Educational Scale Model of Autonomous, Automated, Telemetric System for Leak Prompt Detection and Monitoring in Waste Management Applications

PANTELIS SOUPIOS[1], JOHN P. MAKRIS[2], GEORGE HLOUPIS[1], FILIPPOS VALLIANATOS[1], LOUKAS GAVRILIDES[3] and THRASSYVOULOS MANIOS[4]

[1] Department of Natural Resources & Environment, Laboratory of Geophysics & Seismology
Technological Educational Institute of Crete
Romanou 3, Halepa, 73133, Chania, Crete, Greece
http://www.chania.teicrete.gr

[2] Department of Electronics, Laboratory of Optoelectronics, Laser and Plasma Technology
Technological Educational Institute of Crete
Romanou 3, Halepa, 73133, Chania, Crete, Greece
http://www.chania.teicrete.gr

[3] KALLIERGOS S.A, Environmental Management
Vas. Herakleiou 14, 54625, Thessaloniki, Greece

[4] School of Agricultural Technology, Laboratory of Solid Waste & Waste Water Management
Technological Educational Institute of Crete
Stavromenos, Heraklion, 71004, Crete, Greece

Abstract: - It is important that as part of developing a landfill, the landfill applicant, whether public or private, be required to convincingly demonstrate that a proposed landfill will be sited, designed, constructed, operated, closed and provide post-closure care such that it will protect the groundwater resources, public health and the environment. For that reasons, many leak detection systems have been constructed to satisfy the above mentioned demands. The proposed scale model prototype system is based on the detection and evaluation of the local resistance distribution patterns on the plastic sealing on the bottom of a waste disposal area. This is achieved using a parallel arrangement of electrode branches in connection with the own conductivity of the layers separated by the sealing. A distributed electrode above the sealing layer functioning as a dielectric produces a potential against a remote underground electrode. The actual measurement takes place via multi-point linear electrodes which are laid underneath the plastic seal. The electrode can register each potential alteration in the environment for which the tapping range is responsible. They do this through contact with the surrounding base surface, which is electrically conductive due to its own humidity.

Key-Words: - Leakage Detection, Automated system, Electrode Grid Method, Waste Management

1 Introduction

A landfill is a carefully-engineered depression in the ground (or built on top of the ground, resembling a football stadium) into which wastes are put. The intention is to avoid any hydraulic (water-related) connection between the wastes and the natural environment. To achieve this goal, there are four important parts of all landfills: a bottom liner, a leachate collection system, a cover, and the natural hydrogeologic setting (the earth). The hydrogeologic setting can be selected to slow the entry of wastes into the natural environment. The other three components must be engineered.

The most important of the above mentioned four parts of a landfill is the properly operation of the bottom liner system. Thus, identifying leaks in landfill liners is an essential part of waste management. Several types of leak detection tools can be installed in addition to monitoring wells to identify leaks soon after they occur. This paper provides an overview of some tools for vadose zone monitoring, as well as the advantages, disadvantages, and costs associated with them [4].

State law requires all landfills to include a leak detection system above the bottom composite liner. The reason is that composite lined systems often could leak at the time of construction due to imperfections in the construction. Important source of leaks for a new landfill is also the inadequate protection of the liner system from the initial placement of the wastes in the site. The system must consist of a layer of granular drainage materials with a slope of at least one percent, so any leachate which passes through the top liner will drain into the sump at the bottom of the unit, where its volume is recorded. This system establishes what volume of leachate has leaked through the top liner, but it does not indicate whether or not leachate is leaking through the bottom liner [5].

In addition, all landfills are required to install a groundwater monitoring system. The system must consist of both up gradient and down gradient wells which allow sampling of the groundwater in the uppermost aquifer, as shown in Fig.1. The number, spacing, and depths of the required wells are dependant on the geologic and hydrologic properties of the area [6].

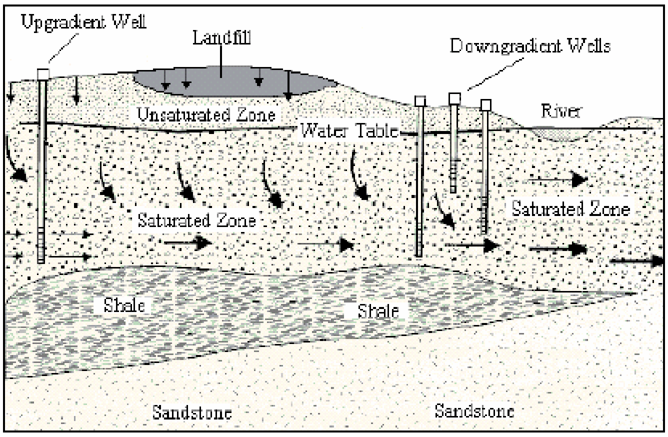

Fig.1 Cross section of a traditional groundwater monitoring system [1].

By collecting groundwater samples and analysing them, landfill operators can usually detect contaminant plumes caused by leaks in the landfill liner. One limitation of this method is that it does not prevent the groundwater from becoming contaminated. Another limitation is the expense of comprehensive monitoring for all groundwater which comes in contact with a landfill. Because most landfills are lined with geomembranes, most leaks are point sources, not widespread. If there is no monitoring well in the path of a plume, it is possible for the front of the plume to pass by the line of wells at the point of compliance without being detected. Installing enough monitoring wells to be sure of intercepting a narrow plume in any position can be prohibitively expensive [2].

2 Overview of leak detection options

In addition to the monitoring methods required by law, some landfill owners are choosing to install systems of leak detection sensors. These sensors permit early leak detection without laboratory analysis, and often locate the leak.

Several different types of sensors provide these benefits. Some work by electrical methods, measuring the resistivity or dielectric constant of the soil. Others work by chemical methods, either analysing soil vapour or reacting directly to leachate. These sensors are often dependant on the composition of the leachate. Still others use tracer chemicals to detect leaks. Use of these technologies is not widespread, mainly because of cost. Most must be installed during construction and are not applicable to existing landfills.

Each of the leak detection systems available has different advantages and disadvantages. The perfect vadose zone monitoring system has not yet been designed, but the ideal system would: 1) be affordable, 2) be durable enough to last through the life of the landfill and the 30 year post-closure period, 3) locate leaks and determine their sizes, 4) be automated, 5) be applicable to all types of landfills and all types of leachate, 6) provide full spatial monitoring for the entire area below the landfill [8, 9].

Research on new sensors for leak detection at landfills is ongoing, but it is also limited because the market for this optional extra level of detection is extremely small.

2.1 Other types of leak detection

This paper includes information on permanently emplaced monitoring systems which detect leaks in the vadose zone. Surface geophysical techniques such as ground penetrating radar will not be covered; nor will direct push site characterization techniques or sampling techniques such as lysimeters.

Most of the techniques used for locating leaks in subsurface barriers are not readily applicable to landfills. More information on ground penetrating radar, electrical resistance tomography and other subsurface barrier monitoring techniques are given by Rumer and Mitchell [3].

3 Installations of Sensors – Electrical Methods

There are two main ways of detecting leaks using electrical methods: the two electrode method and the electrode grid method (Fig.2). Both leak detection techniques utilize the insulative properties of geomembrane liners. The first method detects the flow of current from one electrode to another through a hole in the insulative liner. The second method depends upon the liner to insulate the containment area so that only leachate which has escaped into the soil will be detected.

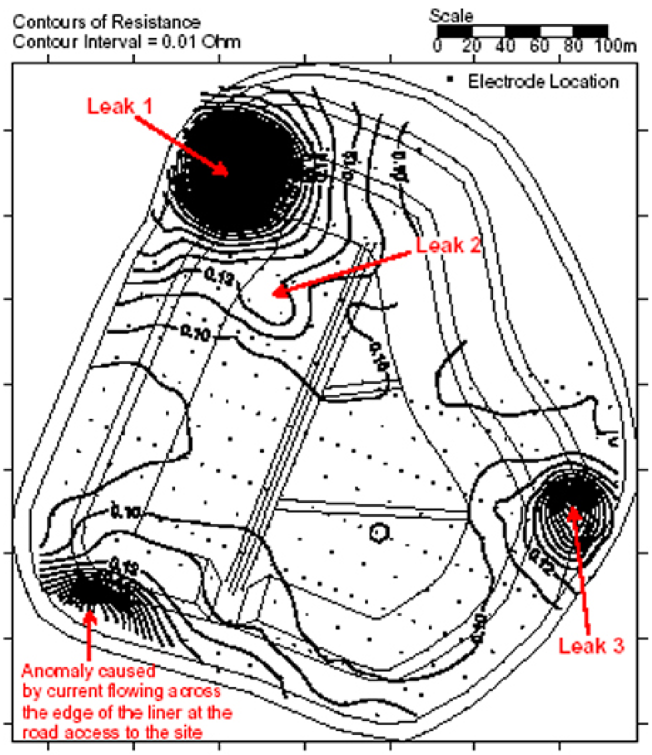

Fig.2 Application of the electrode grid method as a leak detection system on an active small scale landfill.

In the present work we implemented the second method. Specifically, this method makes it possible to actually locate leaks in active and closed solid waste landfills. It requires installing a grid of electrodes beneath the primary liner during construction. The electrodes are used to energize the area around the liner and to measure the resulting voltage of the soil near each electrode (Fig.3). Because leachate has a higher electrical conductivity than soil or water, an area of a difference in voltage indicates that leachate has escaped from the liner at that location.

3.1 Advantages – Disadvantages

This system involves simple, durable components that can last for several decades. It monitors the entire area below the liner, not just certain points. In addition to detecting leachate releases, the electrode grid can also detect holes in the liner before waste is placed in the cell in the manner described above in section 3. Current is introduced into the protective soil layer. If the current is detected by the electrodes, it has passed through a hole in the insulative geomembrane liner.

The only problem for the implementation of the proposed detection system is that it is not applicable to existing landfills because the electrodes must be installed initially, during the construction of the cell.

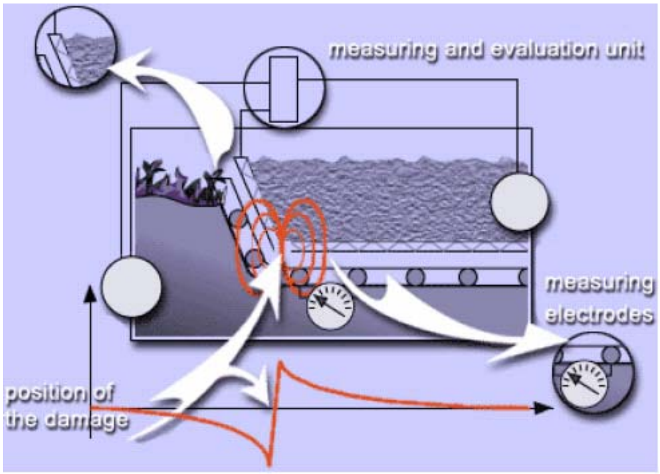

Fig.3 A sketch on how a leak detection system works (GEOLOGGER®, 2002).

3.2 System Installation

The lower liner is underlain by a grid of stainless steel monitoring electrodes spaced e.g. 20m apart, as shown in Fig.4. The appropriate distance should be chosen based on mathematical modelling and small-scale testing.

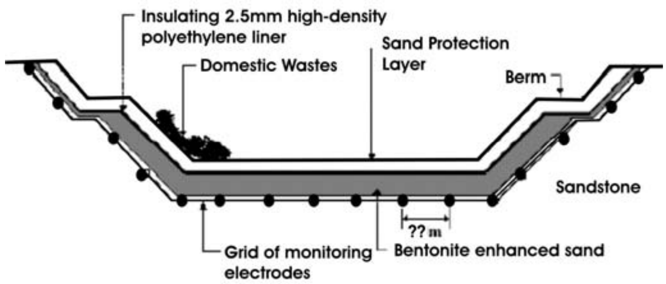

Fig.4 A schematic cross section that depicts the position of the grid below a landfill [10].

The electrodes are connected, via a multicore cable, to the telemetric system, and the measured values are allocated to the co-ordinates of the electrodes. This measuring data is then transmitted to the evaluation program that calculates an interpolated potential field, triggers the alarm and determines the position of the damage with the precision required. The area around the electrodes should back-filled with bentonite enhanced sand because of its high conductivity.

The system was first used to verify the continuity of the liner after it was installed. One intentional and one unintentional hole were located and repaired. During the first period of operation, monitoring was conducted daily. Data collection typically took about half an hour. All voltage irregularities were found to correspond to holes in the geomembrane. After the test period, the system would monitor according to a schedule based upon past data.

In case of significant contamination of the area below the landfill, the monitoring system can be used to map the pollution plume as it moves toward the monitoring wells, both in the vadose zone and in the groundwater.

4 Autonomous, Automated, Telemetric Systems

The autonomous, automated telemetric system consists of the datalogger, the power supply complex and the radio telecommunications link. The power supply complex comprises a high-powered solar panel (64W), a 12V charging regulator and a conventional 12V/60Ah battery and ensures uninterruptible overall system operation.

4.1 Datalogger

The heart of the measuring system is a programmable datalogger. The CR23X Micrologger of Campbell Scientific Inc has been selected (Fig.5) as it combines precision measurement with processing and control capability in a 12V-battery operated system [11].

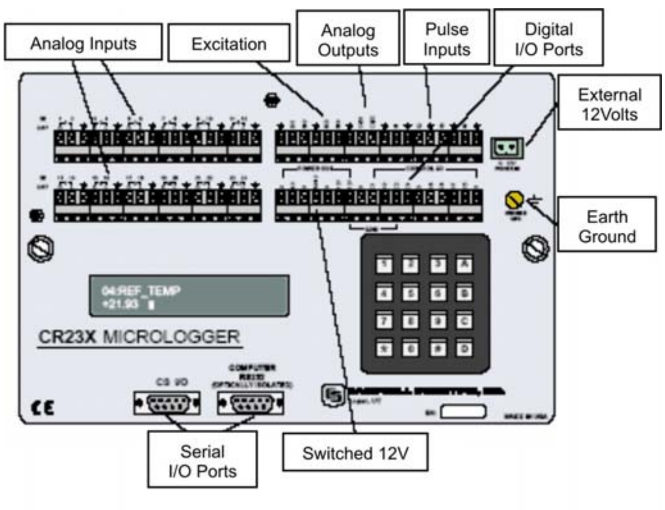

Fig.5 Schematic representation of 23X Micrologger's front panel. A short description of the various types of connections is given.

The CR23X can be powered by any 12Vdc source through the green power connector on the front panel (see Fig.5), which is reverse polarity protected. It is important to earth datalogger during operation. When primary power falls below 11Vdc, the CR23X stops executing its programs but user's program and stored data remain in memory and the clock continues to keep time in the cause of its internal lithium battery.

The 16 character keyboard (Fig.5) is used, in situ, to enter programs, commands and data; these can be viewed on the LCD display. Both are necessary for cursory on-site inspection of datalogger functions.

4.1.1 Memory Allocation and Usage

The internal memory of CR23X is divided into five areas [11]: (i) the *system memory*, for operating tasks (no user access), (ii) the active user *program memory*, (iii) the *input storage*, where the measurements are held and by default 64 locations are available, (iv) the *intermediate storage*, for data processing and intermediate results, automatically accessed by the program instructions, with no user access and default allocation of 64 locations, and (v) the *final storage* which contains the finally processed data ready to transfer via telecommunication links. While the total size of the last three areas remains constant, memory may be reallocated between these areas to accommodate different measurement and processing needs.

4.1.2 Differential and Single Ended Measurement

The datalogger makes voltage measurements by integrating the input signal for a fixed time and then holding the integrated value for the analog to digital (A/D) conversion. Integrating the signal removes noise (especially rejects 50Hz ac-noise). The A/D conversion is achieved with a 15bits successive approximation technique with resolution 33μV, in 2V full scale range, for differential measurement (for single-ended measurement is twice the above value) [11].

A differential measurement measures the difference in voltage between two successive inputs, each of them being within the datalogger's common mode range of ±5.0V. The measurement sequence on a differential measurement involves two integrations: first with the high input referenced to the low, then with the inputs reversed. The datalogger calculates the differential voltage by averaging the magnitude of the results from the two integrations and using the polarity from the first.

A single-ended measurement is performed on a single input which is referenced to ground and a single integration is carried out, thus taking about half the time of a differential measurement. It is quite satisfactory in noiseless cases and when care has been taken to avoid ground potential problems. Furthermore, available single-ended channels are twice as many compared to differential.

A differential measurement has better noise rejection than a single-ended measurement. Integrating the signal in both directions also reduces input offset voltage due to thermal effects in the amplifier section of the datalogger. On the other hand, attention should be paid to the fact that a single-ended measurement is referenced to datalogger's ground, thus any difference in ground potential between the sensor and the datalogger will result in an error in the measurement [11].

4.1.3 Analog Voltage Inputs

The datalogger's front panel contains four terminal strips which are used for sensor inputs, excitation, control input/outputs, powering, etc. (Fig.5).

There are 12 pairs of analog voltage input terminals. Each pair corresponds to a differential channel and its inputs are labeled #H and #L respectively, where # denotes the number of the channel. In a differential measurement, the voltage on the H-input is measured with respect to the voltage on the L-input. When making single-ended measurements, either the H or L input may be used as an independent channel to measure voltage with respect to the analog ground [11]. Thus, there are 24 single-ended channels available.

Moreover, the analog input terminal strips have an insulated cover to reduce temperature gradients across the input terminals.

4.1.4 Grounding - Earthing

The CR23X features two types of grounding terminals the analog- and the power-grounds respectively. Signal returns of analog inputs and their associated shields returns are to be tied to the terminals located in the analog input terminal strips.

The power ground terminals, marked G, are intended to carry these potentially large return currents from dc power and prevent them from flowing through and corrupting analog measurements [e.g., offset voltage errors in single-ended measurements can occur for large (50mA) currents flowing into the terminals in the analog input terminal strips]. Furthermore, an independent ground lug is also available in the front panel (see Fig.5), providing a rugged ground path from the individual ground terminals to earth or chassis ground for ESD protection [11].

4.2 Analog Multiplexer

The sensor grid of the leak monitoring and detection system consists of 64 (8×8) electrodes. On the other hand the maximum single-ended available inputs of the datalogger are 24, as aforementioned. Contextually, it is necessary to use an analog multiplexer in order to meet the due analog inputs. For this purpose, an analog relay multiplexer, AM16/32 (Fig.6), has been added, offering up to 48 single-ended inputs, if 4×16 operational mode is selected. The rest of the input channels are provided on the datalogger [12].

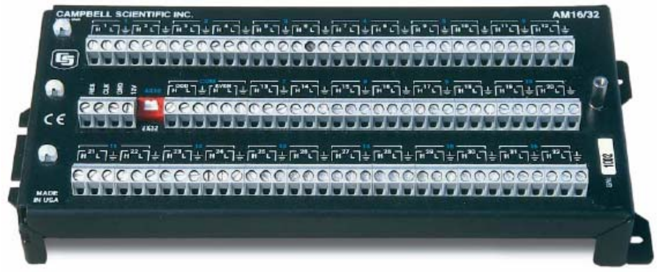

Fig.6 Analog Relay Multiplexer AM16/32.

The multiplexer is wired to the datalogger via four data lines ("COM ODD H/L" and "COM EVEN H/L"), analog ground, two control lines ("RES" for reset – activation, "CLK" for pulsing – input scanning), 12Vdc power and power ground.

Special consideration must be taken into account for environmental protection of AM16/32, as it designed for indoor and non-condensing operation. Thus, a water-resistant enclosure together with desiccant packs has to be used to mitigate humidity influence. In order to reduce cross-talk no lengthy cabling is preferable. Furthermore, an aluminium cover plate minimizes thermal gradient effects [12].

4.3 Telemetry

As in real case, a continuous, real time monitoring is desirable. The most cost effective, reliable solution is a radio link non-dedicated UHF frequency range 400-470MHz, by considering the existence of line of sight between measuring area and base station (of course, for the actual application).

At the datalogger, an optically isolated standard RS-232 DCE/DTE port is provided for *direct* connection (in situ). For the telemetric implementation, the no-standard serial CS I/O port (Fig.5) provides connection and power to RF95 serial data communication radio modem (Fig.7).

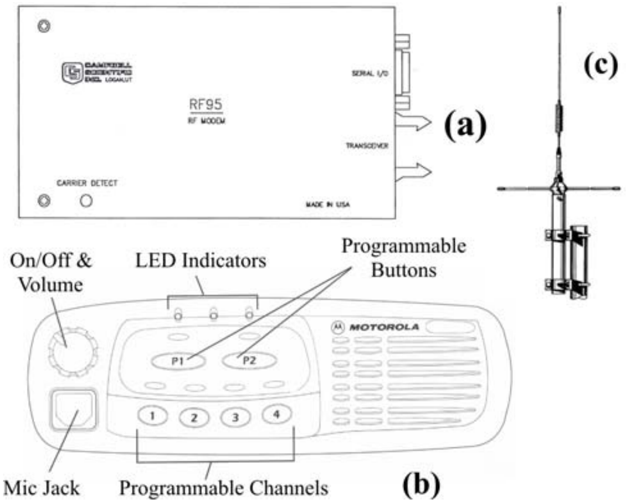

Fig.7 Pictorial representation of radio-telecommunication link equipment. (a) Campbell RF95 radio modem; (b) Motorola GM340 mobile radio transceiver; (c) Sirio GP 400-470 omnidirectional antenna.

An opto-isolation external module, SC32A, is required to interface the datalogger's CS I/O port to the radio modem by converting the datalogger's logic levels to RS-232 signalling [13]. Signals entering from either side of SC32A are electrically independent, protecting against ground loops, static discharge and noise.

Radio modem has a unique station ID and is the interface (provides the communication protocol) between field datalogger or base station computer and the respective radio transceiver (GM340), at both ends of the telecommunication RF-link (see Fig.7). The mobile radio transceiver is able to emit at up to 25W and "fine tuning" of its volume/squelch control is necessary to optimize RF-link communication quality. The medium gain, monoband tunable, vertically polarized, omnidirectional, $\lambda/4+\lambda/2$ colinear antenna (Sirio GP 400-470) completes the telecommunication equipment on each end of the link (Fig.7). When reliable radio connection is established the data are transferred with a baud rate up to 9600bps.

5 Programming – Support Software

5.1 Field Station Program

The CR23X datalogger must be programmed before carry out any measurements. A program consists of a group of instructions entered into a program table. There are three different instruction types which act on data [11]: (i) *input/output instructions*, control the terminal strip inputs and outputs, storing the results in input storage (destination); (ii) *processing instructions* perform numerical operations or even developed high level processing algorithms on input storage's data values and store the results back in input storage; (iii) *output processing instructions* (discriminated between intermediate and final) which process input storage values over time and store data in final storage.

The program table is given an execution interval (in seconds) which is usually determined by how often the sensors are to be measured. The interval at which output occurs normally is an integer multiple of the execution interval. Different output intervals and conditions, each with a unique data set (Output Array) could be defined using *program control instructions* followed by output processing instructions that determine the data output and its sequence. *Program control instructions* consist a fourth type of instructions that are mainly used for logic decisions, conditional statements and program execution, (they can set flags and ports, compare values or times, execute loops, call subroutines, etc).

The students have to develop themselves the program for the data acquisition procedures (including the control of the multiplexer operation), preliminary data processing and analysis and data manipulation and storage, by consulting the relevant sections of the CR23X's manual [11]. Following is indicatively outlined (for a detailed description, the reader is referred to the CR23X's manual) a bunch of important instructions that are indispensable for the correct program development:

```
Table 1 Program
01: 600 Execution Interval (seconds)
1:  Do (P86)
   1: 41   Set Port 1 High
2:  Begin Loop (P87)
   1: 0    Delay
   2: 16   Loop Count
3:  Step Loop Index (P90)
   1: 3    Loop Index Increment
4:  Do (P86)
   1: 72   Pulse Port 2
5:  Excitation with Delay (P22)
   1: 1    Excitation Channel
   2: 0    Delay w/Excitation
   3: 1    Delay after Excitation
   4: 0    mV Excitation
6:  Volt (Single-ended) (P1)
   1: 3  Reps
   2: 34    ±1000mV, 50Hz Reject.
   3: 1    SE-channel
   4: 1--  Input Loc Successive
   5: 1.0  Mult
   6: 0.0  Offset
7:  End Loop (P95)
1:  Do (P86)
   1: 51   Set Port 1 Low
```

8: Volt (Single-ended) (P1)
1: 16 Reps
2: 34 ±1000mV, 50Hz Reject.
3: 5 SE-channel
4: 49-- Input Loc Successive
5: 1.0 Mult
6: 0.0 Offset
9: Do (P86)
1: 10 Set Output Flag High
10: Resolution (P78)
1: 1 High Resolution
11: Real Time (P77)
1: 1121 Year, Julian Day, Hour/Minute, Seconds
12: Sample (P70)
1: 64 Reps
2: 1 Input Loc
13: Do (P86)
1: 20 Set Output Flag Low

5.2 Base Station Telemetry and Data Analysis Software

At the base station a personal computer is running continuously a graphical user interface the Campbell Scientific's PC208W Datalogger Support Software Bundle [14]. Among a lot of features it contains a set-up module for device configuration (modems, ports, etc), on-line datalogger communication and set-up and data graphing, a datalogger program editor, a module for scheduled data retrieval, a data reduction module. It is anticipated a thorough study and use of this software package for educational purposes.

At present, is under development a MatLab code aiming (i) to provide a frequently updated (e.g. every half an hour) of a 2D-contour of the measured self-potential with the electrode grid and (ii) to generate leak-alarm after performing leak detection and location (e.g. when the observed value exceeds ±2σ the hebdomadal mean).

6 Conclusions

The system that presented in this paper provide more complete spatial monitoring for possible landfill leaks than wells alone, so they allow fewer leaks to go unnoticed. Another advantage of this system is that leaks which are detected in the vadose zone can be managed earlier than would have been possible if they were discovered only when they reached the monitoring wells.

Actually, the ideal monitoring system has not yet been designed, but this system should be affordable, durable enough to last through the life of the landfill and the 30 year post-closure period, automated, and applicable to all types of landfills and leachates. It would provide full spatial monitoring for the entire area below the landfill and locate leaks and determine their sizes. Further research and development is necessary to create a system with these attributes.

Although the ideal system has not yet been developed, landfill managers who wish to avoid unexpected remediation expenses down the road do have options to limit their risk. Those who are willing to pay for extra monitoring during construction of the landfill can decrease the possibility of having to pay for a significant cleanup later on.

7 Acknowledgements

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