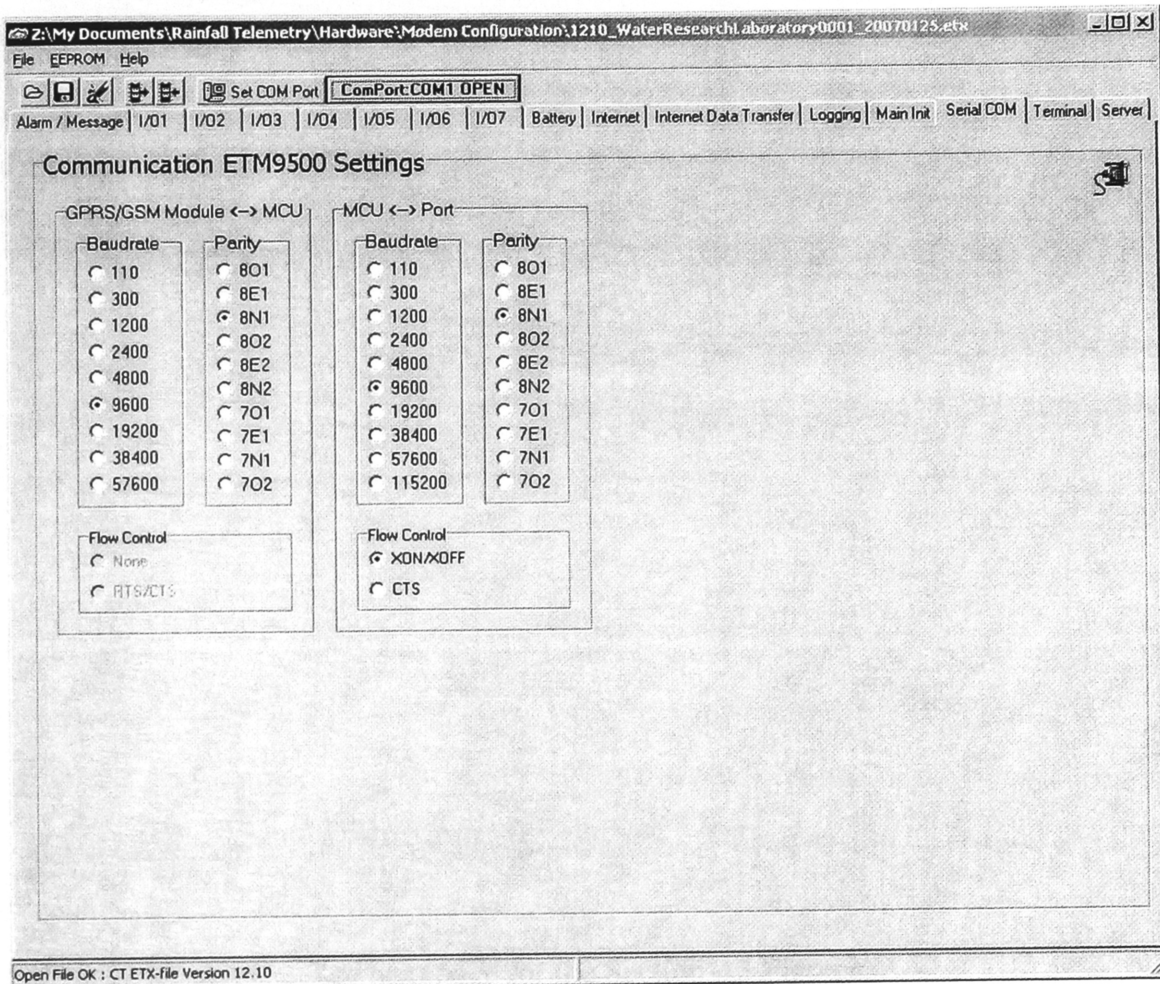

Figure A.5: Communication settings

A.3 Drawings

See next page for the Section A3 Figures.

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PLAN VIEW OF FIELD MONITORING STATION

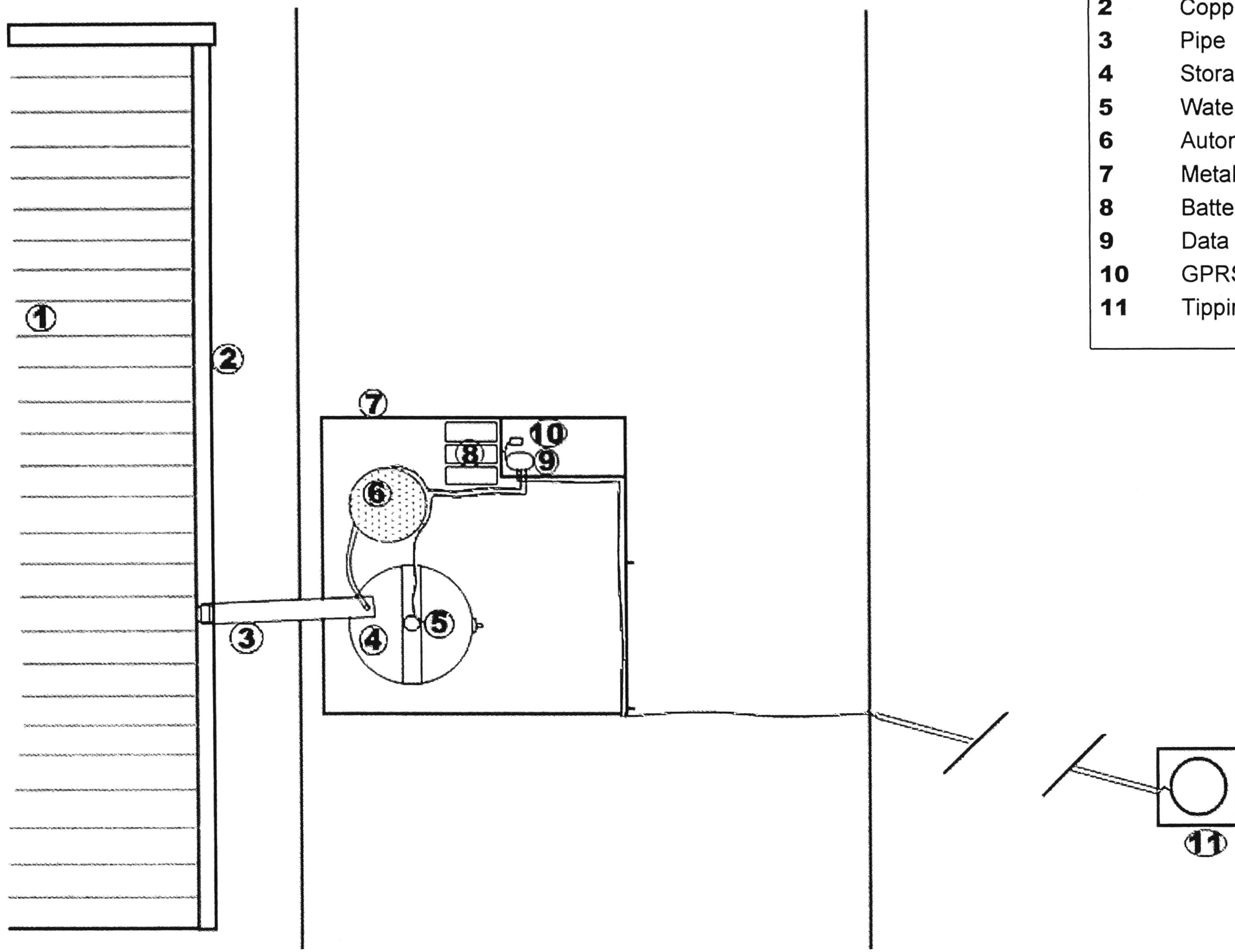
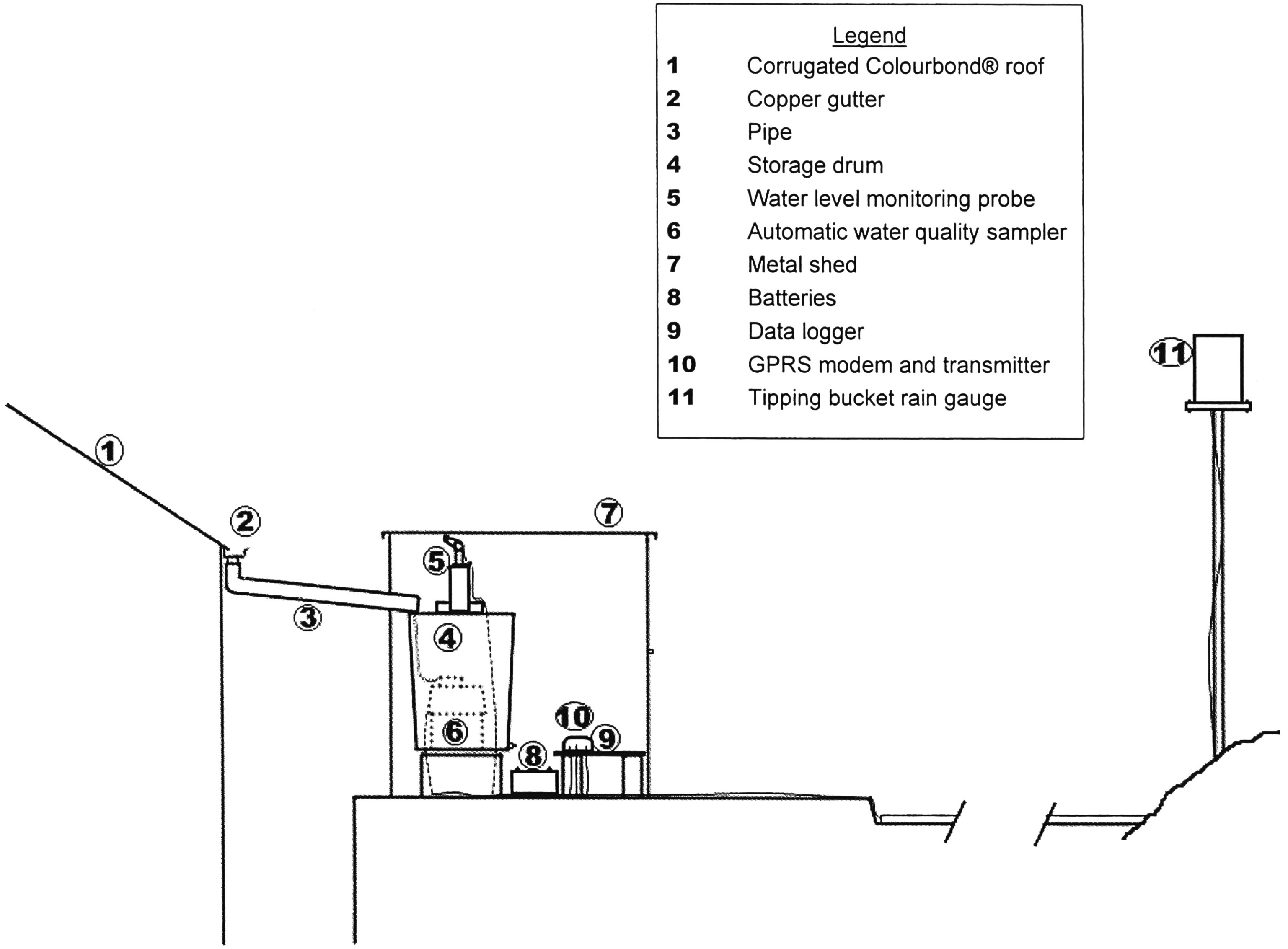


Figure A.6

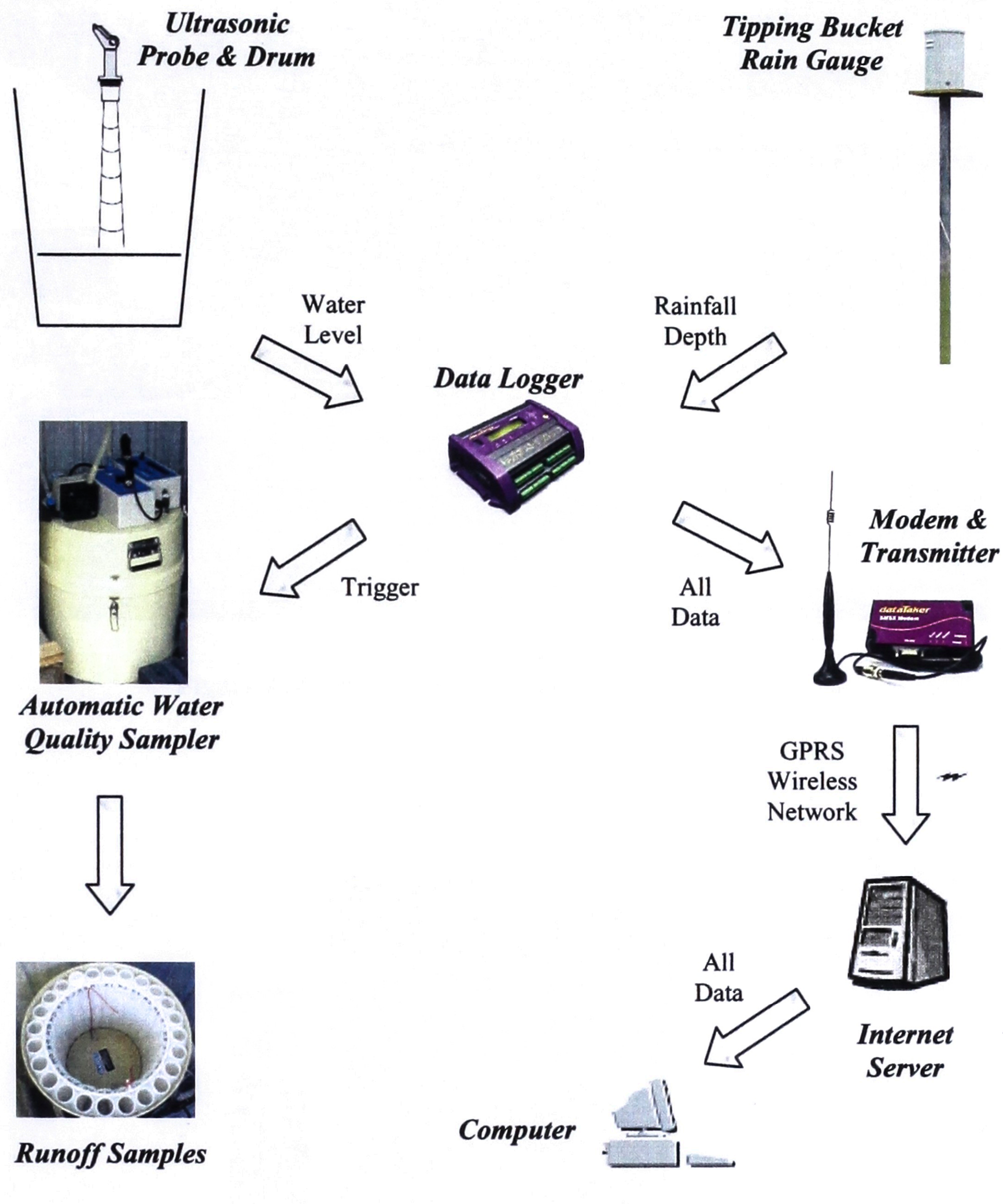


ELEVATION VIEW OF FIELD MONITORING STATION

Figure A.7

A.4 Schematic Layout of Equipment

See next page for the Section A4 Figures.



WRL Report No. 230	SCHEMATIC LAYOUT OF EQUIPMENT	Figure A.8

A.5 Photos

Figure A.9: Outside view of field monitoring station

Figure A.10: Front view of shed

Figure A.11: Equipment in the shed

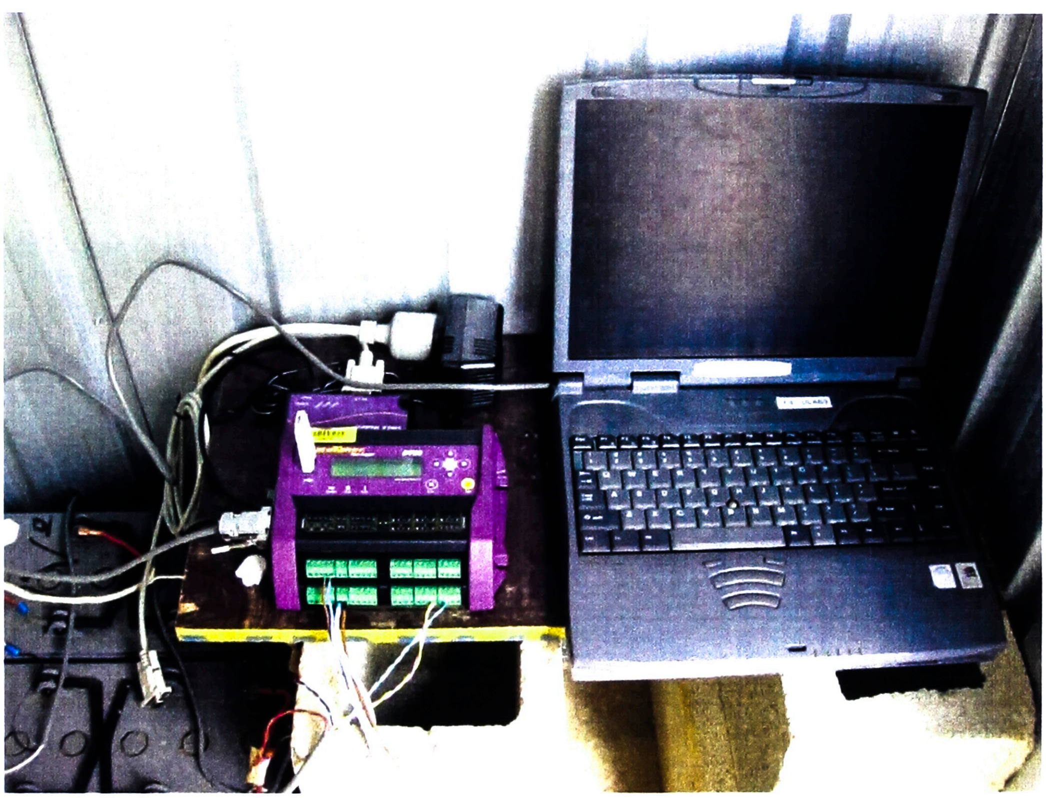


Figure A.12: Data logger and laptop

Figure A.13: Pipe connection

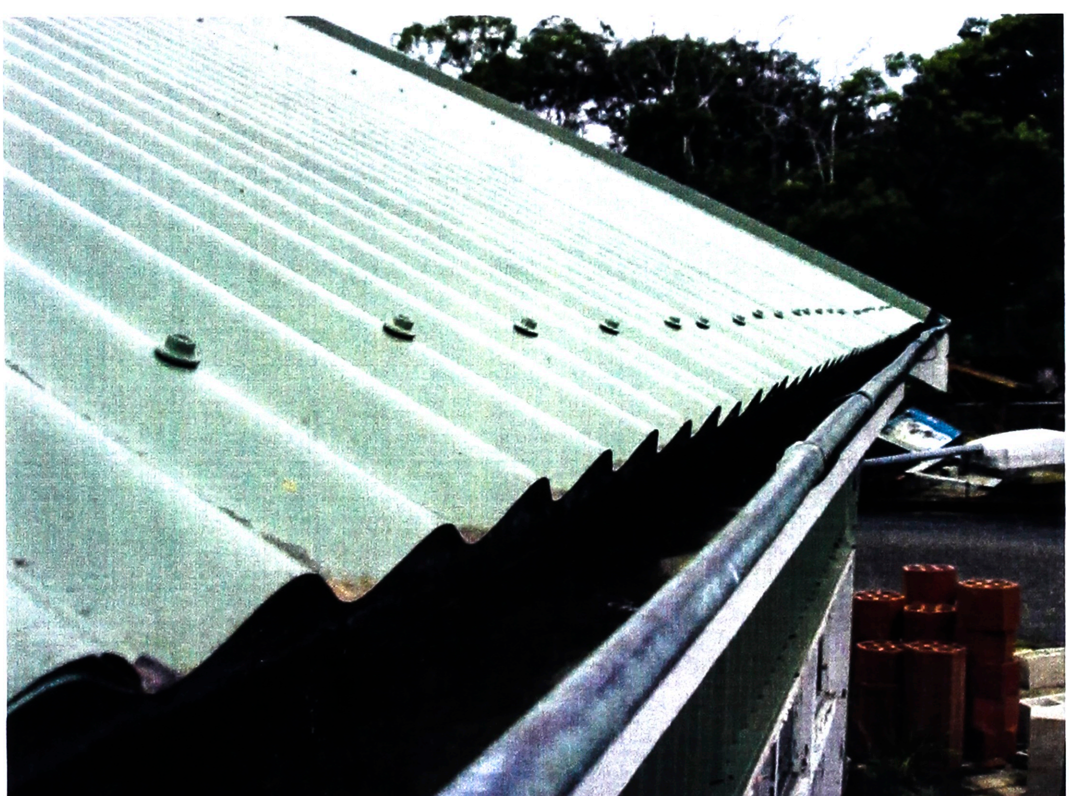


Figure A.14: Roof catchment and gutter

A.6 Wiring Connections

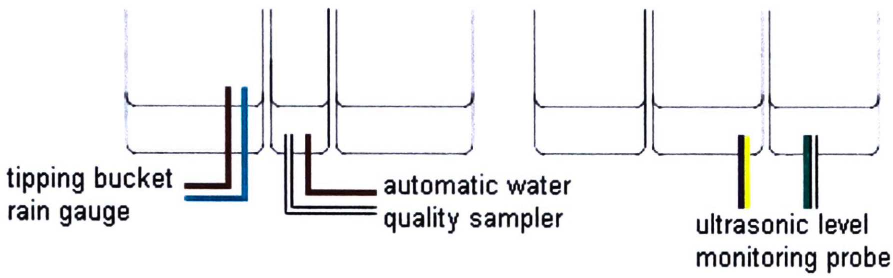


Figure A.15: Connections to data logger

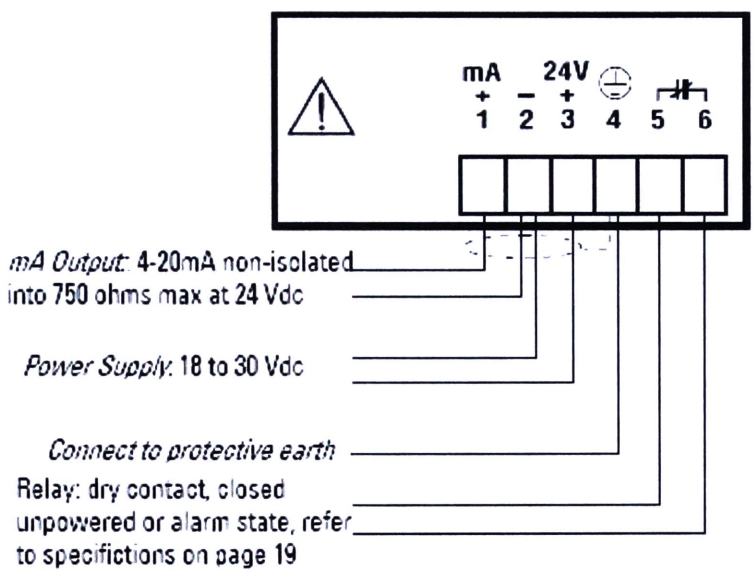


Figure A.16: Connections to ultrasonic probe

A.7 Sampling and Determining Drum Water Levels

A time step of 30 seconds was picked for sampling the drum water levels. During a storm event, roof runoff flows from the sloping roof surface down to the gutter, before being channelled by a pipe to the storage drum located inside the shed. Water then drops at the end of the pipe and fills up the drum as runoff increases. At the same time, the ultrasonic probe that is located above the drum scans the water level at the preset time interval so that the rise in water level over the time period can be determined, as shown in Figure A.17.

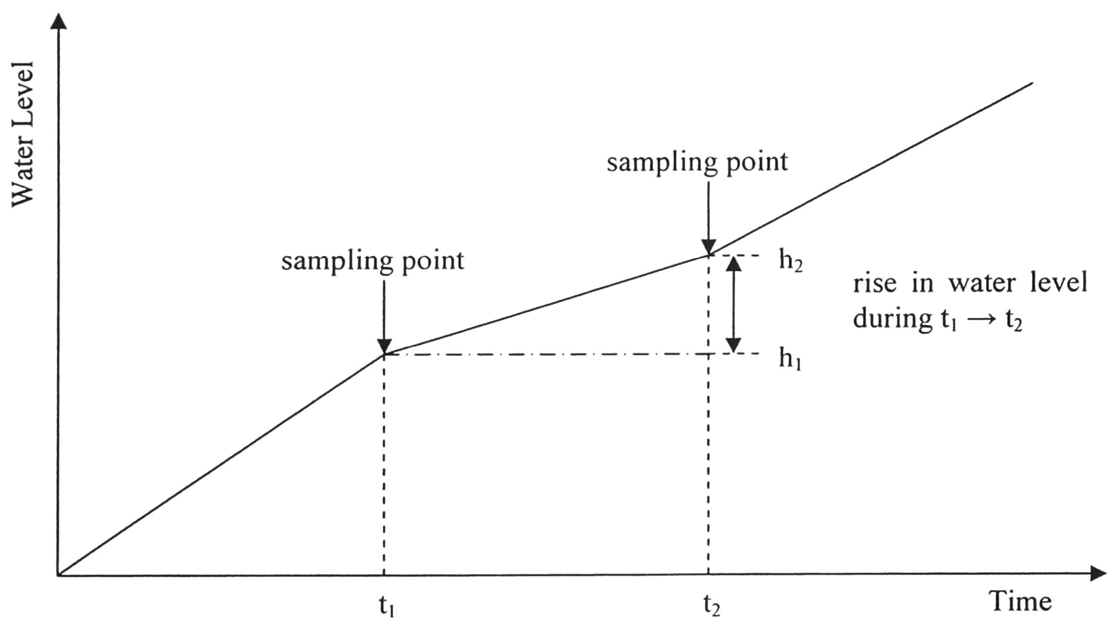


Figure A.17: Sampling and determining drum water levels

Since the ultrasonic probe transmits mA output signals, they have to be converted into water levels before the actual runoff volumes can be determined. The following equation is used for the conversion:

$$h_i = \frac{x_i}{100} \times H \qquad (2)$$

Where

h_i = water level at time step i (m)

x_i = output at time step i (%)

H = total height of the drum (m)

= 0.852m

The unit of the output signal, x_i is defined in percentage, with 20mA output yielding 100% at the highest water level whereas 4mA output yielding 0% for vice versa, as the unit is calibrated in proportional span. Since the accuracy of the ultrasonic probe is given as 0.25% of the measured range, all measurements made would contain an error of ±2mm.

A.8 Calculating Runoff Volumes and Flow Rates

After converting the time series data to the correct water levels, the next step would be to determine the runoff volume in the drum. The computation of the runoff volume in the tapered drum can be carried out using the following equation (also refer to Figure A.18):

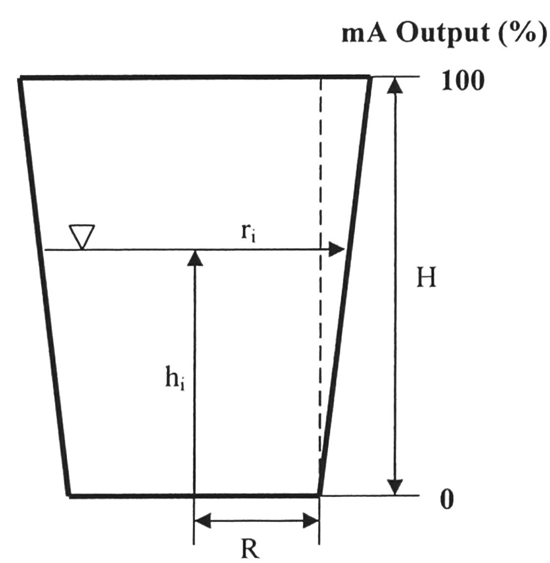


Figure A.18: Calculating runoff volume

$$V_i = \frac{\pi\left(R^2 + r_i R + r_i^2\right)h_i}{3} \quad (3)$$

Where

V_i	= volume of water in the drum at time step i (m^3)
r_i	= radius of surface water at time step i (m)
h_i	= water level at time step i (m)
R	= radius at the base of the drum (m)
	= 0.275m
H	= total height of the drum (m)
	= 0.852m

Subsequently, the flow rate can be determined using:

$$Q_i = \frac{V_{i+1} - V_i}{\Delta t} \quad (4)$$

Where

Q_i = flow rate (m^3/s or L/s)

V_i = volume of water in the drum at time step i (m^3 or L)

Δt = time interval between sampling points

= $t_{i+1} - t_i$

= 30 seconds

This flow rate is actually the average rate of inflow into the drum during the time interval rather than the instantaneous flow rate occurring at the time of level sampling. The accuracy of the flow rate is determined to be ±0.02L/s.

A.9 Instruments Specification

INSTRUMENT	*Tipping Bucket Rain Gauge*
MODEL	TB3
MANUFACTURER	Hydrological Services Pty. Ltd.
RECEIVER	200 ± 0.3mm diameter machined aluminium rim. Powder coated.
BUCKET CAPACITY	0.2mm
SENSITIVITY	1 tip
MEASURING RANGE	0 to 700 mm/hr
CALIBRATION ACCURACY	± 2% for intensities from 25 to 500 mm/hr.
TEMPERATURE	-20 to 70°C
CONTACT SYSTEM	Dual reed switches potted in soft silicon rubber with varister protection.
LEVEL	Bulls eye level adhered to aluminium base.
HEIGHT	342 mm
WEIGHT	3kg

INSTRUMENT	*The Probe (Ultrasonic Level Monitoring Probe)*
MANUFACTURER	Siemens Milltronics Process Instruments Inc.
POWER	18 to 30V DC, 0.2A max
AMBIENT TEMPERATURE	Continuous: -40 to 60°C
RANGE	0.25 to 5 m, liquids only
BEAM ANGLE	10° at -3dB boundary
PROGRAMMING	2 tactile keys
TEMPERATURE COMPENSATION	Built-in to compensate over the operating range.
mA OUTPUT	Range: 4 – 20 mA Span: proportional or inversely proportional Accuracy: 0.25% of full scale Resolution: 3 mm (0.125") Loading: 750 ohms max at 24V DC supply
MEASUREMENT RESPONSE	0.03m/min, 1m/min, 5m/min, immediate
CALIBRATION	Reference method, scrolling method
CONSTRUCTION	Combined sensor and electronics package
WEIGHT	1.7kg

INSTRUMENT	*Waste Watcher (Automatic Water Quality Sampler)*
MANUFACTURER	Gamet Equipment Pty. Ltd.
OUTER CASING	Reinforced fibreglass
POWER REQUIREMENT	12V DC
POWER SAVING	Standby "sleep" feature in float mode
SAMPLING CAPACITY	24 x 1L discrete samples in natural HDPE bottles
CURRENT DRAWN	5 Amps (max) under load 6 milliamps between samples Less than 1 milliamp using "sleep" standby feature
PUMP	Peristaltic 9.5 mm ID silicone delivery tubing Self priming 5.0L per minute flow rate Variable run duration up to 99.99s Adjustable duration pre sample reverse run purge
CONTROLLER	Analogue/digital micro processor 4 button setting with self prompting LCD response
MODES	Time: Interval between samples from 30 seconds to over 100 hours Float: Sampling frequency dictated by external float switch Pulse: Triggered by electronic switch closure signals as required Level: % change rise and fall
DIMENSIONS	48 cm diameter x 84 cm high
WEIGHT	22kg (empty)

INSTRUMENT	*dataTaker DT80 (Data Logger)*
MANUFACTURER	Datataker Pty. Ltd.
ANALOG INPUTS	5-15 sensor inputs Measure voltage, current, resistance and frequency.
DIGITAL CHANNELS	8 bi-directional channels for state & count input or state output. 1 latching relay 4 high speed counters or 2 phase encoder (quadrature) inputs.
OTHER CHANNELS	SDI-12 channels Serial sensor channel
MAXIMUM SAMPLE SPEED	25Hz (up to 70Hz without noise rejection)
ALARMS	Set digital outputs, execute command, transmit message
DATA STORAGE	Internal storage capacity: 64MB Removable USB store device
DISPLAY AND KEYPAD	LCD, 2 line by 16 characters, backlight. 6 keys for scrolling and function execution
POWER SUPPLY	10 to 30V DC or 240V AC
INTERNAL MAIN BATTERY	6V (1.2AHr) lead acid gel cell
COMMUNICATION INTERFACES	Ethernet, RS232, USB 1.1, modem
DIMENSIONS	181 mm x 136 mm x 63 mm
WEIGHT	1.5kg

INSTRUMENT	*dataTaker SMSX GSM Modem*
MANUFACTURER	Datataker Pty. Ltd.
FUNCTIONS	Connects to the GSM network Full SMS communications Remotely download data from the data logger to a PC
SUPPLY VOLTAGE	6 to 40V DC
OPERATING TEMPERATURE	-20°C to 50°C
DIMENSIONS	100 mm x 50 mm x 17 mm
WEIGHT	100g