SECTION 2: TRIALS OF AUTOMATIC PIEZOMETRIC DATA ACQUISITION SYSTEMS

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FOREWORD

This Report presents the results of controlled trials carried out for the assessment of the performance of three automatic piezometric data acquisition systems. These include a combined downhole pressure sensor and datalogger, a downhole pressure sensor and top-of-the-hole datalogger with telephone lines as a means of data transmission, and a downhole pressure sensor and top-of-the-hole datalogger with radio waves as a means of data transmission. The trials were carried out between July 1999 and October 2000.

The systems were set up by contractors, who carried out the supply, calibration/checking, installation, operation and maintenance of the systems, the acquisition, processing and reporting of piezometric data, and the preparation of monthly monitoring reports and a final report to document the details of the field trials.

A working party consisting of Dr L.S. Cheung, Mr Anthony Y.T. Lam, Mr Tony M.F. Lau (representing Materials, Advisory and Design Division respectively) and Miss Christine K.L. Wong of Special Projects Division oversaw the project.

The Design Division has also assisted in the selection of the sites for the trials. The Survey Division has rendered assistance in carrying out monthly manual checking of piezometric levels.

The project was planned and the contractors' services were procured under the supervision of Mr B.N. Leung when he was in Special Projects Division. The subsequent phase of the project was implemented by Miss Christine K.L. Wong who prepared this Report, under the supervision of Mr Y.K. Shiu.

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ABSTRACT

In February 1999, the Geotechnical Engineering Office commissioned three contractors to carry out field trials of their piezometric data acquisition systems. The main objective of the trials is to identify and try out automatic data acquisition systems which would be suitable for use in Hong Kong. The three contractors comprise Fong On Construction & Engineering Co., Ltd, Fugro Geotechnical Services (HK) Ltd and Gammon Construction Limited. The respective systems include combined downhole pressure sensor and datalogger (without off-site data transmission capability), a system of downhole pressure sensor and top-of the-hole datalogger with telephone lines as a means of data transmission and another one using radio waves as a means of data transmission. The field trials commenced in July 1999 and ended in October 2000.

During the trial period, the contractors were required to provide the following services: (a) supply, calibration/checking, installation, operation, maintenance and removal of the system, (b) acquisition, processing and reporting of piezometric data, and (c) preparation of monthly monitoring reports and a final report to document the details of the field trials.

This Report presents the benefits of automatic piezometric data acquisition systems and describes the field trials of the three selected systems. It summarises and discusses the results of the trials and the performance of the systems. Conclusions of the trials and recommendations relating to selection of automatic systems, specification of automatic data acquisition service and data quality control are also presented.

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1. INTRODUCTION

As part of Government's long-term strategy, the Geotechnical Engineering Office (GEO) will be upgrading 250 Government substandard slopes each year under the 10-year extended Landslip Preventive Measures (LPM) Programme starting in the year 2000. Slope stability assessment and upgrading works design are carried out under the LPM Programme and acquisition of piezometric data is an essential part of these processes.

Currently the data acquisition is mainly done manually using dipmeters. This can take up staff resources throughout the whole year and place critical demand on staff resources during the wet season and after heavy rain. It has often resulted in the recommended level of data collection not being met in the wet season and very limited data collection after heavy rain. There is a need to explore more reliable, cost-effective and efficient means (in terms of staff deployment) than manual readings to expedite the acquisition of piezometric data.

It is recognised that considerable benefits could be gained by adopting automatic data acquisition systems, particularly those with remote data transmission capability. These include the following:

(a) there will be a reduction in the human resources needed, as a result of reduction in the number of site visits by staff,

(b) when coupled with manual counter-checking, double checking of the key data is possible, thus improving the confidence in the quality of data obtained,

(c) more reliable collection of critical piezometric data is possible during and immediately following periods of heavy rain than manual dipping of piezometers (which can be difficult due to concerns over the safety of personnel accessing slopes in wet weather), and

(d) continuous records provided by an automatic system are more useful when compared with the occasional results given by Halcrow buckets and manual dipmeters. Rate of rise and fall of groundwater table and the peak piezometric levels and their times of occurrence could be determined more accurately (especially in permeable ground layers), facilitating further understanding of the groundwater response to rainfall and development of improved design practices to support improvement in the LPM Programme.

In February 1999, the GEO commissioned three contractors, viz. Fong On Construction & Engineering Co., Ltd, Fugro Geotechnical Services (HK) Ltd and Gammon Construction Limited to carry out field trials of their piezometric data acquisition system. The respective systems include a combined downhole pressure sensor and datalogger (without off-site data transmission capability), a system of downhole pressure sensor and top-of-the-hole datalogger with telephone lines as a means of data transmission and another one using radio waves as a means of data transmission. The field trials commenced in July 1999 and ended in October 2000.

This Report summarises the field trials and discusses the results of the trials.

2. DESIGN OF THE TRIALS

The objective of the project is to identify and try out systems which would be suitable for use in Hong Kong for the automatic acquisition of piezometric data.

The contractors engaged for the trials were required to work closely with the GEO to provide the following services:

(a) supply, calibration/checking, installation, operation, maintenance and removal of the system,

(b) acquisition, processing and reporting of piezometric data, and

(c) preparation of monthly monitoring reports and a final report to document the details of the field trials.

The following functional requirements were specified for the systems:

(a) Reliability - reliable for use outdoors under Hong Kong climatic conditions.

(b) Robustness - weather proof with protection against lightning, rainstorm effects and vandalism.

(c) Data capture range - positive pressure ranging from zero up to 200 kPa.

(d) Data capture frequency - 5-minute intervals or longer, as specified/set by the client.

(e) Accuracy - error not exceeding 0.2% full scale or 1 kPa, whichever is higher.

(f) Portability - easy to install, dismantle, transport and re-establish elsewhere on a slope.

(g) Year 2000 compliant.

3. TRIAL SITES

The trials were carried out on slopes within the urban areas. Four sites with a sufficient number of functioning (i.e. not dry) standpipe piezometers were selected subject to the constraints imposed by the limitations of the different piezometric data acquisition systems. The details of which are given in Table 1. The conditions of the trial sites are typical of those normally encountered in the Landslip Preventive Measures (LPM) Programme.

A summary of the trials showing the locations of these sites, the nearby raingauges and the piezometers monitored under the trials, is given below:

System (Contractor)	Site	Number and Location of Nearby Raingauge (Distance from Site (km))	Borehole No./ Pressure Sensor Depth (Measured from Top of Pipe) (m)	
Combined downhole pressure sensor and datalogger (Fong On)	Sai Sha Road (near Kei Ling Ha San Wai, slope No. 8NW-C/C33)	N15 (Sung Tsun Secondary School, Yau Ma Po, Po Tung Road) (3.6)	BH8 BH9 BH10	16.59 13.57 9.55
System using telephone lines as a means of data transmission (Fugro)	Po Shan Road (Mid-levels, adjacent slopes Nos. 11SW-A/CR176 and 11SW-A/R674)	H04 (Knowles Building, Hong Kong University) (0.5)	DC4 PD40	14.00 13.50
	Wing Yip Street (Kwai Chung, slopes Nos. 7SW-C/C1153 and 7SW-C/C234)	N04 (Kai Kwong Lau, Cho Yiu Estate) (1.6)	BH3 BH5	20.50 13.00
System using radio waves as a means of data transmission (Gammon)	Po Shan Road (Mid-levels, adjacent slopes Nos. 11SW-A/CR176 and 11SW-A/R674)	H04 (Knowles Building, Hong Kong University) (0.5)	PD18L PD19L	20.90 22.99
	Ching Cheung Road (Kwai Chung, slope No. 11NW-A/C54)	K06 (Carnation House, So Uk Estate) (1.1)	VH17 VH18	4.70 13.67

4. CLIMATIC CONDITIONS DURING THE SITE TRIALS

According to the records of the Hong Kong Observatory (HKO, 1999a, b, c, d, e & f; HKO, 2000), the climatic conditions of Hong Kong over the period 14 July 1999 to 31 October 2000 are summarised as follows:

Daily air temperature	5.8 to 35.1°C
Daily mean atmospheric pressure	987.1 to 1030.2 mbar
Daily mean relative humidity	27 to 97%
Maximum daily rainfall	276 mm
Number of Tropical Cyclone Warning signals, including: (a) No. 8 signal during Typhoon SAM (12:30 on 22 August 1999 to 03:50 on 23 August 1999) (b) No.10 signal during Typhoon YORK (06:45 on 16 September 1999 to 17:45 on 16 September 1999) (c) No. 8 signal during severe Tropical Storm CAM (05:20 on 25 September 1999 to 14:10 on 26 September 1999)	12

5. DATA ACQUISITION SYSTEMS

5.1 General

The system provided by Fong On comprises a combined sensor/data acquisition system (i.e. sensor and datalogger), whereas the other two systems provide also data transmission systems, which involve additional components and site installation for off-site transmission of data from dataloggers located at the top of the boreholes.

5.2 Combined Downhole Pressure Sensor and Datalogger

The data acquisition system adopted by Fong On consists of a proprietary miniature automatic datalogger with a built-in pressure transducer and a read-out unit for downloading data on site. Three sets of combined sensor and datalogger unit (TD-DIVER DI215 manufactured by Van Essen Instruments bv) were placed inside piezometer tubes and they can measure, capture and store the values of the piezometric pressure directly. They are powered by an internal battery with a claimed expected life time of 8-10 years. An additional set was used on site and placed in the piezometer tubing above groundwater level to record atmospheric pressure.

The system has no off-site data transmission capability, hence manual downloading of data is required. It does not require any field connection to other components. Details of the system are given in the report submitted by the contractor (Fong On, 2000). Some details of the trial of this system and records of piezometric data, provided by the contractor, are given in Appendix A (Fong On, 2000).

5.3 Downhole Pressure Sensor and Top-of-the-hole Datalogger with Telephone Lines as a Means of Data Transmission

The data acquisition system adopted by Fugro consists of proprietary sensors (i.e. vibrating wire piezometers) and dataloggers. The sensors (Model 92610120 Vibrating Wire Piezometer manufactured by Slope Indicator Company) were placed inside the standpipe tubings and connected to dataloggers placed at the top of the borehole. Two different types of logger were used in the trial. A pair of single-channel dataloggers (VW Minilogger manufactured by Slope Indicator Company) were used at the Po Shan Road site, with each sensor connected to a logger. At Kwai Chung, the sensors were connected to a multi-channel datalogger (Datataker DT615 Geologger manufactured by Data Electronics Pty Ltd). Both types of datalogger stored readings in local memory for subsequent retrieval either manually or remotely. They were battery-powered. There was no on-site atmospheric pressure measurement. A standard atmospheric pressure value was assumed in data processing.

Field connection of the components of the data acquisition and the transmission system was required. At each site, a data transmission system was installed to allow the accumulated readings stored in the dataloggers to be remotely downloaded to a central location. Conventional modems were used to transmit readings over standard telephone lines.

Details of the data acquisition system and the data transmission system are given in the report submitted by the contractor (Fugro, 2000). Some details of the trial of these systems and records of piezometric data, provided by the contractor, are given in Appendix B (Fugro, 2000).

Although not part of this trial, the contractor has taken the initiative to try out the GSM transmission mode on another site at Tsing Yi. Some details of this trial are also given in Fugro (2000).

5.4 Downhole Pressure Sensor and Top-of-the-hole Datalogger with Radio Waves as a Means of Data Transmission

The data acquisition system adopted by Gammon also consists of proprietary components, i.e. vibrating wire piezometers and dataloggers. The sensors were placed inside the standpipe tubings and were connected to dataloggers placed at the top of the drillhole. Initially all four sensors used in the trial were GEOKON 4500C series, subsequently three of these were replaced by two number of GEOKON 4500S and one number of GEOKON 4500B series. Single-channel dataloggers (GEOKON Model 8001 LC-1 manufactured by GEOKON Incorporated) were used. The battery-powered dataloggers stored readings in local memory for subsequent retrieval either manually or remotely. There is no on-site atmospheric pressure measurement. Mean sea-level atmospheric pressure readings recorded every 5 minutes at the Hong Kong Observatory headquarters in Tsim Sha Tsui were used for pressure corrections to the automatic readings.

Field connection of the components of the data acquisition and the data transmission system was required. At each site, a data transmission system was installed to allow the accumulated readings stored in the dataloggers to be remotely downloaded to a central location at the contractor's office. The radio transmission system consisted of a 'site subscriber' unit which comprised a mobile radio transceiver with an associated VHF antenna. The systems on both sites included GSM modems to enable microwave communication as an alternative to the VHF radio systems. The GSM transmission was not part of the trial. Both the radio transceiver and GSM modem were powered from batteries backed up by a solar panel.

Details of the data acquisition system and the data transmission system are given in the report submitted by the contractor (Gammon, 2000). Some details of the trial of these systems and records of piezometric data, provided by the contractor, are given in Appendix C (Gammon, 2000).

6. CALIBRATION AND CHECKING

As part of the trials, calibration and checking of the systems were carried out by the contractors and GEO staff at the following stages:

(a) Initial manufacturers' calibration. The sensors were calibrated under factory conditions by the sensors' manufacturers.

(b) Workshop checking in Hong Kong prior to installation on site. Each contractor checked the sensors in his own workshop in Hong Kong to ensure that no damage had occurred while in transit from the manufacturer, and that there were no gross differences and obvious non-conformances compared with the expected readings.

(c) Checking during or shortly after installation on site. Each contractor checked his whole system during or shortly after installation on site, including manual comparisons between data downloaded on site and the data retrieved using the off-site data transmission system.

(d) Checking during the trial. Each contractor recorded water levels in the piezometers using dipmeters throughout the trial duration. Monthly readings were also taken by the contractors jointly with staff of the Survey Division of the Civil Engineering Department.

7. SYSTEM PERFORMANCE

7.1 General

A summary of the performance of the three systems and the problems encountered in the trials are presented in Tables 1, 2, 3 and 4. A summary of data loss (inclusive of data of uncertain reliability) and difference between automatic readings and manual dippings are presented in Table 5, 6 and 7 respectively.

The data loss of the three systems was assessed using two criteria:

(a) the total data loss (inclusive of data of uncertain reliability) over the whole trial period, and

(b) the data loss during the period of individual rainstorms in which the maximum rolling 24-hour rainfall is greater than or equal to 50 mm at the nearby raingauge (all raingauges except one are less than 2 km away (the closest raingauge N15 to the Sai Sha Road site is 3.6 km away).

In addition to the criteria above, the following criteria were also set to assess the performance of the automatic systems:

(a) for each borehole, the percentage of automatic readings within ±100 mm of manual dippings (i.e. approx. 1 kPa) and the maximum deviation, and

(b) for each system, the maximum deviation of 90% of automatic readings from the manual dipmeter readings.

The automatic systems were set to capture data at 5-minute intervals for all piezometers. For the combined sensor and datalogger system, a different sampling mode (a 5-minute 'event-based sampling' at ±0.1% of the full range) was also set for one of the sensors in borehole BH10 for a few months. For this 5-minute event-based sampling, measurement is taken according to the entered sampling rate (in this case, every 5 minutes) but the measurement is not automatically stored. Every new measurement is compared with the last recorded measurement before being stored. It is only stored if a programmed difference (in this case, ±0.1% of the full range of the sensor) between the new measurement and the last recorded measurement arises. However, since no corresponding manual dipmeter readings were taken at the same time as the automatic readings, the performance of the system during this sampling mode, in terms of deviation from the manual dipmeter readings, could not be assessed.

7.2 Combined Downhole Pressure Sensor and Datalogger System

7.2.1 General

A summary of the problems encountered in this trial is presented in Table 2.

7.2.2 Data Loss and Uncertainty during the Trial Period

During the trial period, the system experienced data loss due to human error during the manual downloading process, which ranges from 3% to 13% (Table 5) for any one sensor.

For borehole BH10, there was a period of four months (May 2000 to August 2000) in which the readings of the sensors were doubtful. This period represents 30% (Table 6) of all readings from this borehole. In conjunction with the 6% (Table 5) loss due to human error, the total percentage of data loss and doubtful data amounted to 36% (6% + 30%) in BH10.

7.2.3 Data Loss within Rainstorm Periods

During the trial period (17.7.1999 to 31.8.2000), there were 15 storm periods (as recorded at the nearby raingauge N15, 3.6 km away from Sai Sha Road). The period in which data loss occurred due to human error during the manual downloading coincides with two of these rainstorms. This resulted in total loss of data from BH9 for these two rainstorms. There was 28% (Table 5) data loss within all the 15 rainstorm periods for borehole BH9.

7.2.4 Comparison with Manual Dipmeter Readings

For boreholes BH8 and BH9, most of the automatic readings (100% in BH8, 89% in BH9 (Table 7)) fell within ±100 mm of the manual dipmeter readings. All automatic readings fell within ±200 mm for these two boreholes. However, for BH10 only 57% (Table 7) of the automatic readings fell within ±100 mm. Over a period of four months (May 2000 to August 2000), the deviation was up to 603 mm (Table 7). This was later investigated to have been caused by the drifting of the zero setting of the sensor.

For this system (other than those doubtful readings in BH10 at the end of the trial period) 90% of the automatic readings fell within ±50 mm of the manual dipmeter readings.

7.3 System Using Telephone Lines as a Means of Data Transmission

7.3.1 General

A summary of the problems encountered in this trial is presented in Table 3.

7.3.2 Data Loss and Uncertainty during the Trial Period

During the trial period the system experienced data loss ranging from 7% to 12% (Table 5) for any one sensor. This is mainly due to problems with battery life for the telephone modem (6% to 10%) (Table 5) and two other minor problems: breakdown of telephone lines (up to 1% for any one sensor) (Table 5) and human error during downloading of data (up to 4% for any one sensor) (Table 5). The data loss was wholly associated with the data transmission components and there is no period of doubtful or unstable readings noted.

7.3.3 Data Loss within Rainstorm Periods

(1) Po Shan Site. During the trial period (10.7.1999 to 31.10.2000), there were 29 storm periods, (as recorded at the nearby raingauge H04, 0.5 km away). The periods in which the system experienced data loss due to short battery life for the telephone modem resulted in total data loss in one rainstorm and partial data loss in two others (100% data loss at PD40 on 4 August 1999, 75% data loss at borehole DC4 during 22-25 August 1999 and

20% data loss at borehole PD40 at 16-17 September 1999). The data loss within the 29 rainstorm periods amounted to 6% (Table 5) at borehole DC4 and 1% (Table 5) at borehole PD40.

(2) Wing Yip Street Site. During the trial period (11.8.1999 to 31.10.2000), there were 24 storm periods (as recorded at the nearby raingauge N04, 1.6 km away). The periods in which the system experienced data loss due to short battery life for the telephone modem resulted in partial data loss in one rainstorm and total data loss in two others (100% data loss at BH3 and BH5 in 11-12 August 1999 and 16-17 September 1999, 19% data loss at borehole BH5 in 22-26 August 1999). The data loss within the rainstorm periods amounted 10% (Table 5) in borehole BH3 and 14% (Table 5) in borehole BH5.

7.3.4 Comparison with Manual Dipmeter Readings

For any one borehole, the percentage of records falling within ±100 mm of the manual dipmeter readings ranged from 20% to 58% (Table 7). With the exception of 4 records (deviations of 4 m in DC4, 1.27 m and 0.89 m in PD40, and 0.53 m in BH5), all others fell within ±500 mm.

It was reported by the contractor that this large discrepancy could have been the result of the atmospheric pressure correction not having been applied to the automatic readings (i.e. a standard atmospheric pressure of 1013 mbar was assumed). The atmospheric pressure drop during typhoons could be as much as 33 mbar (equivalent to about 0.33 m of water head).

For this system, 90% of the automatic readings (uncorrected for atmospheric pressure variations) fell within ±280 mm of the manual dipmeter readings.

7.4 System Using Radio Waves as a Means of Data Transmission

7.4.1 General

A summary of the problems encountered in this trial is presented in Table 4.

7.4.2 Data Loss and Uncertainty during the Trial Period

During the trial period, the system experienced data loss due to datalogger battery discharge during thunderstorms. Up to 2% (Table 5) of data for any one sensor was lost.

In the beginning of the trial period (July to December 1999), the sensor readings were unstable in three of the boreholes PD18L (19.8.1999 to 30.12.1999), VH17 (15.7.1999 to 29.10.1999) and VH18 (15.7.1999 to 14.10.1999). The percentage of unstable readings ranged from 19% to 30% for any one sensor (Table 6). In conjunction with the 2% data loss (Table 5) due to datalogger battery discharge, the total percentage of data loss and doubtful data amounted to 32% (2% + 30%) in PD18L. The three unstable sensors were all replaced by January 2000. No unstable readings were recorded after the replacement.

7.4.3 Data Loss within Rainstorm Periods

(1) Po Shan Road. During the trial period 19.8.1999 to 31.8.2000, there were 25 storm periods (as recorded at the nearby raingauge H04, 0.5 km away). The periods in which the system experienced data loss due to battery problem in the datalogger resulted in total data loss in three storm periods (24-25 August 2000, 26-27 August 2000, 27-28 August 2000) for both boreholes PD18L and PD19L. The data loss within the 25 rainstorm periods amounted to 9% (Table 5) for both boreholes PD18L and PD19L.

(2) Ching Cheung Road. During the trial period (15.7.1999 to 31.10.2000), there were 19 storm periods (as recorded at the nearby raingauge K06, 1.1 km away). The periods in which the system experienced data loss due to battery problem in the datalogger resulted in total data loss in two storm periods 12-13 June 2000, 24-25 August 2000 for both boreholes VH17 and VH18. The data loss within the rainstorm periods amounted to 9% (Table 5) for both boreholes VH17 and VH18.

7.4.4 Comparison with Manual Dipmeter Readings

Apart from the unstable readings noted in the beginning of the trial period, for any one borehole, the percentage of automatic readings falling within ±100 mm of the manual dipmeter readings ranged from 32% to 90% (Table 7). With the exception of 5 records (deviations of 0.215 m in PD18L, 0.377 m in PD19L, 0.320 m, 0.290 m and 0.220 m in VH18), all others fell within ±200 mm of the manual dipmeter readings. "Spikes" in the automatic readings were noted to occur every 1 to 2 weeks in VH17 and once every couple of months in VH18 and PD18L. The contractor has provided explanations for these "spikes" including elevated water levels during function tests, sensor being raised in the standpipe, the loss of digits in the vibrating wire reading, and possible interference generated by road traffic and associated road works. However, the problem could not be resolved within the trial period.

For this system (other than those unstable readings in the beginning of the trial period), 90% of the automatic readings fell within ±160 mm of the manual dipmeter readings.

8. OBSERVATIONS RELATED TO THE SERVICE OF PROVISION OF PIEZOMETRIC DATA BY THE CONTRACTORS DURING THE TRIALS

Some observations related to the service of provision of piezometric data by the contractors during the trials are given in Table 8.

9. OBSERVATIONS OF GROUNDWATER CONDITIONS DURING THE TRIALS

The maximum rises in groundwater level observed at the trial sites during the trial period are summarised in Table 9.

10. CONCLUSIONS

Trials of three automatic piezometric data acquisition systems were carried out under this project. The following conclusions can be drawn:

(a) For the combined downhole pressure sensor and datalogger system, all data loss during the trial period could have been avoided with more care from the contractor. The probable causes for the doubtful readings from one of the sensors at the end of the trial period is still being investigated. Other than these doubtful readings, the deviations from the manual dipmeter readings were mostly within ±50 mm. The system is highly portable and can be re-used, but the one under trial has no data transmission capability. Therefore, periodic manual downloading of data on site is required. The size of the sensor is 22 mm in diameter, and hence it cannot be accommodated in an existing 19 mm diameter standpipe.

(b) The system using telephone lines as a means of data transmission worked fairly reliably. Some problems of quick discharge of battery occurred at the initial stage of the trial but they were subsequently resolved. For the automatic readings not corrected for variations in atmospheric pressure, their deviations from manual dipmeter readings were mostly within ±280 mm. The system is not highly portable although the individual components are readily removable and can be re-used. The system can be easily set up by experienced personnel at any accessible site.

(c) The system using radio waves as a means of data transmission worked fairly reliably. Problems with unstable readings encountered during the initial period of the trial were resolved by using a more stable type of sensor. The transmission of data using both radio waves and GSM was successful. Other than the unstable readings in the beginning of the trial, the deviations from manual dipmeter readings were mostly within ±160 mm. There were "spikes" in the automatic readings throughout the trial period. The contractor has provided some explanations but the problem could not be resolved within this trial period. The system is not highly portable although the individual components are readily removable and can be re-used. The system can be easily set up by experienced personnel at any accessible site.

(d) In general, the performance of the two systems with transmission capability (by means of telephone lines, radio waves and GSM) and the contractors providing the data acquisition service were reasonably satisfactory within the trial period. Initially, there were major problems with individual components but these were resolved during the trial. For the system using radio waves there were two minor problems which have not been resolved during the trial, namely the discharging of datalogger batteries during thunderstorms and "spikes" in the automatic readings. The problem of discharge of datalogger batteries during thunderstorms, although appeared only once during the trial, could potentially affect the performance of such a system during periods of adverse weather conditions.

(e) The doubtful readings (starting May 2000, 6 months before the end of the trial) in BH10 were investigated to have been caused by the drifting of the zero setting of the sensor.

(f) The yearly fluctuation of atmospheric pressure is significant and could amount to over 40 mbar (equivalent to 0.4 m of water head). According to the experience from Typhoon SAM and Typhoon YORK, pressure compensation was essential for accurate monitoring of piezometric level rise during the typhoons. Temperature fluctuation has minimal effects on the results.

(g) For an existing standpipe piezometer tube with a small (19 mm) internal diameter, the use of the combined sensor and datalogger is not possible. Although installation using other types of smaller diameter piezometer sensor would be feasible, the manual checking during monitoring could be cumbersome. From the experience of the trial, the internal diameter of new standpipe piezometer tubes should be at least 25 mm to facilitate installation of the pressure sensors of the automatic systems and manual checking during monitoring.

(h) The maximum deviation of the 3 systems from the manual dipmeter readings was more than ±100 mm specified originally as a functional requirement of the system. It was noted that the deviations were considerably larger on trial sites used by Fugro and Gammon where existing piezometer standpipe tubes with smaller diameters were used (see items (a) to (c) above).

(i) The trial period lasted about 16 months. Therefore, the long-term performance of the various components of the three systems and possible deterioration of system performance (such as data drift) beyond this period are not known.

(j) The experience and performance of the service provider is as important as, if not more than, that of the system.

11. RECOMMENDATIONS

(a) The designer should establish if there is a need to obtain piezometric data for his project. In assessing the need, the designer should take into consideration the specific project requirements and the total cost of piezometric data acquisition, balanced against the additional cost of adopting conservative designs in the absence of such data. In all cases, monitoring should only be initiated after a suitable method for making use of the data in the project and dedicated human resources to carry out the interpretation of the data collected have been identified.

(b) In considering whether to select an automatic data acquisition system, the site constraints, benefits (highlighted in Section 1 of this Report) and cost of providing such a system compared with manual dipping of piezometers should be examined. The total cost including that of procuring a data acquisition service, cost of paralleled manual spot checking and the cost of interpretation of the data collected should be considered. Estimates of the potential savings in human resources in using an automatic system can be worked out from the information given in Table 10. The order of costs of setting up such systems (provided by the contractors at the time of preparation of the Report) are given in Tables 11, 12 and 13. If a data transmission system is required, sufficient lead time (up to two months) should be allowed for to make the necessary arrangements (more time is needed if civil works are required). It is necessary to consider whether real-time transmission is necessary, and if not, the data downloading intervals. The merits of the different types of data transmission should be considered (Table 14).

(c) For systems incorporating off-site data transmission facilities, remote monitoring of battery voltage should be incorporated.

(d) If an automatic system with electrical cables is to be installed at high or open ground, consideration should be given to providing an appropriate lightning protection system. The performance of such a system should be closely monitored and reviewed, as necessary.

(e) For monitoring systems the accuracy of which is affected by changes in atmospheric pressure, corrections for such changes should be made. Atmospheric pressure monitoring by means of installation an additional piezometer should be considered. It is suggested that the 'control' piezometer should be installed in a hole above the highest expected groundwater level. The depth should be at least 2 m below ground where the temperature is stable and the security is less of a problem. One piezometer for a system/site should be adequate.

(f) Ideally a standpipe piezometer tube with a minimum internal diameter of 25 mm should be specified for new piezometers using automatic data acquisition systems. When an existing standpipe piezometer tube with a 19 mm internal diameter is to be monitored using an automatic system, the deviation between manual readings and automatic readings may be high (as illustrated by the larger deviations from manual dippings on trial sites used by Fugro and Gammon, where existing smaller diameter standpipe piezometer tubes were used). Checking of the whole system under field conditions should be carried out to establish the maximum deviation of the proposed system to see if this is acceptable for measurement purposes.

(g) The designer should make arrangement to carry out parallel manual readings of the piezometric levels at appropriate intervals to check the automatic readings, and to check for any possible deterioration of system performance of the sensors. An annual calibration of the piezometer may be necessary to provide the user with data on drift and long term stability. The latter is especially important if the system is to be used over a long period (say more than two years).

(h) Performance criteria should be clearly specified in procuring a piezometric data acquisition service using an automatic system. The maximum permissible deviation (e.g. ±200 mm of manual dippings at specified intervals), as well as the permissible percentage (e.g. 10%) data loss and doubtful (inaccurate or uncertain) readings during monitoring periods, should be specified in the data procurement service contract for payment purposes.

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Table 1 - Summary of System Performance

Factor	Combined Sensor and Datalogger		System Using Telephone Lines as a Means of Data Transmission		System Using Radio Waves as a Means of Data Transmission	
Limitations identified in initial site selection	- Need easily accessible sites because the system used in this trial has no data transmission capability. On-site manual downloading of data required (once per 10 to 12 weeks is required for a 5-minute intervals sampling frequency) due to limited data storage capacity (24,000 data). - Need large standpipe to accommodate unit (22 mm in diameter). The internal diameter of the standpipe had to be at least 25 mm.		Restricted by the availability of telephone connections.		Restricted by the area coverage of the transmission system and licensing requirements on the transmission of data using radio waves.	
Percentage of data loss during trial period (during rainstorms) for any one sensor						
- human error	3 - 13	(0 - 28)	0 - 4	(0)	0	(0)
- data acquisition	0	(0)	0	(0)	2	(9)
- transmission	N. A.		7 - 11	(1 - 14)	0	(0)
Total	3 - 13	(0 - 28)	7 - 12	(1 - 14)	2	(9)
Percentage of doubtful/unstable readings	0 - 30		0		0 - 30	
Maximum percentage of data loss and doubtful/unstable readings for any one sensor	36		12		32	
Deviation from manual dipmeter readings	Mostly within ±50 mm(1)		Mostly within ±280 mm(2)		Mostly within ±160 mm(3)	
Robustness						
- data acquisition	Doubtful readings in BH10 due to the zero drift of the sensor.		Satisfactory		Satisfactory	
- transmission	N. A.		Satisfactory		Satisfactory	
Data capture at fixed time mode at 5-minute intervals	Yes		Yes		Yes	
Portability	The system is highly portable.		The system is not highly portable although the individual components are readily removable.		The system is not highly portable although the individual components are readily removable.	
Year 2000 compliance	Yes		Yes		Yes	

Notes:
(1) Other than those doubtful readings in BH10 at the end of the trial period. Deviation from manual dipmeter readings is not available during the event-based sampling mode.
(2) Corrections for changes in atmospheric pressure have not been made.
(3) Other than those unstable reading in the beginning of the trial period.

Table 2 - Summary of Problems in the Trial for Combined Downhole Pressure Sensor and Datalogger System

Problem	Probable Causes	Proposal by Contractor for Probable Remedy	Resolution of Problem	Comment
Data loss during downloading	Downloading of data onto a floppy diskette in excess of its capacity.	Download data directly onto the hard drive of a portable computer.	Yes	Data loss could have been avoided with more care.
	Datalogger memory was full.	Timely downloading of data to be carried out.	Yes	
Large discrepancies between automatic and dipmeter readings at borehole BH10 (May 2000 to August 2000)	Drifting of the zero setting of the sensor.	Checking of the zero setting every 3 months or when the memory is re-set.	Yes	

Table 3 - Summary of Problems in the Trial for the System Using Telephone Lines as a Means of Data Transmission

Problem	Probable Causes	Proposal by Contractor for Probable Remedy	Resolution of Problem	Comment
Data loss	Telephone line problems.	Yes, by reporting to telephone company.	Yes, telephone lines were fixed.	Problem caused by external service provider.
Data loss due to short battery life	Power consumption exceeds supply.	(1) Re-design electronic module to reduce power consumption. (2) Install solar panel.	Yes, by implementing Proposal (1).	An improvement to the life of the battery was demonstrated. Regular site visits to change batteries were still required. The contractor reported that for data capture at 5-minute intervals, fortnightly site visits were necessary. However, were the data capture frequency to be extended to hourly intervals, site visits at 3-monthly intervals would be sufficient.
Large discrepancies between automatic and dipmeter readings	Absence of atmospheric pressure corrections.	Apply atmospheric pressure corrections.	Nil	Proposal submitted but not implemented in this trial.

Table 4 - Summary of Problems in the Trial for the System Using Radio Waves as a Means of Data Transmission

Problem	Probable Causes	Proposal by Contractor for Probable Remedy	Resolution of Problem	Comment
Datalogger batteries discharged during thunderstorms	Lightning.	Suggestions proposed for future installations include use of galvanised steel conduit to protect the electrical cables running at or above the ground level, with both ends earthed, and installation of lightning protection devices to other components.	Nil	Proposal submitted but not implemented in this trial.
"Spikes" in data	Electrical interference generated by road traffic and associated road works. Loss of digits in the vibrating wire reading.	Installation of earthing rod, and shielding of cables and dataloggers. Nil	Nil	
Unstable automatic readings in boreholes PD18L, VH17 and VH18	Baseline shifting and unstable readings from a small diameter sensor.	Use of different models of sensors.	Yes	
Difficulties in taking manual readings in PD18L and PD19L	The sensors in PD18L and PD19L were installed in 19 mm internal standpipe tubings. The annulus between the tubing inside wall and the sensor cable was consequently too small to allow insertion of a standard-sized dipmeter sonde to record the water level manually. A standard dipmeter tape was therefore modified by exposing the conductor wires at the end and attaching two thin lead weights to the tape immediately above the exposed conductors. This device allowed the water level to be recorded manually but the accuracy of the readings is uncertain.	Nil	Nil	Random checking in the form of manual readings for automated systems would be more difficult in existing piezometers with small diameter standpipe tubings.
Rapid changes in VH18 data	The surface box constructed at the collar of VH18 does not have a drainage outlet and consequently rainwater accumulates inside the surface box and covers the piezometer top.	Remove standing water inside the surface box before the piezometer cap is removed.	Yes	Not a system problem. Drainage outlets should be constructed for surface boxes.

Table 5 - Summary of Data Loss

System (Contractor)	Site	Trial Period	Borehole	Data Loss During the Trial Period (%)					Data Loss within Rainstorms (%)				
				Human Error	Data Acquisition System	Transmission System		Total	Human Error	Data Acquisition System	Transmission System		Total
					Datalogger	Modem	Telephone Line			Datalogger	Modem	Telephone Line	
Combined sensor and datalogger (without data transmission) (Fong On)	Sai Sha Road, near Kei Ling Ha San Wai	17.7.1999 to 31.8.2000	BH8	3	0	N. A.	N. A.	3	0	0	N. A.	N. A.	0
			BH9	13	0	N. A.	N. A.	13	28	0	N. A.	N. A.	28
		20.9.1999 to 31.8.2000	BH10	6	0	N. A.	N. A.	6	0	0	N. A.	N. A.	0
System using telephone lines as a means of data transmission (Fugro)	Po Shan Road, Mid-levels	10.7.1999 to 31.10.2000	DC4	0	0	10	1	11	0	0	6	0	6
			PD40	0	0	6	1	7	0	0	1	0	1
	Wing Yip Street, Kwai Chung	11.8.1999 to 31.10.2000	BH3	0	0	6	1	7	0	0	10	0	10
			BH5	4	0	7	1	12	0	0	14	0	14
System using radio waves as a means of data transmission (Gammon)	Po Shan Road, Mid-levels	19.8.1999 to 31.10.2000	PD18L	0	2	0	0	2	0	9	0	0	9
			PD19L	0	2	0	0	2	0	9	0	0	9
	Ching Cheung Road	15.7.1999 to 31.10.2000	VH17	0	2	0	0	2	0	9	0	0	9
			VH18	0	2	0	0	2	0	9	0	0	9

Table 6 - Summary of Data of Uncertain Reliability

System (Contractor)	Site	Trial Period	Borehole	Percentage of Data of Uncertain Reliability Arising from Doubtful or Unstable Sensor Readings During the Trial Period (%)
Combined sensor and datalogger (without data transmission) (Fong On)	Sai Sha Road, near Kei Ling Ha San Wai	17.7.1999 to 31.8.2000	BH8	0
			BH9	0
		20.9.1999 to 31.8.2000	BH10	30
System using telephone lines as a means of data transmission (Fugro)	Po Shan Road, Mid-levels	10.7.1999 to 31.10.2000	DC4	0
			PD40	0
	Wing Yip Street, Kwai Chung	11.8.1999 to 31.10.2000	BH3	0
			BH5	0
System using radio waves as a means of data transmission (Gammon)	Po Shan Road, Mid-levels	19.8.1999 to 31.10.2000	PD18L	30 (0)(1)
			PD19L	0
	Ching Cheung Road	15.7.1999 to 31.10.2000	VH17	23 (0)(1)
			VH18	19 (0)(1)

Note: (1) Values in ( ) are percentage of data of uncertain reliability after the replacement of the sensors.

Table 7 - Differences between Automatic Readings and Manual Dippings

System (Contractor)	Site	Borehole	Number of Manual Dippings	Number (Percentage) of Manual Dippings within ±100 mm of Automatic Readings	Maximum Difference between Manual Dippings and Automatic Readings (mm)		Remarks	
					+	-		
Combined sensor and datalogger (without data transmission) (Fong On)	Sai Sha Road, near Kei Ling Ha San Wai	BH8	41	41 (100)	54	49	All within ±200 mm	90% of data are within ±50 mm (excluding doubtful readings in BH10)
		BH9	37	33 (89)	54	188		
		BH10	23	13 (57)	603	24	Other than those readings taken during periods of uncertain reliability at the end of the trial period, all within ±200 mm	
System using telephone lines as a means of data transmission (Fugro)	Po Shan Road, Mid-levels	DC4	64	28 (44)	4,000	350	All except 4 records are within ±500 mm (see Note 1)	90% of data are within ±280 mm
		PD40	64	25 (39)	1,270	230		
	Wing Yip Street, Kwai Chung	BH3	57	33 (58)	270	350		
		BH5	55	11 (20)	530	290		
System using radio waves as a means of data transmission (Gammon)	Po Shan Road, Mid-levels	PD18L	59	19 (32)	10,564	1,433	Other than those readings taken during periods of uncertain reliability in the beginning of the trial period, all except 5 records are within ±200 mm	90% of data are within ±160 mm (excluding unstable readings in the beginning of the trial period)
		PD19L	58	52 (90)	146	377		
	Ching Cheung Road	VH17	70 (34 Dry)	21 (58)	183	10,755		
		VH18	71	38 (54)	6,830	670		

Legend:

+ Piezometric level as indicated by manual reading is higher than the automatic reading

– Piezometric level as indicated by the manual reading is lower than the automatic reading

Note: (1) The information in this Table is based on data provided by the contractors, which have not been corrected to account for variations in atmospheric pressure.

Table 8 - Observations Related to the Service of Provision of Piezometer Data by the Contractors During the Trials

Aspects \ Contractor	Fong On	Fugro	Gammon
1. Understanding of the Engineer's requirement	Fair (Guidance needed on several occasions).	Good	Good
2. Adequacy of technical support	Fong On is basically a supplier who has indicated that the DIVER system "has no servicing part by the user."	Fair	Fair
3. Problem solving capability	Fair	Fair	Fair
4. Responsiveness to site problems	Not timely (Doubtful readings have been noted in BH10 for four months and no remedial action was taken before the unit became inaccessible due to LPM works).	Responsive	Responsive

Table 9 - Observations of Groundwater Conditions (Information Provided by the Contractors)

System (Contractor)	Site	Borehole	Pressure Sensor Level (mPD)	Groundwater Levels in Borehole (mPD)		Maximum Rise Recorded by Sensor (m)	Maximum Head Recorded by Sensor (m)
				Max.	Min.		
Combined sensor and datalogger (without data transmission) (Fong On)	Sai Sha Road, near Kei Ling Ha San Wai	BH8	38.36	50.47	43.85	6.62	12.118
		BH9	50.92	59.49	51.74	7.75	8.570
		BH10	38.79	49.43 (?)	40.05	9.38	10.642 (?)
System using telephone lines as a means of data transmission (Fugro)	Po Shan Road, Mid-levels	DC4	182.70	187.62	186.89	0.73	4.92
		PD40	184.70	194.50	185.11	9.39	9.80
	Wing Yip Street, Kwai Chung	BH3	32.00	39.95	35.10	4.85	7.95
		BH5	24.00	33.90	30.21	3.69	9.90
System using radio waves as a means of data transmission (Gammon)	Po Shan Road, Mid-levels	PD18L	187.88	208.439	193.041	(1)	20.559
		PD19L	192.49	203.507	202.901	0.350 (?)	11.017
	Ching Cheung Road	VH17	38.12	41.362	38.120	1.385 (?)	3.242
		VH18	50.61	64.280	60.210	0.640 (?)	13.670

Legend:

(?) Inconsistent data noted in the information provided by the contractors

Note: (1) No rise recorded in PD18 apart from topping up the piezometer tube with water for function check.

Table 10 - Estimates of Human Resources Required for Groundwater Monitoring

Monitoring of Groundwater Levels by Manual Dipping	Checking and on-site Data Downloading of Automatic System (without transmission facilities)	Checking of Automatic System (with transmission facilities)
A. <u>Two Wet Seasons</u> (April to October) Frequency of monitoring: fortnightly Estimated no. of site visits: 30 half man-day per visit Manpower required: 30 × 0.5 = 15 man-days B. <u>Dry Season</u> (November to March) Frequency of monitoring: monthly Estimated no. of site visits: 5 Manpower required: 5 × 0.5 = 2.5 man-days C. <u>After Heavy Rainstorms</u> Say: 20 site visits (one man-day per visit) Manpower required: 20 × 1 = 20 man-days	A. <u>Two Wet Seasons</u> (April to October) Frequency of monitoring: monthly Estimated no. of site visits: 14 half man-day per visit Manpower required: 14 × 0.5 = 7 man-days B. <u>Dry Season</u> (November to March) Estimated no. of site visits: 2 Manpower required: 2 × 0.5 = 1.0 man-days C. <u>After Heavy Rainstorms</u> Say: 6 site visits (half man-day per visit) Manpower required: 6 × 0.5 = 3 man-days	A. <u>Two Wet Seasons</u> (April to October) Frequency of monitoring: monthly Estimated no. of site visits: 14 half man-day per visit Manpower required: 14 × 0.5 = 7 man-days B. <u>Dry Season</u> (November to March) Estimated no. of site visits: 1 Manpower required: 1 × 0.5 = 0.5 man-days C. <u>After Heavy Rainstorms</u> Nil
Total manpower required = 15 + 2.5 + 20 = 37.5 man-days	Total manpower required = 7 + 1.0 + 3 = 11 man-days	Total manpower required = 7 + 0.5 = 7.5 man-days

Table 11 - Cost Estimate for the Combined Downhole Pressure Sensor and Datalogger System (Based on Information Provided by the Contractor at the Time of Preparation of this Report)

Item	Cost (HK$)	
	Scenario 1	Scenario 2
(1) Calibration, checking, setting up of a system (which includes sensors, dataloggers, power supplies, means for data transmission and any necessary accessories) for the automatic acquisition of piezometric data, and all other instrument/equipment items and computer hardwares and softwares needed for the processing and presentation of the piezometric data.	75,000	75,000
(2) Maintenance of the system referred to in Item (1).	0	0
(3) Acquisition of piezometric data including the processing of the data and preparation of the monthly reports.	90,000	90,000
(4) Preparation of the end-of-project report.	35,000	35,000
(5) Removal of system referred to in Item (1).	0	0
Total	200,000	200,000

<u>Typical Scenario 1</u>

Assume similar conditions in the trials with the following modifications:

(a) Site conditions - Four boreholes (not sensors) in total, two 100 m apart at crest of slope and two 100 m apart at toe of slope on a 30 m high roadside slope in urban area.

(b) Monitoring period - Two wet seasons (April to October) plus one intervening dry period (November to March).

(c) Accuracy - able to measure water level within ±200 mm of manual readings.

(d) Invalid readings (data loss and inaccurate/uncertain readings) - not more than 10% during anyone rainstorm within which the rolling 24-hour rainfall is greater than or equal to 50 mm.

(e) Frequency of Data Capture (with atmospheric pressure correction).

(i) Dry Period - daily

(ii) Wet Seasons - hourly

<u>Typical Scenario 2</u>

(a), (b) & (e)(i) as above.

(e)(ii) Wet Seasons - every 5 minutes.

Table 12 - Cost Estimate for the System Using Telephone Lines as a Means of Data Transmission (Based on Information Provided by the Contractor at the Time of Preparation of this Report)

Item	Cost (HK$)	
	Scenario 1	Scenario 2
(1) Calibration, checking, setting up of a system (which includes sensors, dataloggers, power supplies, means for data transmission and any necessary accessories) for the automatic acquisition of piezometric data, and all other instrument/equipment items and computer hardwares and softwares needed for the processing and presentation of the piezometric data.	120,000	120,000
(2) Maintenance of the system referred to in Item (1).	38,000 @2,000/month	38,000 @2,000/month
(3) Acquisition of piezometric data including the processing of the data and preparation of the monthly reports.	152,000 @8,000/month	190,000 @10,000/month
(4) Preparation of the end-of-project report.	20,000	20,000
(5) Removal of system referred to in Item (1).	9,000	9,000
Total	339,000	337,000

Typical Scenario 1

Assume similar conditions in the trials with the following modifications:

(a) Site conditions - Four boreholes (not sensors) in total, two 100 m apart at crest of slope and two 100 m apart at toe of slope on a 30 m high roadside slope in urban area.

(b) Monitoring period - Two wet seasons (April to October) plus one intervening dry period (November to March).

(c) Accuracy - able to measure water level within ±200 mm of manual readings.

(d) Invalid readings (data loss and inaccurate/uncertain readings) - not more than 10% during anyone rainstorm within which the rolling 24-hour rainfall is greater than or equal to 50 mm.

(e) Frequency of Data Capture (with atmospheric pressure correction).

(i) Dry Period - daily

(ii) Wet Seasons - hourly

Typical Scenario 2

(a), (b) & (e)(i) as above.

(e)(ii) Wet Seasons - every 5 minutes.

Table 13 - Cost Estimate for the System Using Radio Waves as a Means of Data Transmission (Based on Information Provided by the Contractor at the Time of Preparation of this Report)

Item	Cost (HK$)	
	Scenario 1	Scenario 2
(1) Calibration, checking, setting up of a system (which includes sensors, dataloggers, power supplies, means for data transmission and any necessary accessories) for the automatic acquisition of piezometric data, and all other instrument/equipment items and computer hardwares and softwares needed for the processing and presentation of the piezometric data.	140,000	140,000
(2) Maintenance of the system referred to in Item (1).	26,000	26,000
(3) Acquisition of piezometric data including the processing of the data and preparation of the monthly reports.	67,000	90,000
(4) Preparation of the end-of-project report.	5,000	9,000
(5) Removal of system referred to in Item (1).	7,500	7,500
Total	245,500	272,500

Typical Scenario 1

Assume similar conditions in the trials with the following modifications:

(a) Site conditions - Four boreholes (not sensors) in total, two 100 m apart at crest of slope and two 100 m apart at toe of slope on a 30 m high roadside slope in urban area.

(b) Monitoring period - Two wet seasons (April to October) plus one intervening dry period (November to March).

(c) Accuracy - able to measure water level within ±200 mm of manual readings.

(d) Invalid readings (data loss and inaccurate/uncertain readings) - not more than 10% during anyone rainstorm within which the rolling 24-hour rainfall is greater than or equal to 50 mm.

(e) Frequency of Data Capture (with atmospheric pressure correction).

(i) Dry Period - daily

(ii) Wet Seasons - hourly

Typical Scenario 2

(a), (b) & (e)(i) as above.

(e)(ii) Wet Seasons - every 5 minutes.

Table 14 - Data Transmission Systems

Conventional Dial-up Telephone Lines	GSM/VHF Radio System
<u>Advantages</u> • hardware required is relatively cheap ($4,000 for supply, install and commissioning a set of telephone modem) • relatively low running costs ($300 per month/line to maintain telephone line) <u>Disadvantages/Limitations</u> • may be difficult to install phone lines direct to the monitoring location • phone lines are vulnerable to damage due to, for example, site activities and vandalism • reliance on permanently installed lines makes redeployment difficult • civil works may be required to set up phone lines on site, adding to the cost of data acquisition	<u>Advantages</u> • faster installation and redeployment • GSM system coverage area is greater than the VHF radio coverage area <u>Disadvantages/Limitations</u> • expensive hardware ($10,000 for supply, install and commissing GSM cellular modem) • higher running costs than dial-up lines ($650 per month/line to maintain a GSM phone service (maximum 100 minutes per month), although reduction in cost is expected with the increasing competition) • data transfer rate is much less than may be achieved over a dial-up line (not a big problem given the volume and data to be transmitted) • planned installation may not be adequately covered by the network • when GSM system becomes busy, e.g. during an emergency situation, it may become overloaded in that data transmission may be interrupted or not possible. This may not be a problem unless real-time monitoring is required. The datalogger retains the data, which could therefore be down-loaded at a later time.

APPENDIX A

COMBINED DOWNHOLE PRESSURE SENSOR AND DATALOGGER SYSTEM (FONG ON)

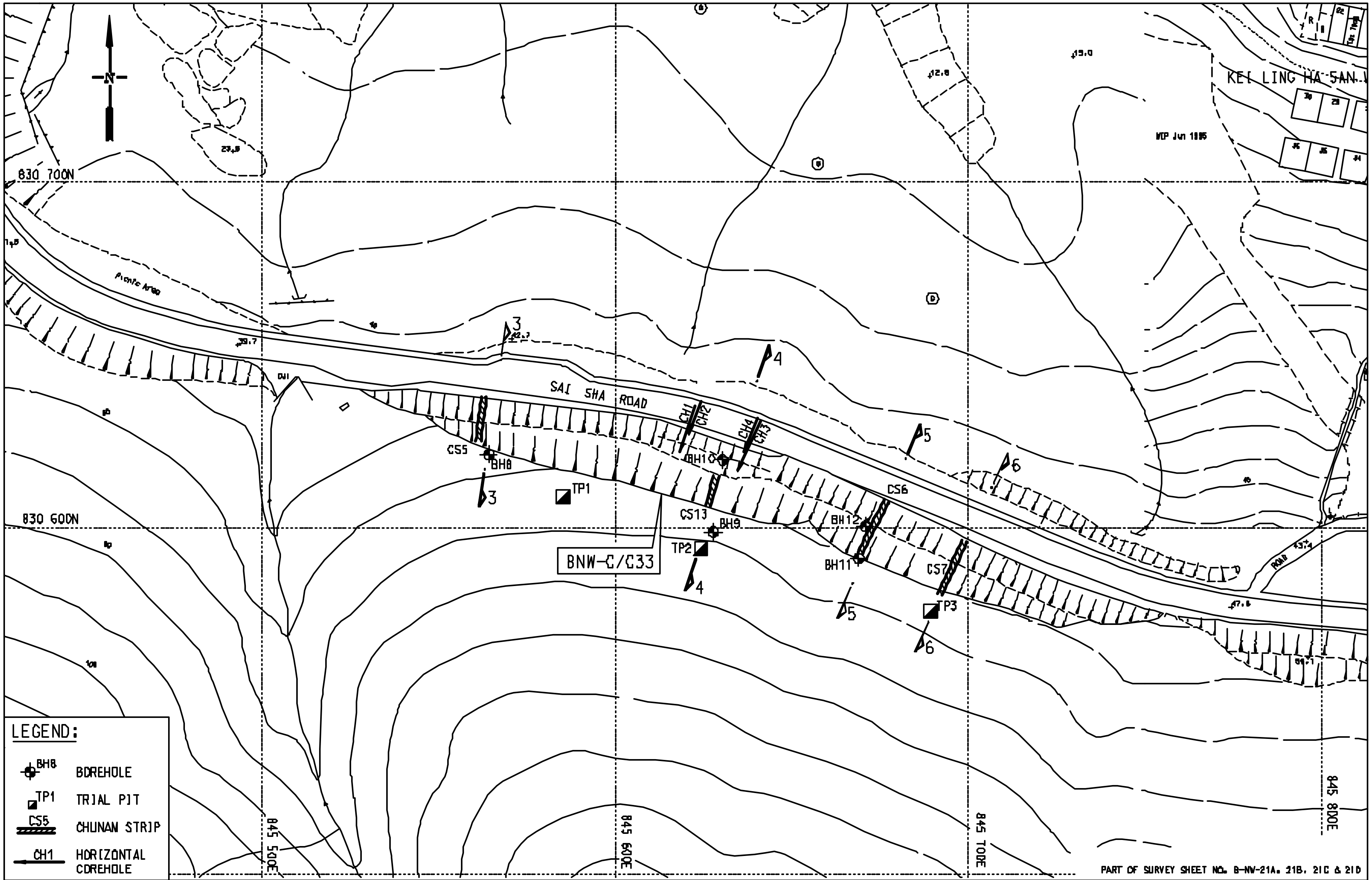
This Appendix contains the following information relating to the combined downhole pressure sensor and datalogger system (Fong On):

(a) Location plan of trial site (Figure A1).

(b) Summary of major items of equipment used (p. 66).

(c) Details of the piezometric data acquisition system (Figures A2 and A3, Plates A1 and A2).

(d) Examples of piezometric records (pp 69 to 71).



SLOPE NO. 8NW-C/C33 SAI SHA ROAD — GROUND INVESTIGATION PLAN

FIGURE A1

Summary of Major Items of Equipment Used

Main Contractor: Fong On Construction & Engineering Co., Ltd

Manufacturer: Van Essen Instruments bv

System Used: TD-DIVER DI215

Equipment Details: The TD-DIVER datalogger measures two parameters, viz. temperature and water pressure.
The temperature measurement is also used to compensate the pressure transducer for temperature effects.

Site location: Kei Ling Ha San Wai on the south side of Sai Sha Road near street light post no. EA06754 and EA06749 on the slope no. 8NW-C/C33.

Borehole No.	Serial No.	Date Installed	Date Removed	Remarks
BH8	sn.17747	17/7/1999	30/10/2000	
BH9	sn.17743	17/7/1999	30/10/2000	
BH10	sn.17744	20/9/2000	N/A	Cannot be removed due to site works.
BH9 (Air)	sn.17741	17/7/1999	30/10/2000	

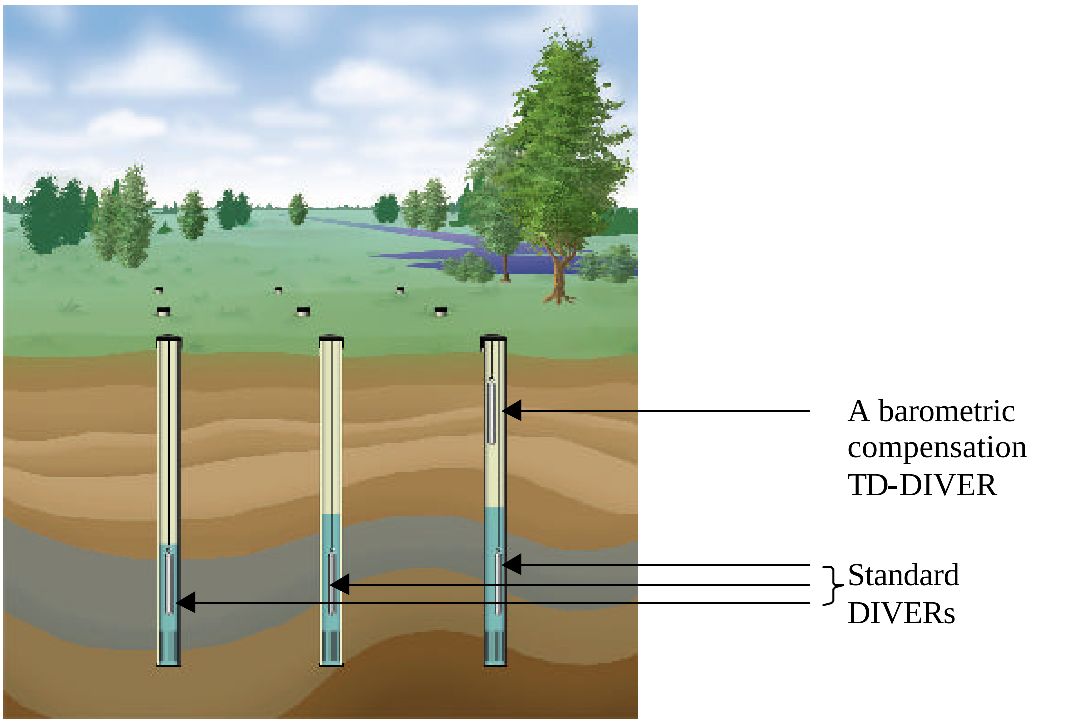


Figure A2

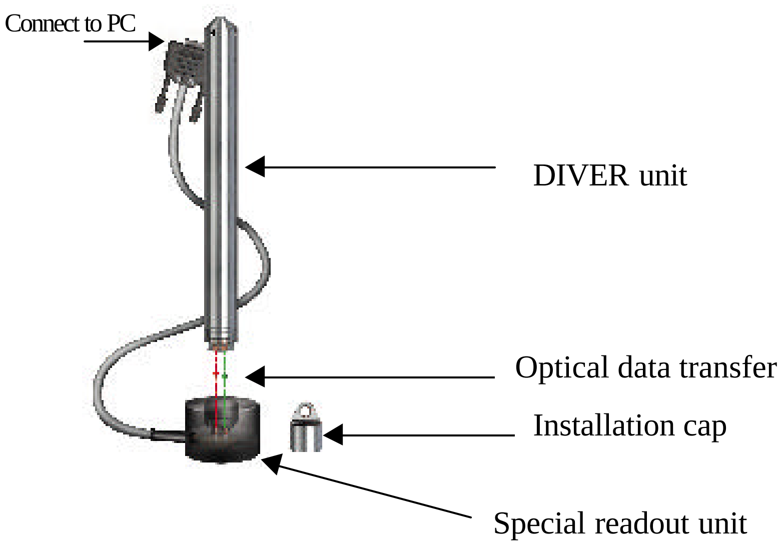


Figure A3

Details of Combined Downhole Pressure Sensor and Datalogger System

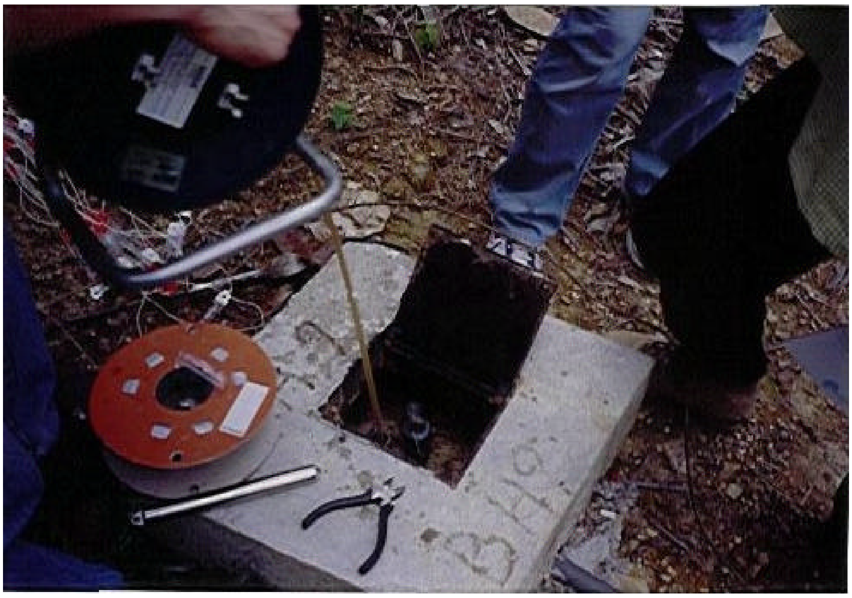


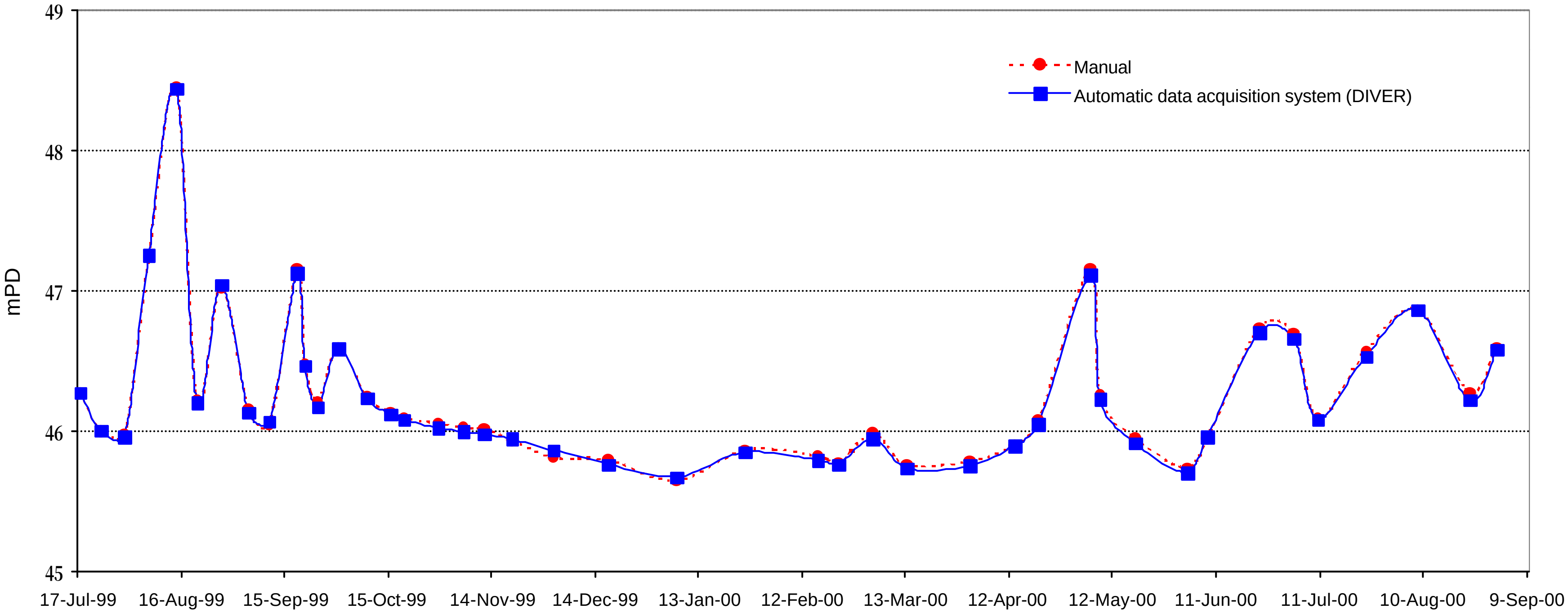
Plate A1 - Manual Measurement of Water Level Prior to Installation of DIVER

Plate A2 - DIVER Installed Inside the Borehole

Project: Automatic Acquisition of Piezometric Data

Comparsion of Piezometric Levels Obtained from Manual Readings and Automatic Data Acquisition System (DIVER)

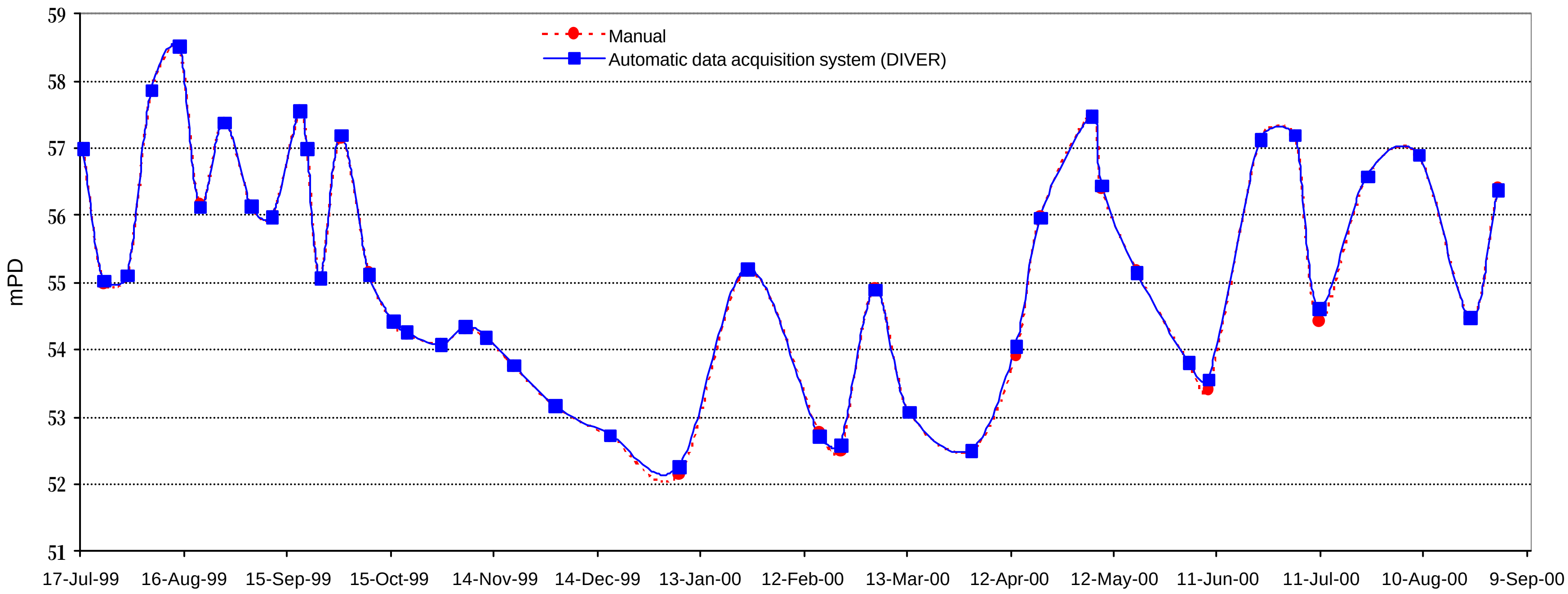
Borehole BH8



Project: Automatic Acquisition of Piezometric Data

Comparsion of Piezometric Levels Obtained from Manual Readings and Automatic Data Acquisition System (DIVER)

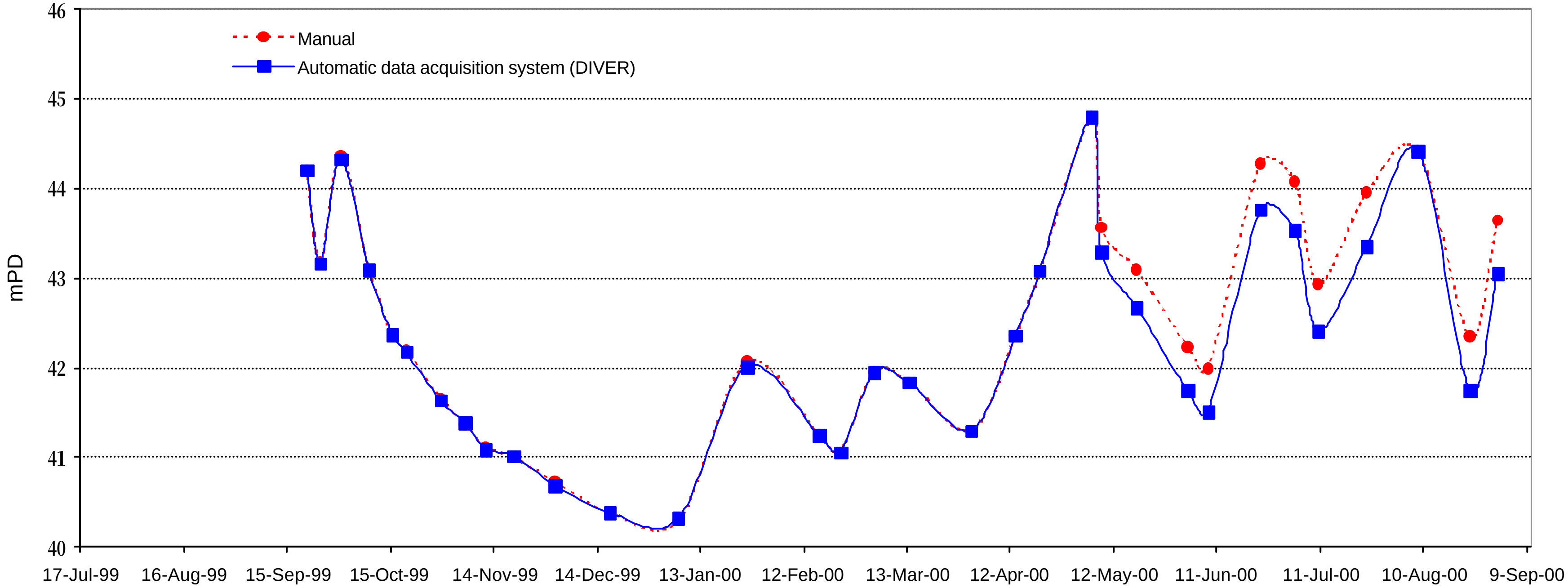
Borehole BH9



Project: Automatic Acquisition of Piezometric Data

Comparsion of Piezometric Levels Obtained from Manual Readings and Automatic Data Acquisition System (DIVER)

Borehole BH10



APPENDIX B

SYSTEM USING TELEPHONE LINES AS A MEANS OF TRANSMISSION (FUGRO)

This Appendix contains the following information relating to the system using telephone lines as a means of transmission (Fugro):

(a) Location plans of trial sites (Figures B1 and B2).

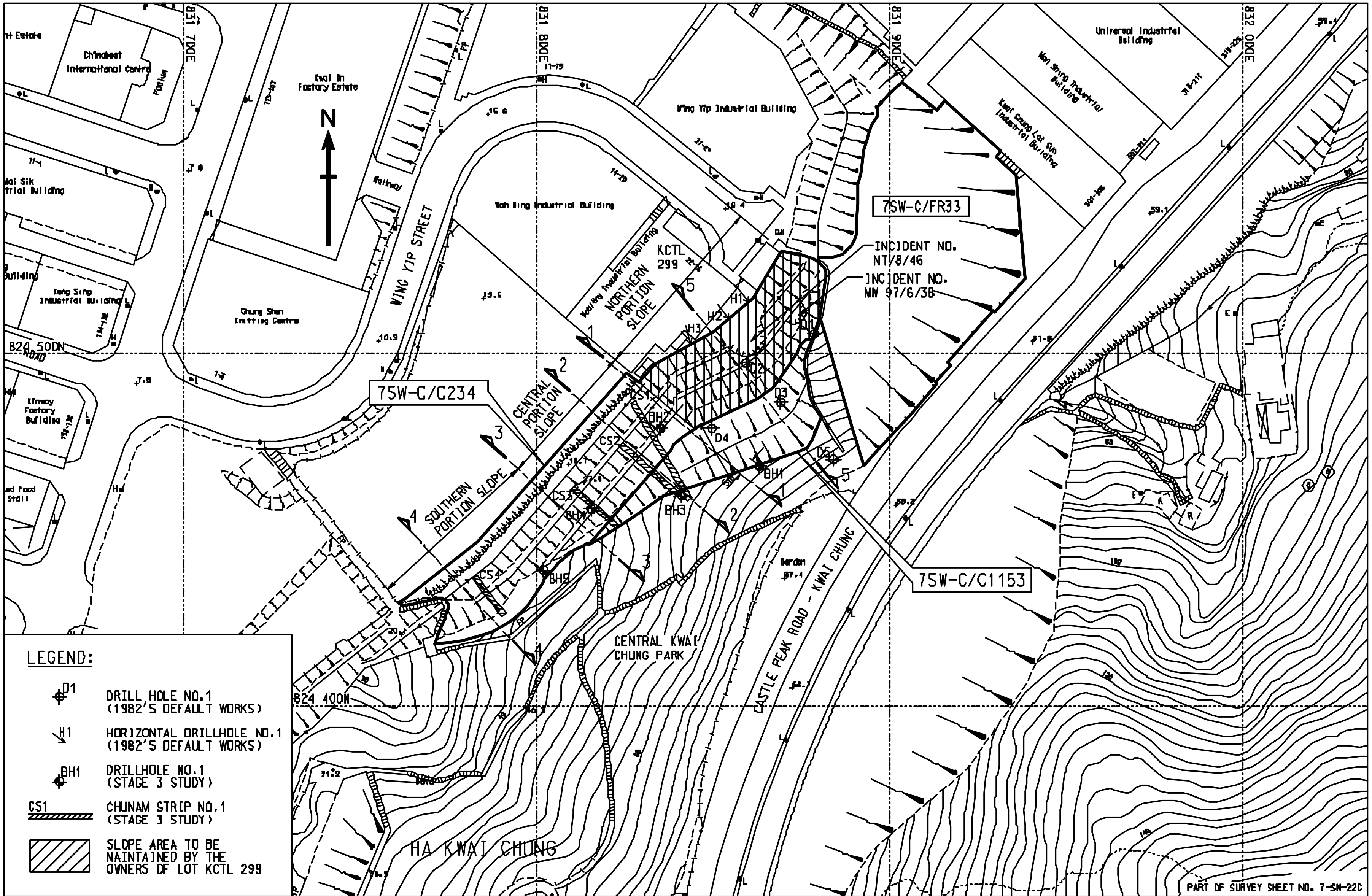
(b) Summary of major items of equipment used (p. 76).

(c) Block diagrams (Figures B3 and B4) and photographs (Plates B1 to B4) of the piezometric data acquisition system.

(d) Examples of piezometric records (pp 81 to 82).

PO SHAN ROAD SITE --- LOCATION OF PIEZOMETERS USED IN AUTOMATIC ACQUISITION OF PIEZOMETRIC DATA PROJECT

FIGURE B1



SLOPE NO. 7SW-C/C234 & C1153, WING YIP STREET, KWAI CHUNG — LOCATION AND GROUND INVESTIGATION PLAN

FIGURE B2

Summary of Major Items of Equipment Used

Main Contractor: Fugro Geotechnical Services (HK) Ltd

Joint Venture Company: N/A

System Used: Public telephone system for data transmission

Equipment Details:

Subsystem	Manufacturer	Type (Serial No.)	Date Installed	Date Removed	Remarks
Po Shan Road Site					
a Sensor	SINCO	48340	30/7/1999	31/10/2000	for borehole PD40
b Sensor	SINCO	48342	14/7/1999	31/10/2000	for borehole DC4
c Datalogger	SINCO	1335	30/7/1999	31/10/2000	for borehole PD40
d Datalogger	SINCO	1336	14/7/1999	31/10/2000	for borehole DC4
e Tel line	HK Telecom	N/A	10/7/1999	9/11/2000	
Wing Yip Street Site					
a Sensor	SINCO	48339	6/8/1999	31/10/2000	for borehole BH3
b Sensor	SINCO	48338	6/8/1999	31/10/2000	for borehole BH5
c Datalogger	DataTaker	30499	6/8/1999	31/10/2000	multi-channel datalogger
d Tel line	HK Telecom	N/A	11/8/1999	9/11/2000	

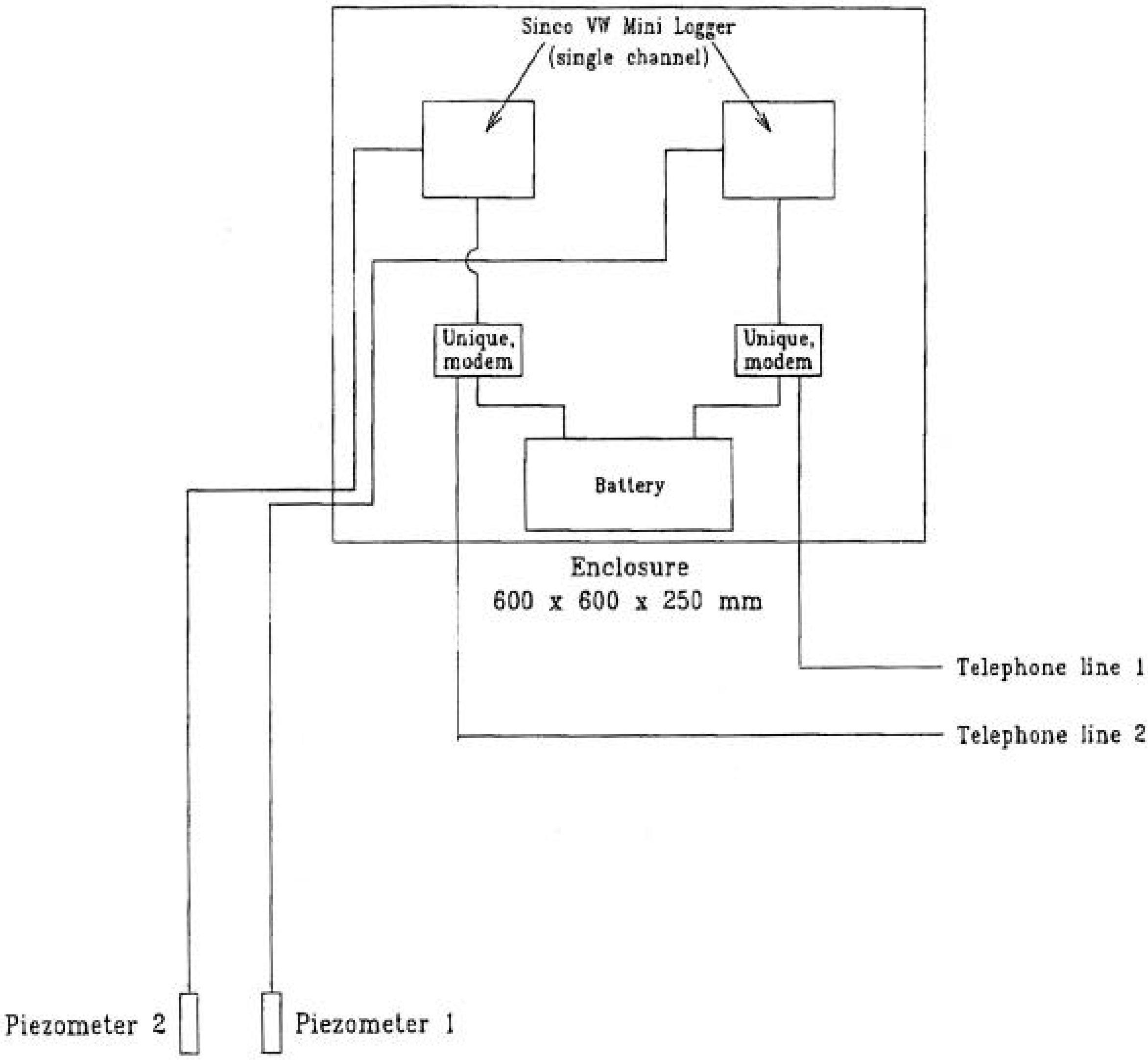


Figure B3 - Block Diagram of System Configuration Used at the Po Shan Road Site

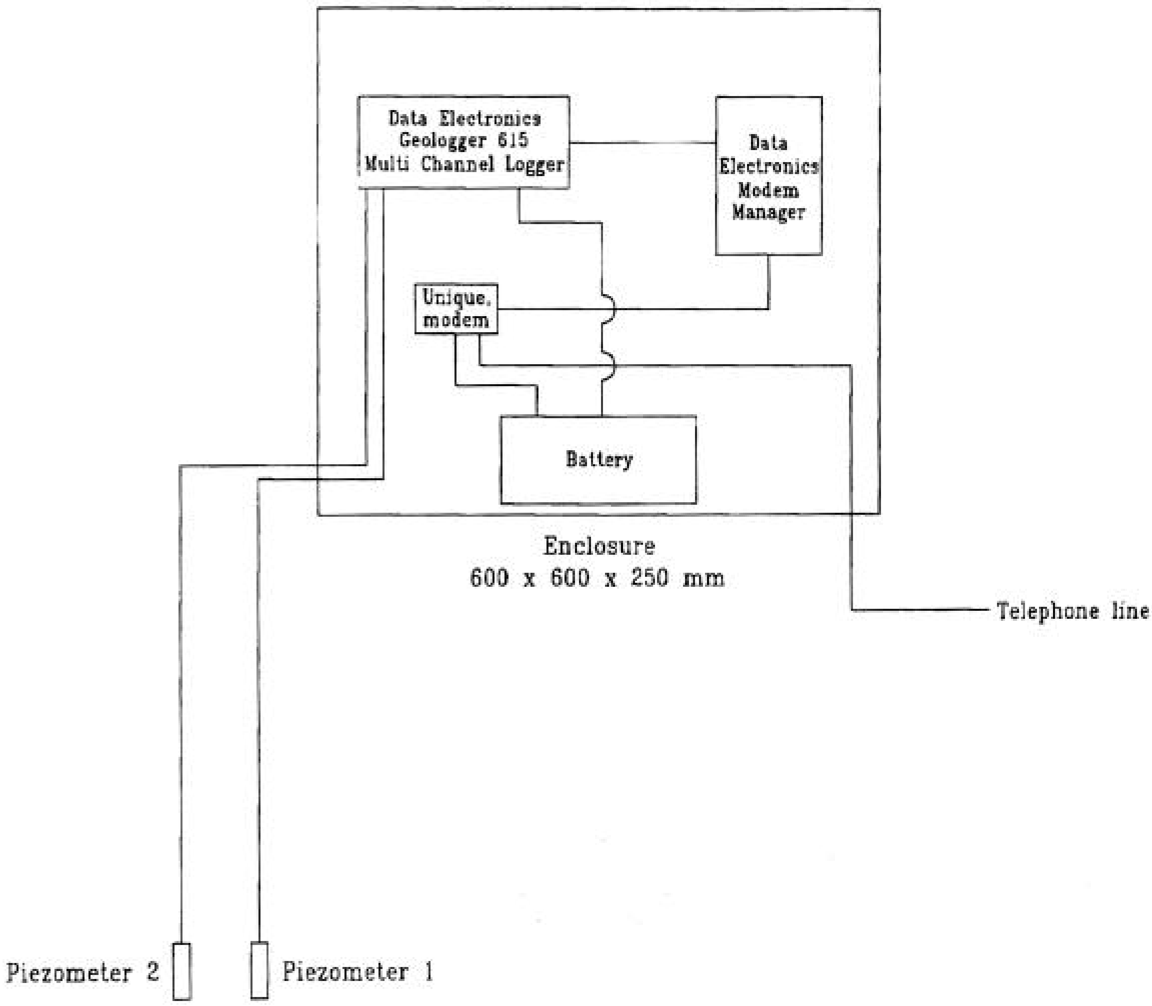


Figure B4 - Block Diagram of System Configuration Used at the Wing Yip Street Site

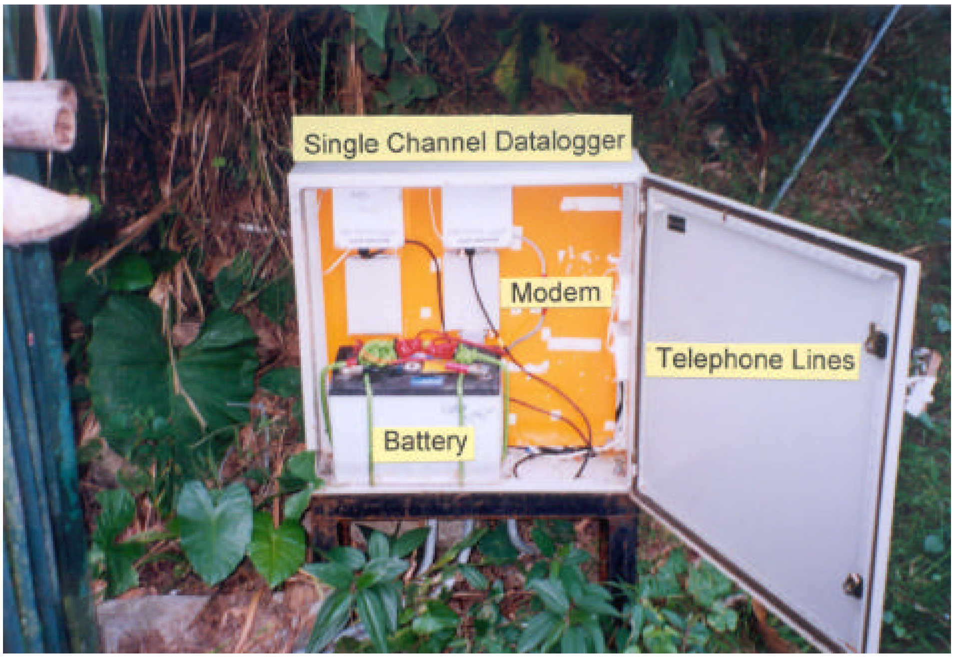


Plate B1

Plate B2

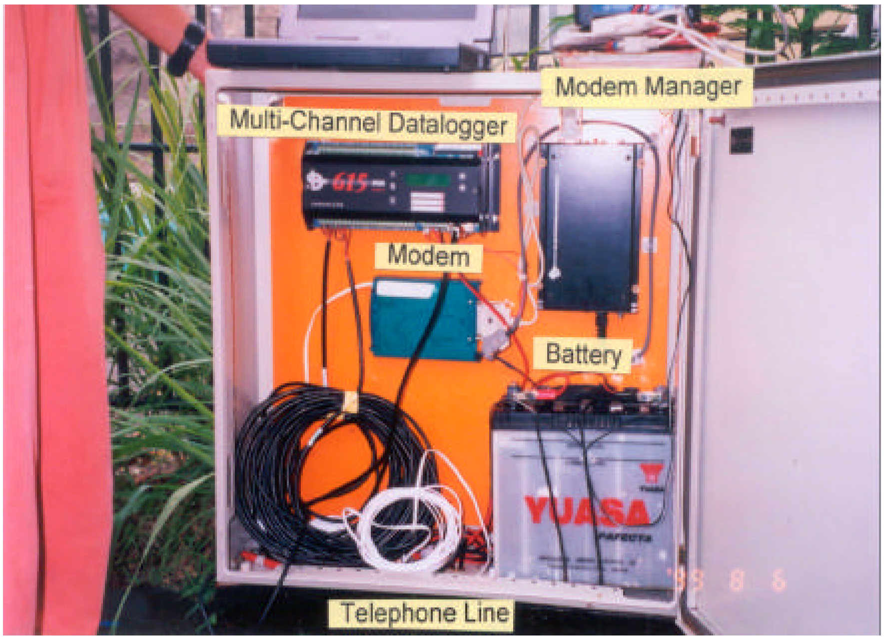


Plate B3

Plate B4

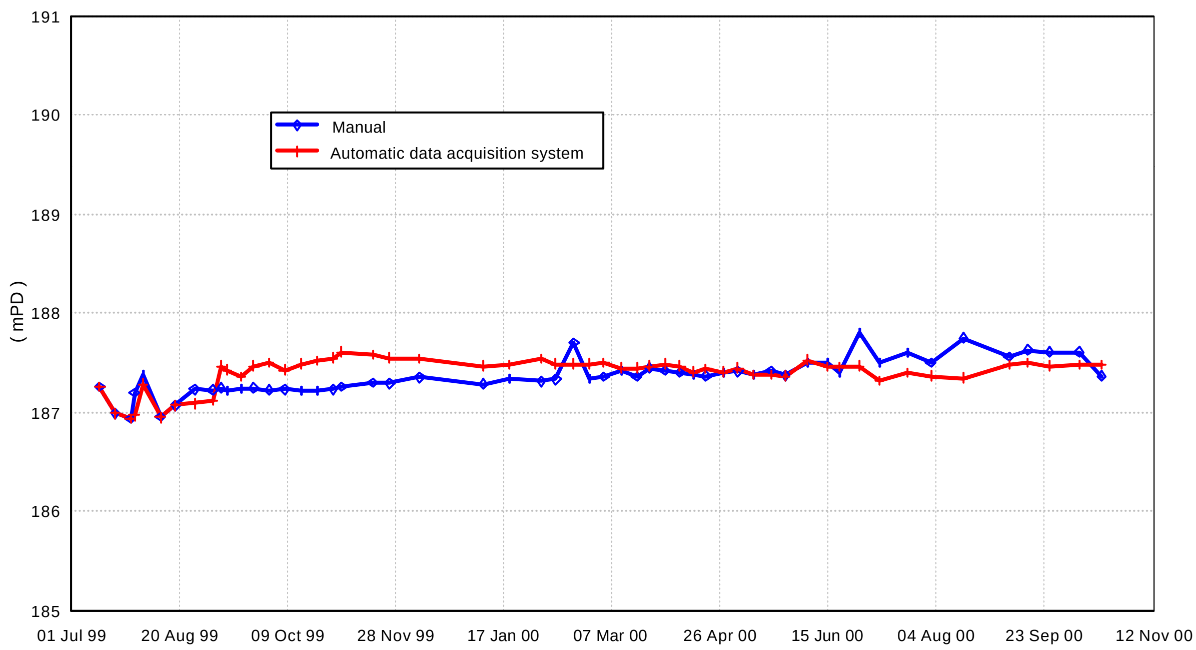
FGS Project : Automatic Acquisition of Piezometric Data Using Telephone Lines for Transmission

FGS Project No. : 98 0205 06

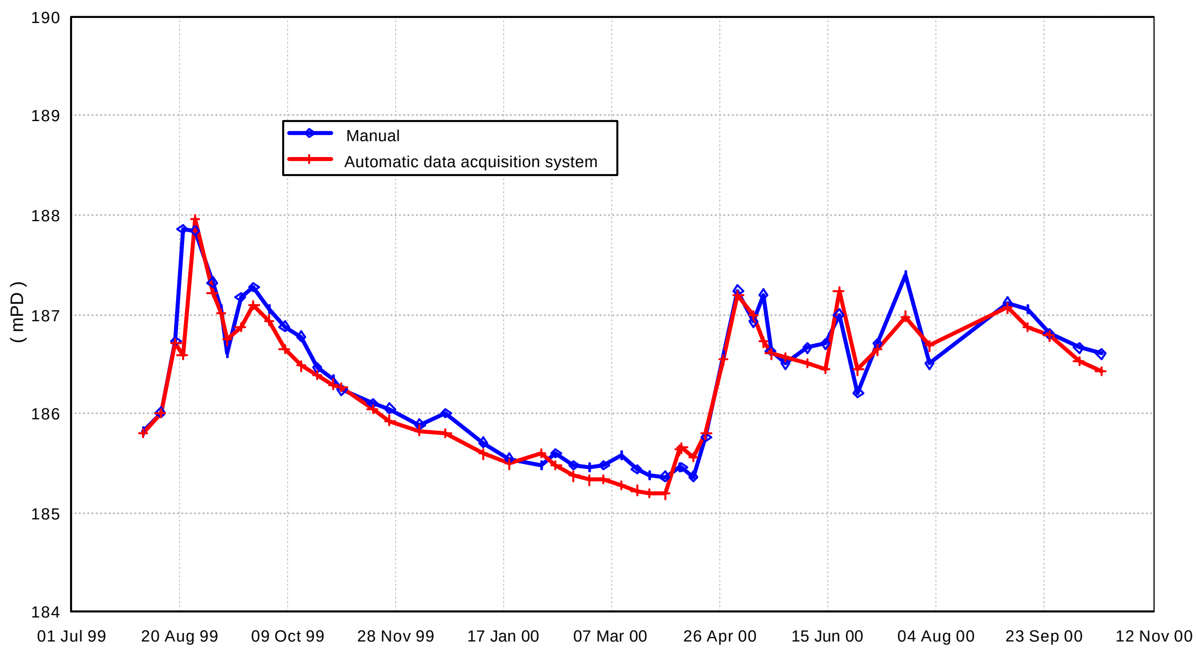
Location : Po Shan Road

Comparison of Piezometric Levels Obtained from Manual Readings and Automatic Data Acquisition System

Instrument No. : DC 4



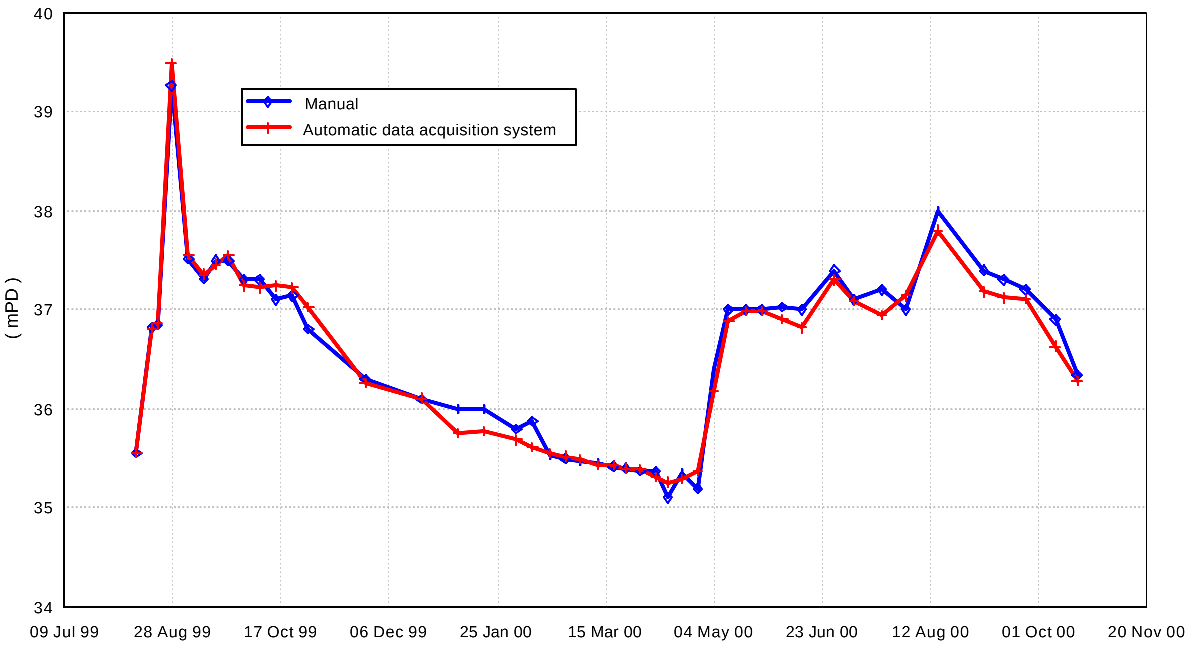
Instrument No. : PD 40



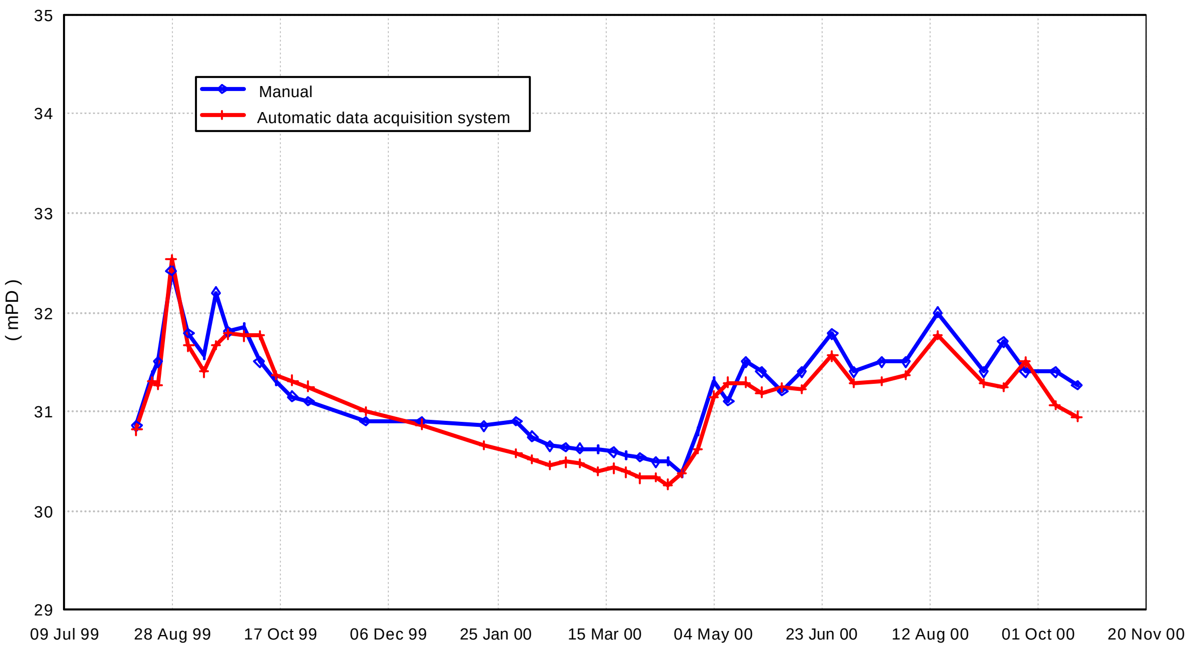
FGS Project :	Automatic Acquisition of Piezometric Data Using Telephone Lines for Transmission
FGS Project No. :	98 0205 06
Location :	Kwai Chung , Wing Yip Street

Comparison of Piezometric Levels Obtained from Manual Readings and Automatic Data Acquisition System

Instrument No. : BH 3



Instrument No. : BH 5



APPENDIX C

SYSTEM USING RADIO WAVES AS A MEANS OF TRANSMISSION (GAMMON)

This Appendix contains the following information relating to the system using radio waves as a means of transmission (Gammon):

(a) Location plans of trial sites (Figures C1 and C2).

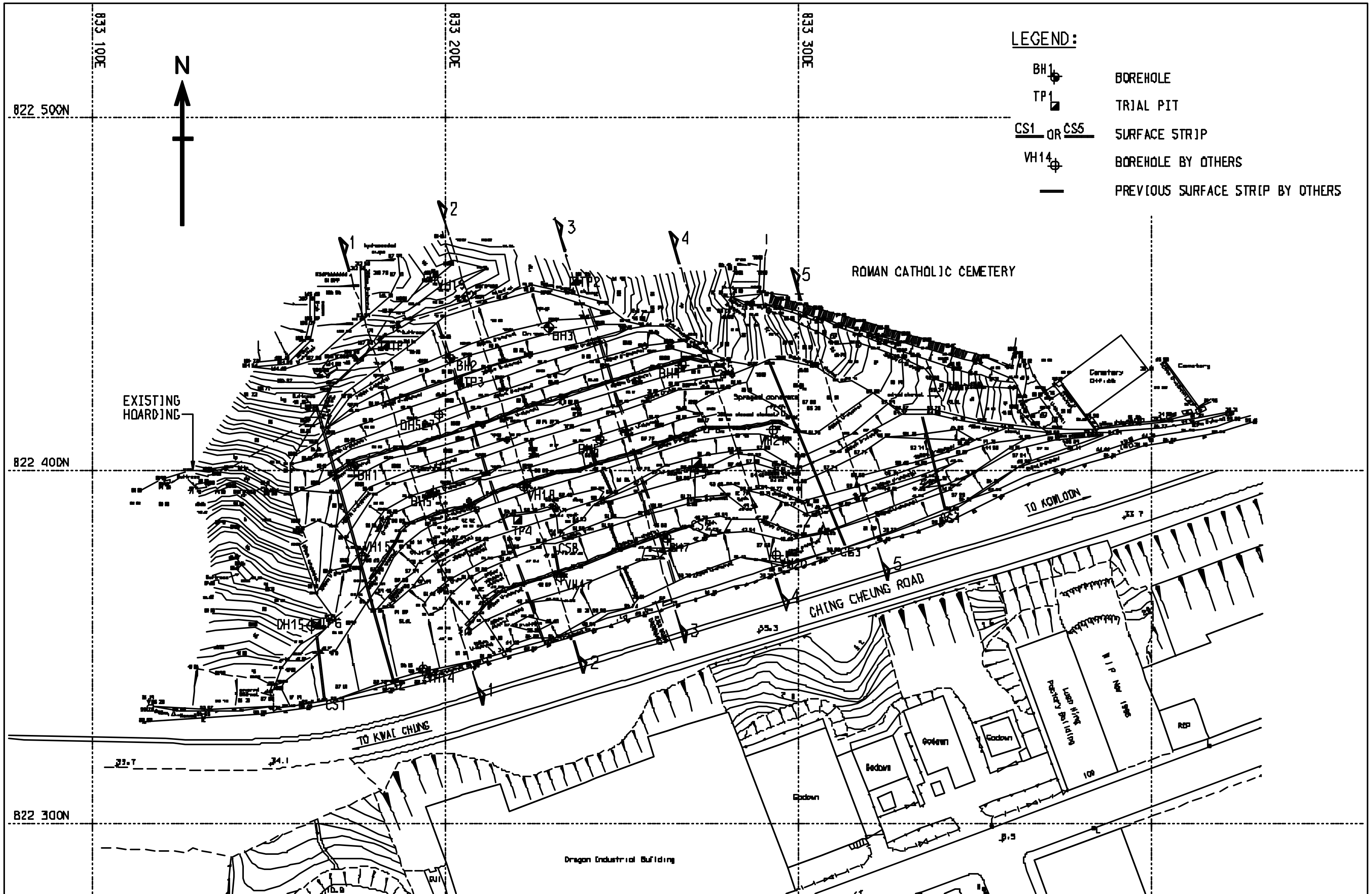
(b) Summary of major items of equipment used (p. 87).

(c) Block diagrams of the piezometric data acquisition system (Figure C3) and Main Control Centre (Figure C4) and photographs of the data acquisition systems (Plates C1 to C8).

(d) Examples of piezometric records (pp 92 to 95).

PO SHAN ROAD SITE — LOCATION OF PIEZOMETERS USED IN AUTOMATIC ACQUISITION OF PIEZOMETRIC DATA PROJECT

FIGURE C1



Site Plan and System Layout — Ching Cheung Road | FIGURE C2

Table C1 - Summary of Major Items of Equipment Used

Description	Serial No.	Date Installed	Date Removed	Remarks
Po Shan Mansion				
VHF radio	-	19/08/1999	-	
GSM modem	-	19/08/1999	-	
GEOKON LC-1 datalogger	1168	19/08/1999	23/08/1999	PD18L - returned to GEOKON
GEOKON LC-1 datalogger	1208	23/08/1999	-	PD18L
GEOKON 4500C-50 sensor	50117	19/08/1999	13/10/1999	PD18L - unstable readings
GEOKON 4500C-100 sensor	50837	13/10/1999	30/12/1999	PD18L - unstable readings
GEOKON 4500B-50 sensor	52249	30/12/1999	-	PD18L
GEOKON LC-1 datalogger	1010	19/08/1999	-	PD19L
GEOKON 4500C-50 sensor	48303	19/08/1999	-	PD19L
Ching Cheung Road				
VHF radio	-	15/07/1999	-	
GSM modem	-	15/07/1999	-	
GEOKON LC-1 datalogger	1168	15/07/1999	06/08/1999	VH17 - swapped to VH18
GEOKON LC-1 datalogger	1170	06/08/1999	-	VH17
GEOKON 4500C-50 sensor	48304	15/07/1999	29/10/1999	VH17 - baseline shift
GEOKON 4500S-50X sensor	51139	29/10/1999	-	VH17
GEOKON LC-1 datalogger	1170	15/07/1999	06/08/1999	VH18 - swapped to VH17
GEOKON LC-1 datalogger	1168	06/08/1999	17/08/1999	VH18 - moved to PD18L
GEOKON LC-1 datalogger	1169	17/08/1999	-	VH18
GEOKON 4500C-50 sensor	48305	14/07/1999	15/07/1999	VH18 - no reading
GEOKON 4500C-50 sensor	50118	15/07/1999	14/10/1999	VH18 - unstable readings
GEOKON 4500S-50X sensor	51140	14/10/1999	-	VH18

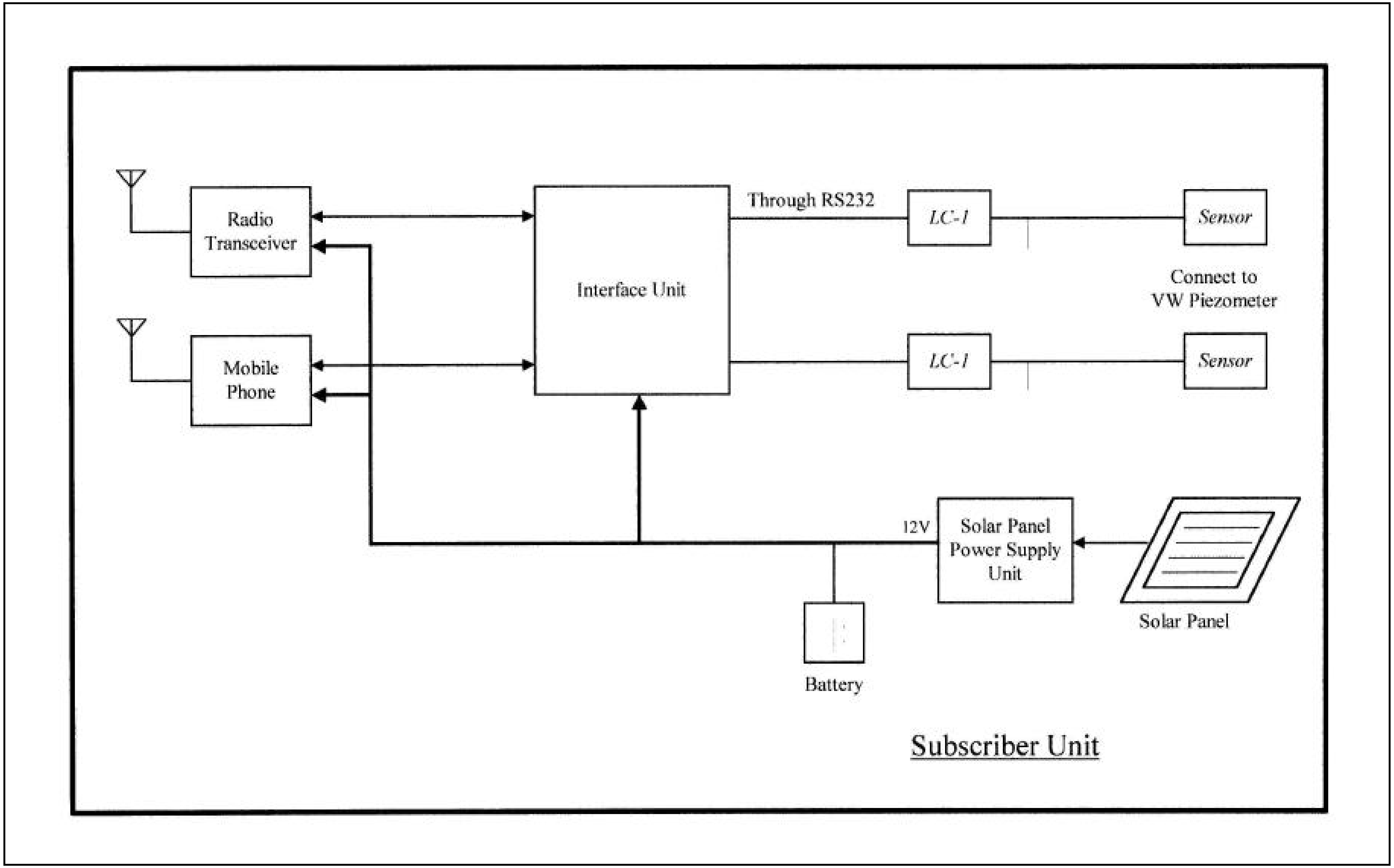


Figure C3 - Block Diagram of Site Subscriber Unit

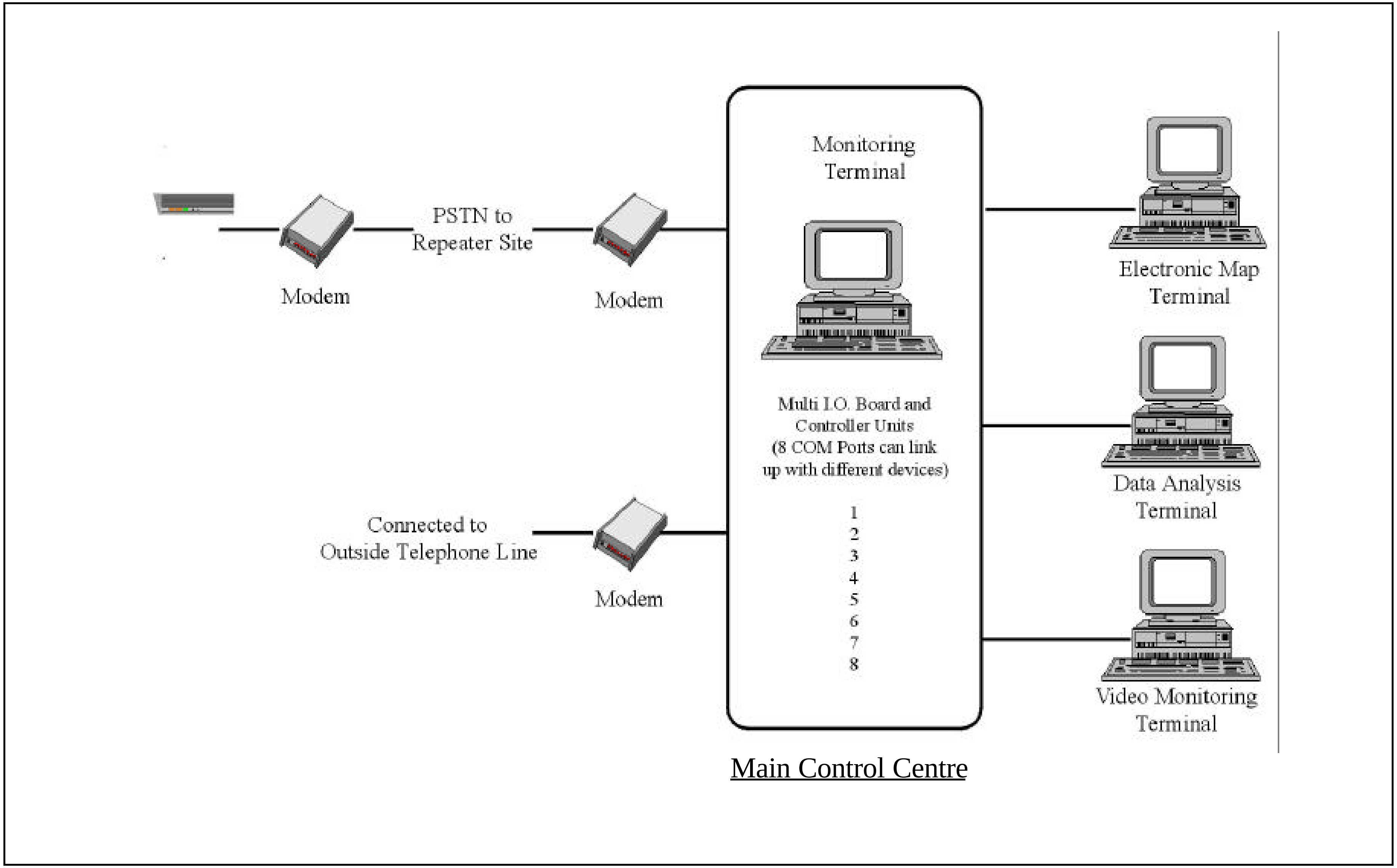


Figure C4 - Block Diagram of Main Control Centre

Plate C1 - Outlook of the Po Shan Road Site

Plate C2 - Outlook of the Po Shan Mansion Site Subscriber Unit

Plate C3 - Details of the Po Shan Mansion Site Subscriber Unit

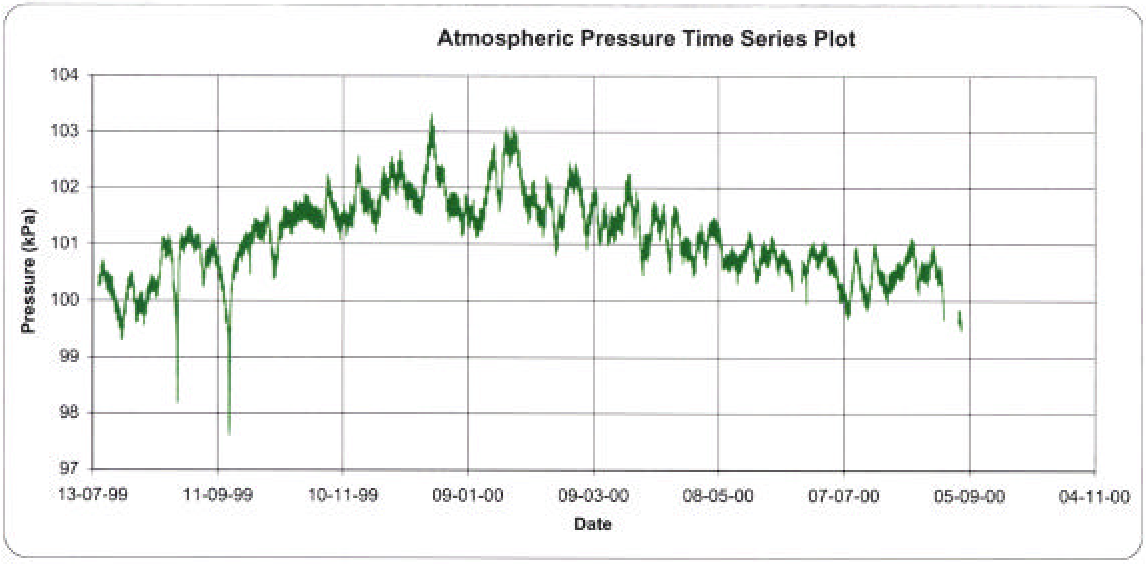
Plate C4 - Main Control Centre

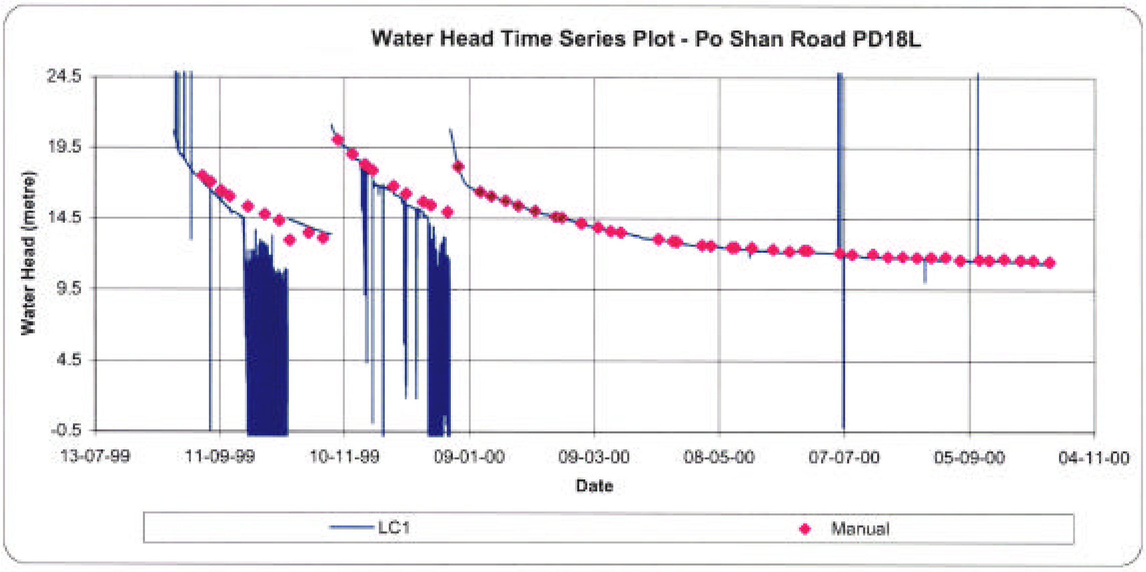
Plate C5 - Outlook of the Ching Cheung Road Site Subscriber Unit

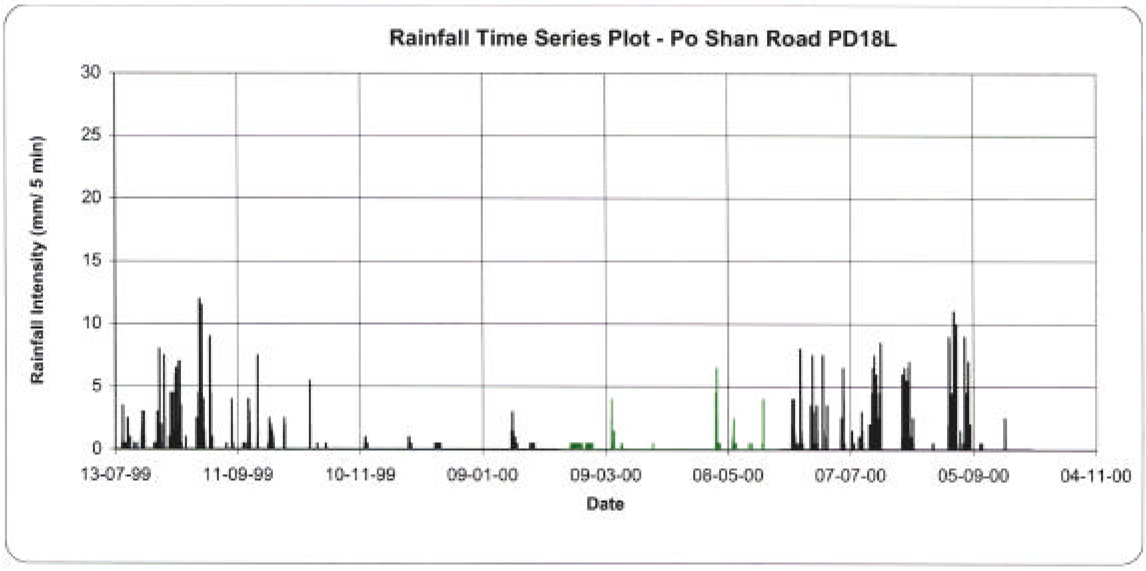
Plate C6 - Installed Vibrating Wire Sensor

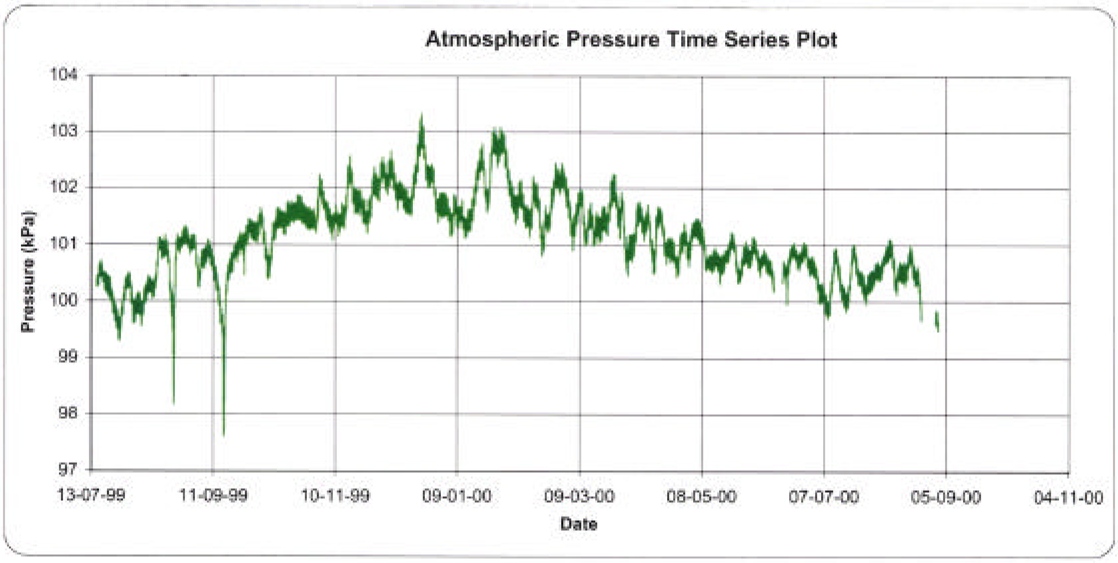
Plate C7 - Details of the Ching Cheung Road Site Subscriber Unit

Plate C8 - Installation of Vibrating Wire Sensor

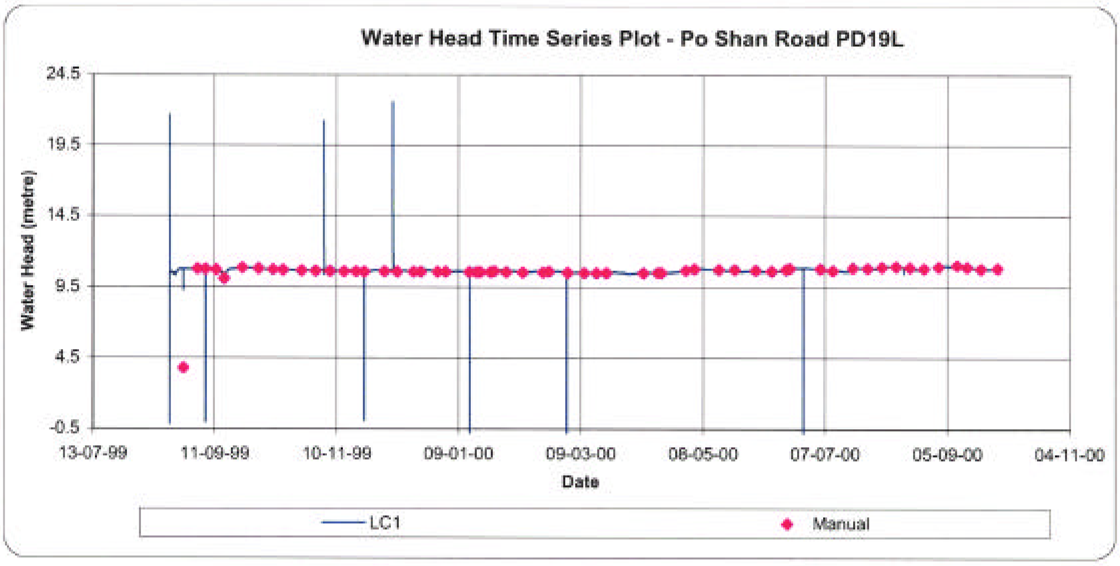

Atmospheric Pressure Time Series Plot
Pressure (kPa)
104
103
102
101
100
99
98
97
13-07-99
11-09-99
10-11-99
09-01-00
09-03-00
08-05-00
07-07-00
05-09-00
04-11-00
Date


Water Head Time Series Plot - Po Shan Road PD18L
Water Head (metre)
24.5
19.5
14.5
9.5
4.5
-0.5
13-07-99
11-09-99
10-11-99
09-01-00
09-03-00
08-05-00
07-07-00
05-09-00
04-11-00
Date
LC1
Manual

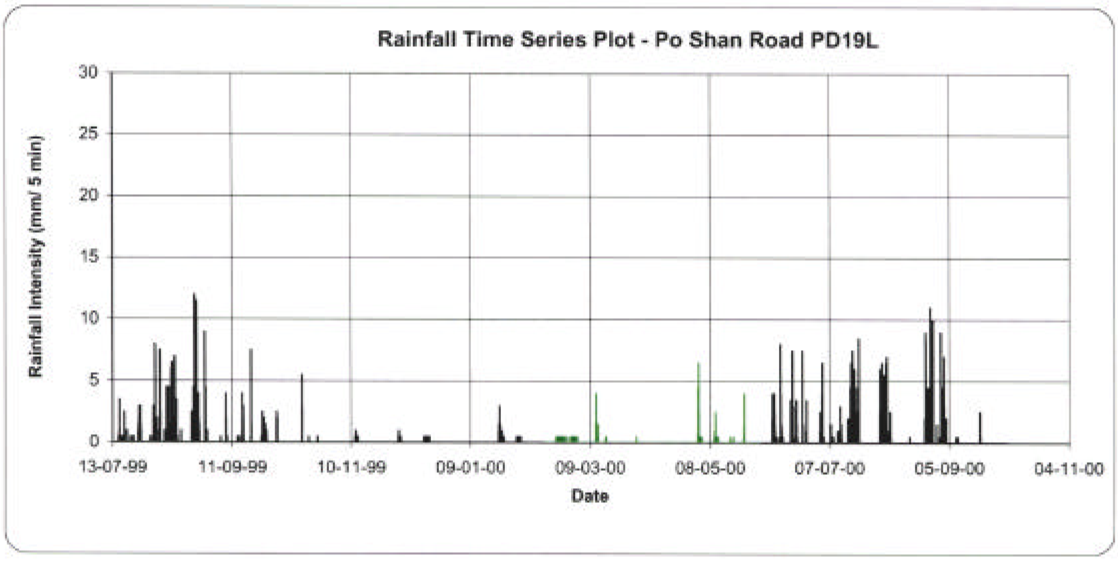

Rainfall Time Series Plot - Po Shan Road PD18L
Rainfall Intensity (mm/ 5 min)
30
25
20
15
10
5
0
13-07-99
11-09-99
10-11-99
09-01-00
09-03-00
08-05-00
07-07-00
05-09-00
04-11-00
Date



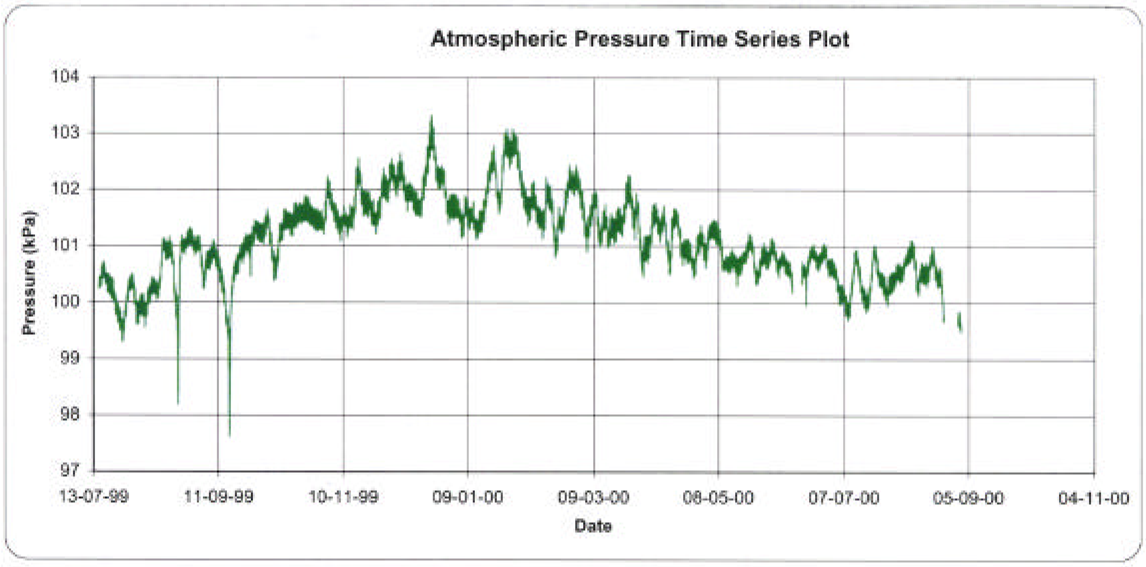
Atmospheric Pressure Time Series Plot
Pressure (kPa)
104
103
102
101
100
99
98
97
13-07-99
11-09-99
10-11-99
09-01-00
09-03-00
08-05-00
07-07-00
05-09-00
04-11-00
Date



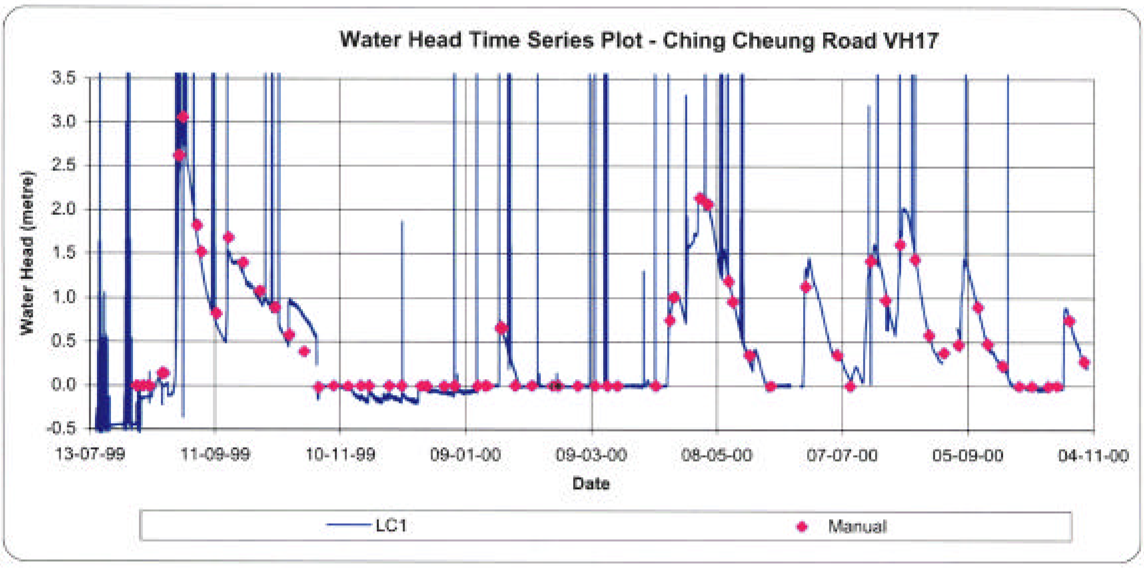
Water Head Time Series Plot - Po Shan Road PD19L
Water Head (metre)
24.5
19.5
14.5
9.5
4.5
-0.5
13-07-99
11-09-99
10-11-99
09-01-00
09-03-00
08-05-00
07-07-00
05-09-00
04-11-00
Date
LC1
Manual



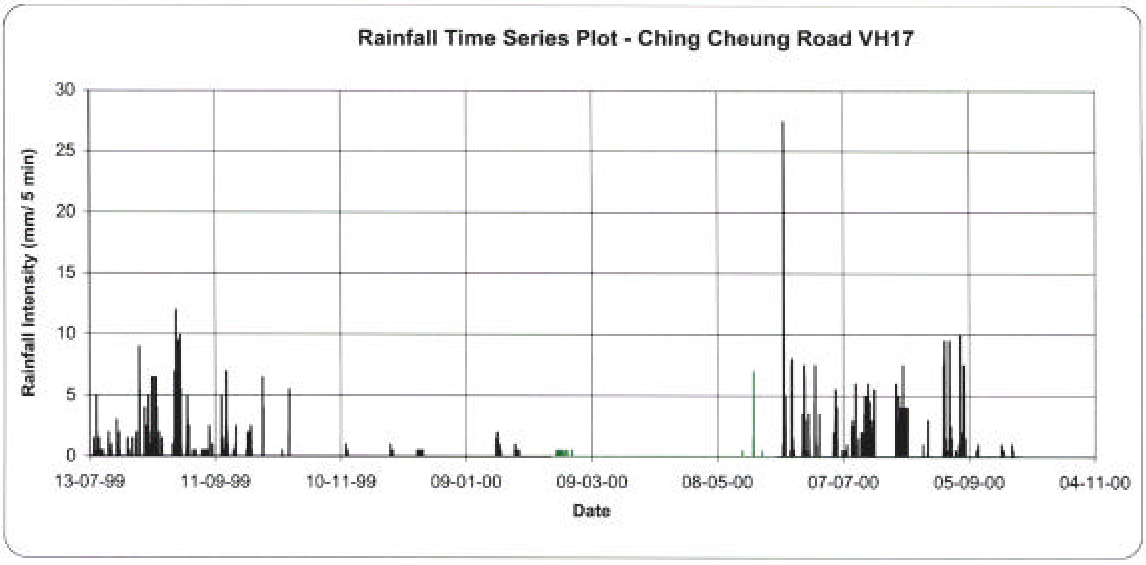
Rainfall Time Series Plot - Po Shan Road PD19L
Rainfall Intensity (mm/ 5 min)
30
25
20
15
10
5
0
13-07-99
11-09-99
10-11-99
09-01-00
09-03-00
08-05-00
07-07-00
05-09-00
04-11-00
Date



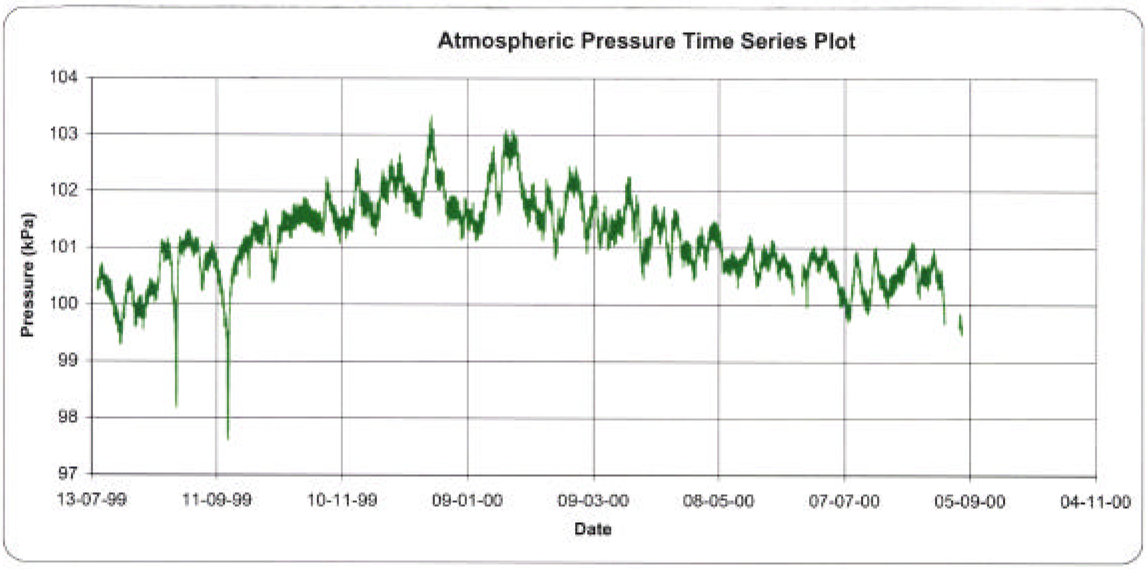
Atmospheric Pressure Time Series Plot
Pressure (kPa)
104
103
102
101
100
99
98
97
13-07-99
11-09-99
10-11-99
09-01-00
09-03-00
08-05-00
07-07-00
05-09-00
04-11-00
Date

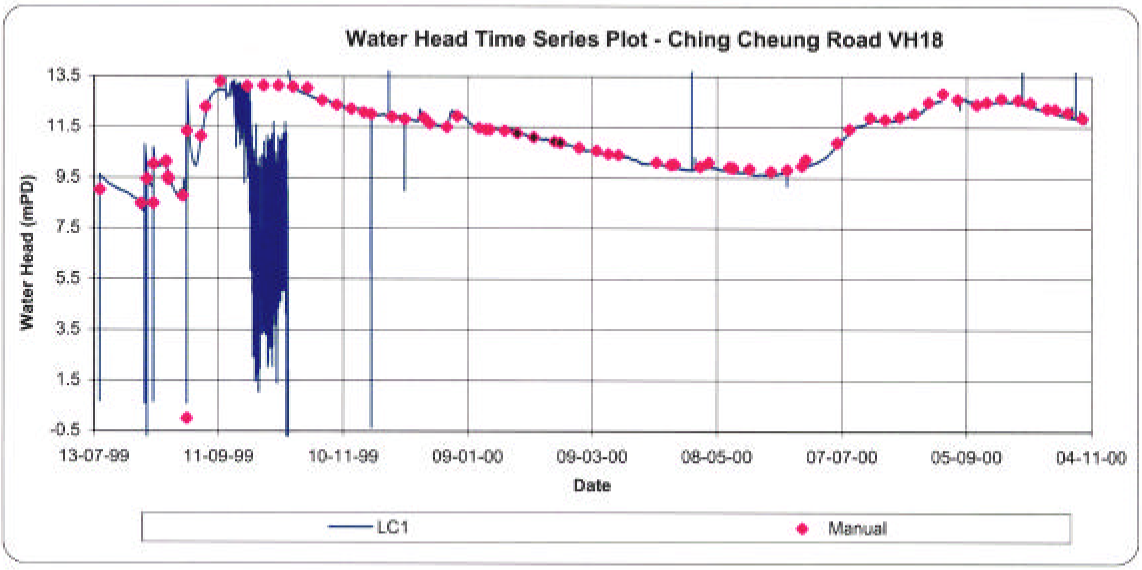


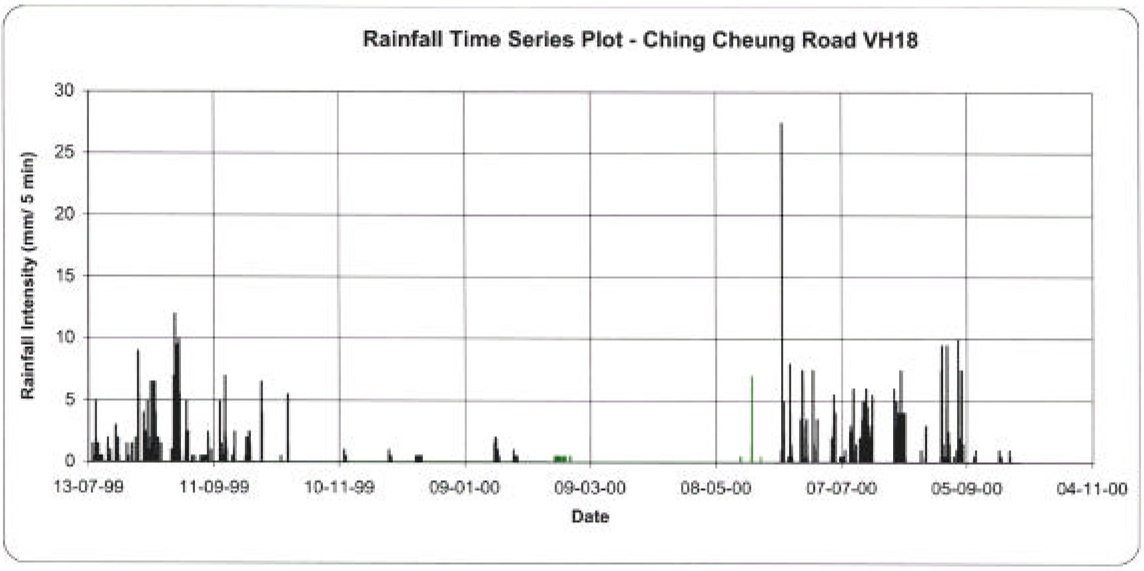
Water Head Time Series Plot - Ching Cheung Road VH17
Water Head (metre)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
13-07-99
11-09-99
10-11-99
09-01-00
09-03-00
08-05-00
07-07-00
05-09-00
04-11-00
Date
LC1
Manual



Rainfall Time Series Plot - Ching Cheung Road VH17
Rainfall Intensity (mm/ 5 min)
30
25
20
15
10
5
0
13-07-99
11-09-99
10-11-99
09-01-00
09-03-00
08-05-00
07-07-00
05-09-00
04-11-00
Date


Atmospheric Pressure Time Series Plot
Pressure (kPa)
104
103
102
101
100
99
98
97
13-07-99
11-09-99
10-11-99
09-01-00
09-03-00
08-05-00
07-07-00
05-09-00
04-11-00
Date


Water Head Time Series Plot - Ching Cheung Road VH18
Water Head (mPD)
13.5
11.5
9.5
7.5
5.5
3.5
1.5
-0.5
13-07-99
11-09-99
10-11-99
09-01-00
09-03-00
08-05-00
07-07-00
05-09-00
04-11-00
Date
LC1
Manual


Rainfall Time Series Plot - Ching Cheung Road VH18
Rainfall Intensity (mm/ 5 min)
30
25
20
15
10
5
0
13-07-99
11-09-99
10-11-99
09-01-00
09-03-00
08-05-00
07-07-00
05-09-00
04-11-00
Date