Accurate Detection and Location of Effluent Leaks Beneath Lined Waste Disposal Sites

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ABSTRACT: The Author describes the need for and the technical development of a new, advantageous, system for the detection of leaks beneath waste disposal linings. The paper sets this technical development within the context of other similar approaches to the problem of leak detection. Essentially, the system comprises the use of cross-laid textiles, containing conductor wires, and separated by an electrically insulating textile layer. This 'sandwich' is placed below the prime impermeable membrane. Leaks are detected by measuring both conductivity and capacitance characteristics between pairs of adjacent wires as well as between overlying wire sets. This complex approach allows the inherent variables of liquid quantity and conductivity to be differentiated and leak locations identified to within half a metre. The system permits rapid and economic repair of leaking membranes, even after a waste disposal site might be full and landscaped, without the need for excavation. Naturally, the system can also be used for construction monitoring of joint efficiency during fabrication and commissioning. The paper describes the successful outcome of large scale trials.

1 INTRODUCTION

There is a world-wide concern to improve the effectiveness of waste retention structures and in particular to prevent them leaking effluent as a contaminant into underlying soils and aquifers. This is generally following the lines of constructing improved multi-layer synthetic/clay composite lining structures.

No matter how effective modern linings are claimed to be, owing to lack of long-term proof, there is a concomitant requirement for the provision of monitoring and leak detection systems to confirm the efficacy of any particular lining chosen.

Such monitoring systems tend to be electrical in nature, heretofore having limitations of spatial reliability, longevity and interpretative accuracy.

2 DEVELOPMENT APPROACHES TO DATE.

As may be expected with such an important subject, experimental attempts to solve the problem of leak detection have been wide ranging over some years. Some of these are still in the development stage and others have been examined and found wanting. The main branches of investigation include the following:-

1 Resistance measurements

One of the earliest techniques to be examined, this procedure measures the resistance between two electrodes. It is one of the oldest methods because it is very simple. Its disadvantage is that it permits the detection of all kinds of fluids, but without the ability to identify what type of fluid it is nor whether it is a fluid containing contaminants which might be affecting the overall conductivity. For example, pure distilled water has a resistance of 10^11 ohm.mm2/m but a dilute saline solution may well be one hundred thousand times more conductive! Therefore, with resistance alone, it is impossible to tell how much liquid is present, since both quantity and conductivity affect the result.

2 Capacity measurement (capacitance)

This is, in fact, the measurement of relative electrical permittivity. It is a more recently examined technique than conductivity, but was well tested around the 1960's. Water has a special permittivity value - ie a relative permittivity of 70 while all other common liquids have values in the order of 5. This figure of 70 is not affected significantly by the addition of impurities and dissolved materials. Therefore, this capacitance is a single measure of the amount of fluid and in particular will identify water quite markedly. This is therefore particularly relevant to water based leaks.

3 Microwave analysis.

As may be expected, this is one of the more recently examined options for assessing effluent leakage. This method measures microwave attenuation within any given small sample of the ground, the exact amount of ground examined depending upon the configuration of the equipment. Usually it comprises a fixed distance device with a transmitter and a measuring receiver. This is calibrated and therefore gives a measure of the amount of water in the ground or dielectric fluids as they absorb microwave radiation. The exact frequency can vary, but typically from literature may be 1.4, 4, 10.5, or 18 GHz.

4 Radar wavelength.
This has also been covered in recent Work. Longer than microwaves in wavelength, radar frequencies have similar in absorption potential. Nonetheless, it is the measurement of reflection rather than transmission which is studied with this technique. The transmitter also acts as the receiver, sequentially emitting pulses and recording the reflected echo. This tends to limit the information received to only having surface or near-surface meaning. Unfortunately, this method does not seem to have produced good results yet, but it is still being worked on.

5 Nuclear Magnetic Response.
An intense magnetic field excites molecules of water within the soil matrix, inducing resonant spin effects, and permitting the deduction of the amount of water from the necessary energy input. This method is exceedingly limited in terms of distance affected within a sample. Current equipment can only penetrate to within 10 cm depth of the surface of the soil.

6 Infra-red Reflection.
This method tries to determine energy absorption at the surface of a soil mass, depending upon the moisture condition of the soil. This is a well recognised technique more commonly used in remote sensing applications such as satellite observation of vegetation and crops. However, as in these larger scale applications, only the surface of the soil is recognised and therefore large assumptions have to be made as to conditions beneath. Frequencies used include 1450 and 1950 and 2950 nanometres.

There have been two reasonable successful individual approaches to date. Firstly the measurement of conductivity and secondly the measurement of capacitance. The ELDEG system combines the two in a unique method of measurement. Other systems measuring conductivity alone have concentrated on two options: firstly measuring conduction between the upper and lower sides of a prime impermeable liner layer and secondly, measuring changes in a pre-established electrical field within the ground beneath a potentially leaking site.

In the absence of a fully satisfactory method, these approaches have achieved a certain level of comfort to waste disposal authorities, mostly in the knowledge that no alarm should mean no problem. It is realistic to consider these older systems as simple indicators where, in the event that some kind of anomaly being detected, a possible leak is flagged.

Under these circumstances, previous systems can be expected to suffer from unreliability and inexact meaning of electrical activity. For example, it is recognised that anomalies from ground field measurements may not be at the point of the leak. Any such system requires interpretation which necessarily brings uncertainty into the exact pin-pointing of the leak position. If the leak position cannot be guaranteed, then any attempted treatment must necessarily be on a trial-and-error basis, with inherently high cost potential. Alternatively, in the cross membrane detectors, where systems have one set of electrodes above the prime membrane, those electrodes are immersed on a long term basis in the retained effluent. This is considerably more aggressive than the dry, clean environment immediately below the prime membrane and it is difficult to avoid the conclusion that the life of comparable electrodes will be considerably less above than below the liner. The old systems often rely upon the measurement of conductivity alone as a basis of alarm notification. Unfortunately, increased conductivity can arise from both an increase in the amount of moisture present and an increase in conductivity from effluent leakage. Interpretation and uncertainties once more arise.

The in-ground field detection systems carry the unfortunate implication that by the time the measurement reveals a leak, the leak is already in the ground and the ground is contaminated - the very thing that a detection system is intended to prevent!

3 THE ELDEG SYSTEM

The system has been made possible by the development of woven textiles containing special wires in the warp, which can be laid over the bottom of a new waste disposal site to detect leaks. Two layers of special textile are cross-laid so that detection can be achieved as shown in Fig.1.

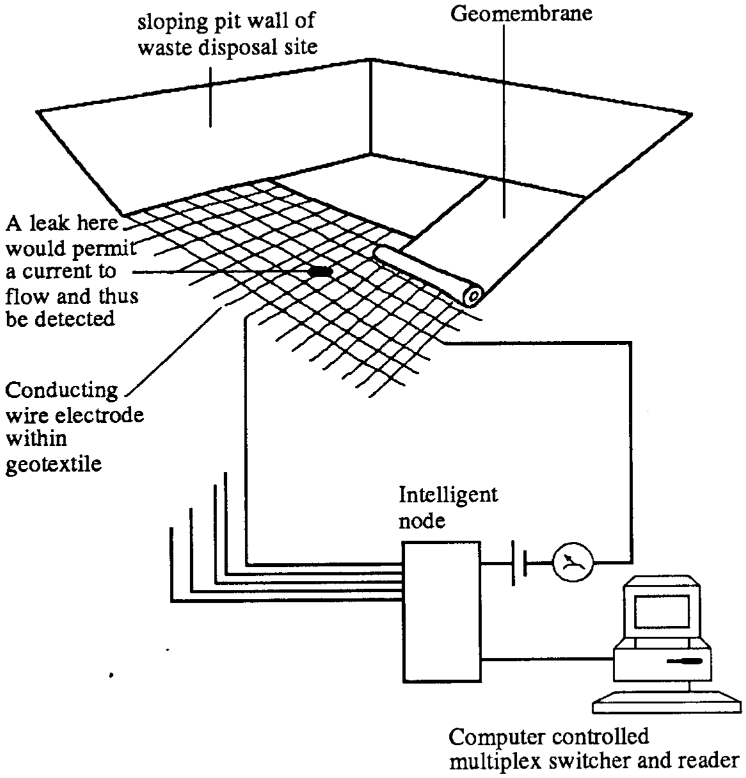

Fig.1. Application of ELDEG geotextiles to waste disposal pit prior to use.

The detailed construction comprises a triple-layer detector sandwich laid beneath the prime impermeable liner. Preferably, but optionally, a further impermeable liner is placed below the detector sandwich - Fig.2. The establishment of an electrical circuit subsequent to leakage is shown in Fig.3. The inherent advantage of this configuration is that both sets of electrodes are kept away from the damaging effluent fluids, until such time as a leak occurs. Therefore life expectancy of the electrodes is more than 100 years.

Since effluents vary, it is impossible to make a confident statement about electrode life above the membrane. Further, the presence of an under-membrane separates the electrodes from variable ground water, thus making the reliability and accuracy of leak measurements certain.

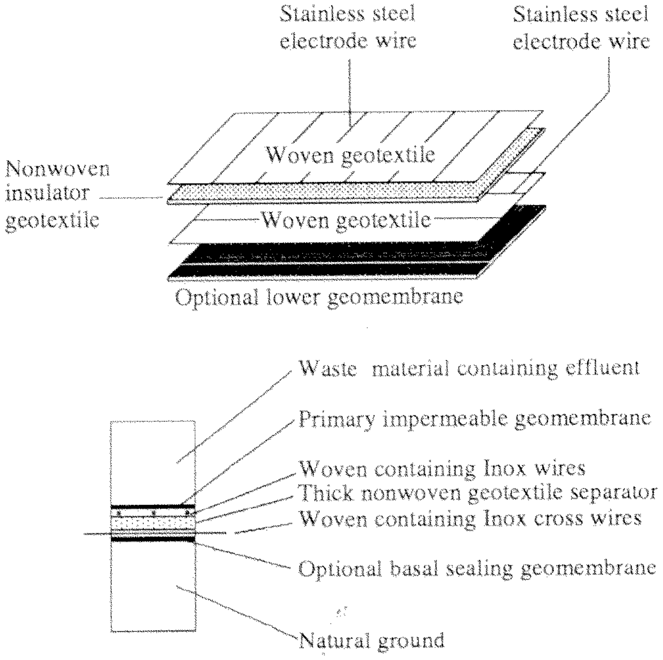

Fig.2. Ideal configuration of layers in an ELDEG installation.

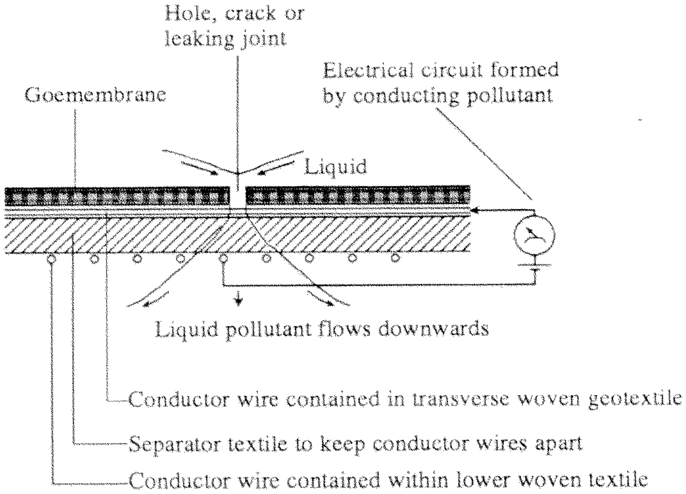

Fig.3. Leakage through the prime membrane leads to the establishment of a detectable electrical circuit.

The large dimensions of these sites bring their own particular problems in connection with the electronic aspects of the work - primarily the number of wires involved to give a satisfactory level of spatial resolution, and in particular their method of connection to the monitoring and analysis equipment.

Consider the capacitance measurement. This can be achieved either between crossed wires or parallel wires. Both options involve the measurement of phase lag between the electrodes, but if they must be performed by hardware components, all wires would have to be centralised, causing impossible practical requirements. Too many wires would have to be drawn into one single connection! Alternatively, the parallel option allows the adoption of a network based measuring system (distributed control system) ie a network with nodes. Nodes are intelligent, are programmed and perform measurements and communicate their data on the network to a central PC. This allows realistic measurement of capacitance through a simple linear wiring system and if only capacitance were being considered, then a parallel wire measurement system would suffice.

Fig.4 is a photograph showing the ELDEG intelligent node unit with internal circuitry exposed. On the left, the lid of the box can be seen to self-sealing, with bolted connections on the four corners to make the unit weather-tight and environment resisting. Fig.5 shows the unit closed and sealed ready for installation. Note that the node is actually placed between the layers of geotextiles and is covered by at least two layers and the sealing element. Then the periphery of the site is covered with soil and buried according to the particular design. Thus the node is kept clean and easy for access and maintenance even though covered in soil for many years.

The heavy wire shown coiled on each side of the unit is the six-core sheathed wire that connects all nodes in series. On the left, the unit can be seen to be connected to the woven metal wires of the textile. Note that the wires are actually woven in pairs. This method of using two wire bundles to act as a single wire in the system increases the reliability of the system and permits system checking at a more sophisticated level than with a single wire.

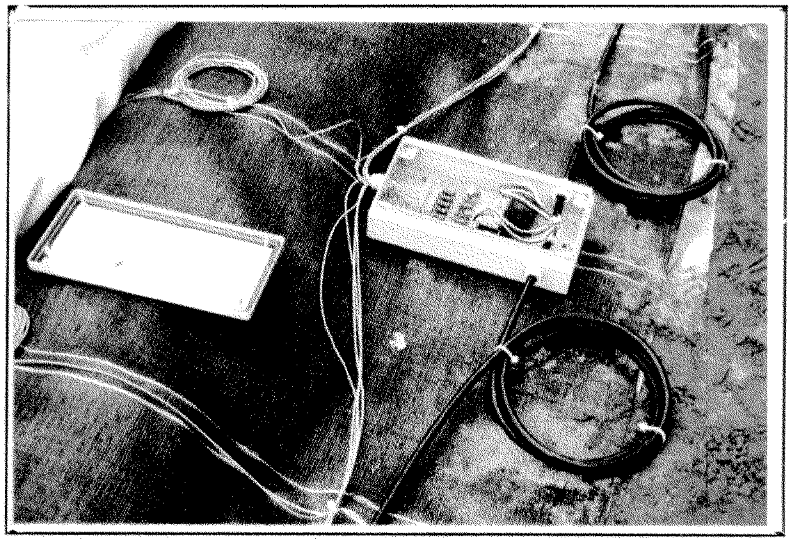

Fig.4. Showing the ELDEG intelligent electronic node unit, which communicates directly with the controlling PC.

As shown in Fig.6, the entire installation of the electronic network system in the field can be achieved with the most simple equipment and hand tools. The wires provided with the nodes are connected to the woven electrode wires by simple mechanical crimping. This method provides a reliable and robust connection. However, since laboratory testing suggests that these crimped connectors are the critical items in determining the likely frequency of maintenance, it is useful to note that they are distributed only around the periphery, buried at a shallow depth and are easily accessible. The electronic software which controls the operation of the network also checks for node failures. If such a failure were to occur, then it would be pin-pointed electronically and repairs could be effected immediately.

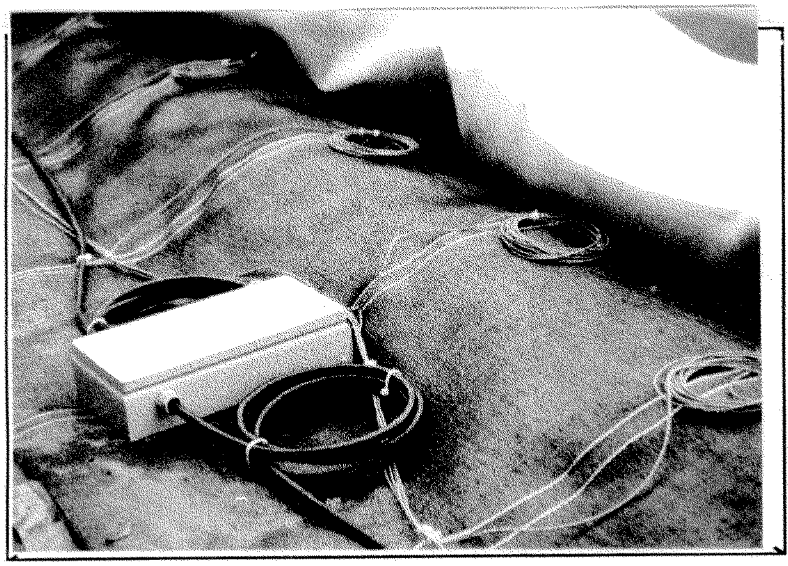

Fig.5. View of a sealed node unit ready for burial between textile layers and under soil cover.

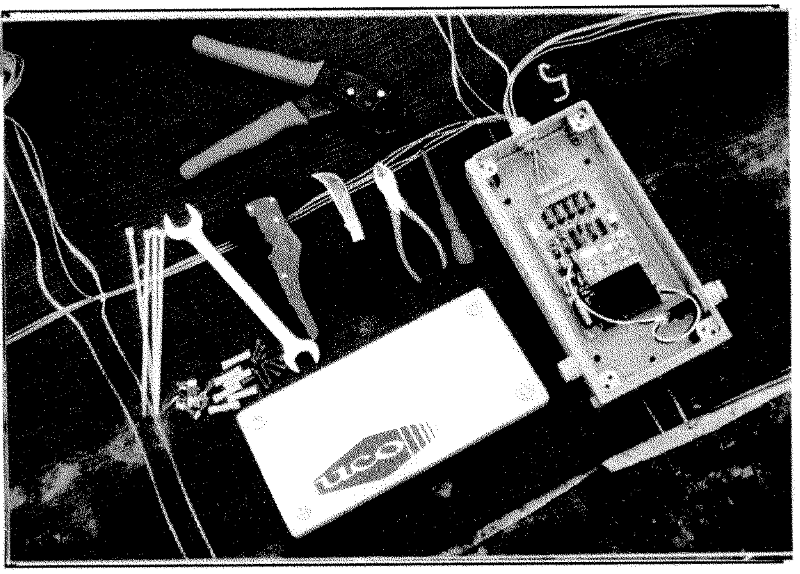

Fig.6. Showing the simple equipment needed to install ELDEG in the field. Highly specialised electronic knowledge is unnecessary for installation purposes.

Fig.7 shows the crimp connections which are attached to loose loops already manufactured in the fabric. The metal wires are woven within the structure of the fabric in the normal way, but at 1 metre intervals, a length of approx. 10 cm is left unwoven. This makes a loop of wire left for easy access. The loop is cut at the outer edge and the loose wire crimped to the insulated wire from the node.

However, consider the resistance measurement, which follows the same logic as for the capacitance measurement, but, in order to locate the position of any given leak, there is a need for bi-dimensional information and thus a cross-wire system is required. In essence, therefore, the amount of resistance is measured between parallel wires, but the information is used through cross wires to identify the location.

Since both sets of wires (upper and lower) are interrogated alternately, the accuracy of the readings is a function of lane width. The layout of the PC screen display reflects this fact and displays location squares to the scale of the sensing electrode separations.

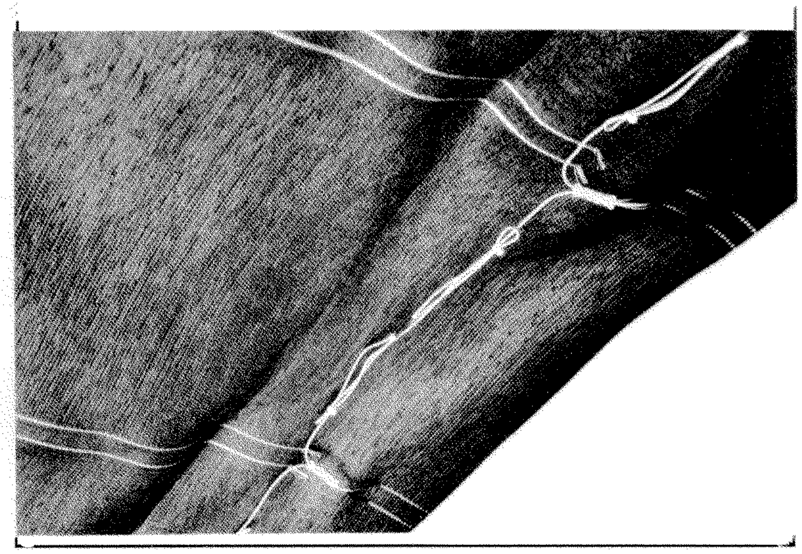

Fig.7. Crimp connectors joining the wire loops from the fabric to the sheathed wires from the intelligent node units.

Consideration must be given to the necessary closeness of the wires (lane width) to achieve a satisfactory resolution and to achieve actual values of measurements that can be discerned and measured by the equipment. After extensive investigation, 50 cm. was adopted as an optimum value for lane width.

The overall system therefore comprises resistance and capacitance, but each of these as measured is affected by two parts of the system.

First capacitor : capacitance between any two parallel wires.
Second capacitor: a capacitance effect induced between the parallel wires and the overlying cross wires. This is a side-effect, but is easily calibrated and catered for.

First resistor: Resistance between the two parallel wires as may be caused by leaks.
Second resistor. The passive conduction or short circuiting that is effected by leaks between overlying cross wires. This, again can be calibrated by the software, which is designed to expect results within the ranges caused by the wires and their induced surrounding effects.

In developing the design, consideration was given to the choice of insulator layer between the electrode textiles. Any synthetic, permeable, reasonably thick geotextile would have done in principle. It was found that 1 mm or more provided sufficient insulation under dry conditions. A nonwoven needlepunched was chosen, because they are manufactured to a suitable thickness and because the capillary properties of the textile could be utilised to enhance the function of the system. A small leak will be spread out by capillarity, so that quickly two sensor wires are connected and the system activated accordingly.

Many different types of wires were researched. Copper was immediately investigated, but work at the University of Gent suggested that Inox stainless steel wire as thick as possible would be the best. Although copper would be better from general considerations of deterioration, ammonia fluids are common by-products of the decomposition of waste matter and copper is particularly attacked by them. Therefore, copper was abandoned in favour of stainless steel since it is resistant to ammonia fluids.

Wire thickness is ultimately limited by the properties of the metal chosen, interacting with the practicalities of the weaving process. They must be thick enough to be connected easily and robust enough to be handled several times.

In order to compromise between flexibility, as required by the weaving process, and the need for robustness and a larger electrical cross section, each 'wire' is actually created by weaving nine individual thin wires into the warp to effectively form a single composite conductor. These nine-wire groups form a single wire conductor woven into the warp of the fabric at intervals of 0.5 metres.

Down the warp, the wires are left out of the weaving every metre, to form short loops which can be used to make physical connection. At the edge of the fabric, the node units are connected to the wires at such loop points. They are connected by crimp connectors of a standard kind.

The method used by the system is electronically sophisticated. The electrodes are interrogated by a sophisticated computer system, at frequent intervals. The following measurements are taken.

a) Resistance between pairs of wires and resistance between immediately adjacent and cross lapping wires.
b) Capacitance between pairs of wires and between any wire and its local environment.

Extensive laboratory testing proved that the use of these two multiple techniques could give a reliable and accurate interpretation of the presence and location of effluent leaks. The location reliability is a function of the distance apart of the electrode wires in the warp of the woven geotextile. At present these are 0.5 metres apart, thus ensuring location accuracy within that distance. If greater accuracies were required, then wires could be woven at smaller intervals. Thus the system has inherent accuracy control.

The resistance of a fluid-filled porous medium can vary with both the amount of fluid present and its conductivity. Therefore, a sudden increase in conductivity at any point might indicate either an increase in clean ground water or a small leak of conductive effluent. Therefore, a simultaneous capacitance reading operation takes place, since capacitance is highly indicative of water or effluent and the two can be distinguished. When the system is calibrated, these two readings together provide the required accurate and reliable answer.

Once laboratory testing had confirmed the effectiveness of the chosen analysis system, a considerable amount of development was needed to produce a practical and economical method of monitoring the hundreds or even thousands of wires laid beneath the site. Clearly, the monitoring of individual wires from a central computer would be unwieldy and impractical, since each wire would have to be extended to reach the processor. Thus an intelligent remote-programmable node unit was developed which could interrogate and handle nine wires at a time. These node units can be connected together in series by a simple four-core coaxially sheathed wire as shown in Fig.8.

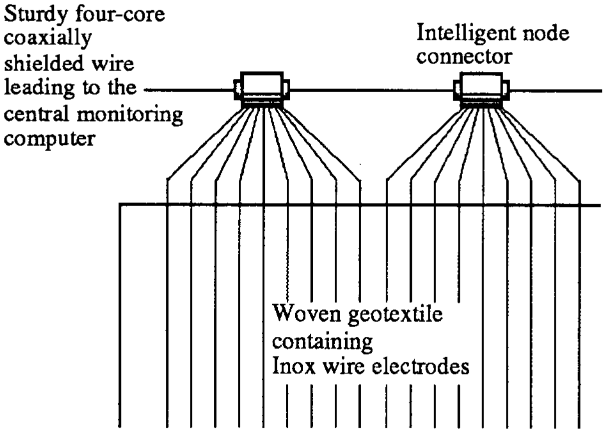

Fig.8. Intelligent nodes enable the use of simple wiring to the monitoring PC.

Since each node will handle nine conductor wire elements, and since the presently chosen spacing of the wires is every half metre, the node units are spaced along the periphery of the waste disposal site at intervals of 4.5 metres. Fig.9 shows how the system easily copes with later extension of the waste disposal facility.

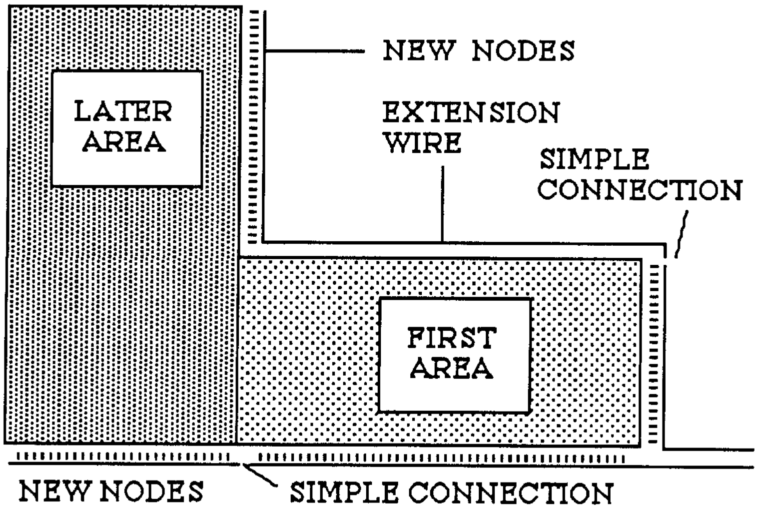

Fig.9 Extension of the waste disposal area is catered for by simple linear extension of the in-series node wires.

This system is elegantly simple and clearly lends itself to future expansion with no inconvenience or added cost since all nodes are remotely re-programmable by the controlling PC computer program running under Windows. This program is highly user friendly and displays a visual map of the waste disposal site. Fig.W shows a small waste disposal demonstration site, formed in a rectangular pit for ease of illustration of the wire configurations. Fig.10. shows the lowest electrode layer with wires running from top left to bottom right, then a white coloured nonwoven needlepunched electrical insulator layer, and finally the top electrode layer with wires running from top right to bottom left. After the detector system has been installed and connected, then the standard operations connected with the placing of the impermeable lining layers can commence.

At this stage, the ELDEG system can be particularly valuable in that it can be used as a quality control tool during the sealing operations. If test liquids are introduced into or onto the sealed membrane, then any leaks will immediately be detected by the ELDEG monitoring PC. Thus, for no additional cost, the initial integrity of the lining system can be assured. Normally, to do this, special equipment and consultants would have to be brought in.

Fig.10 View of the cross-laid detector textiles on site. The three active layers of the ELDEG system are - two conductor wire layers and a white electrical insulator layer.

Fig.11. Impermeable membrane being laid over demonstration waste disposal site.

It can be seen that the system is quick to install and robust in operation. Contractors have no need of specialist experience to lay this system and the manufacturers offer a design and installation service should it be required.

On a typical large site the full permutation of all wires will be checked by the controlling PC software every twenty minutes and so any leak would be detected and displayed virtually instantaneously within the time frame of a waste disposal facility. The software also maintains long term records of all changes, so that should the computer be un-manned when a leak starts, the whole development pattern can be played back and analysed, to reveal the point of origin of the leak.

Fig.12 shows the PC screen, indicating initial variations of moisture on a small rectangular site. Note that the left and right sides show dark. On the actual screen, these colours are blue indicating very minor levels of moisture. Any increase in effluent moisture is detected and analysed by the software using the resistance/capacitance algorithm and where leaks are detected, on screen the colours increase from blue through green to yellow, orange and eventually red for total saturation.

The initial ground conditions are taken into account by the software and used as a 'base reading'. Furthermore, long term variations in ground moisture conditions are also catered for in the software.

Not only does the computer take a long-term view when analysing conditions, but it also keeps mixed short and long-term data in its memory banks, so that the changes over many years can be examined and so that sudden leak events can be studied and back analysed.

Once a leak has been confirmed, then its position can be pin-pointed by the previously undertaken topographical survey work.

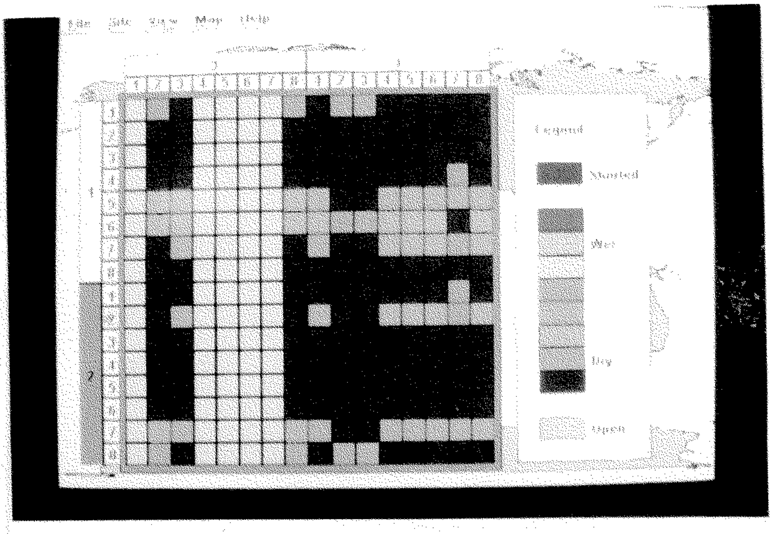

Fig.12. View of the Personal Computer screen displaying the output from a small site immediately after construction, showing a minimal amount of natural ground moisture.

The wiring circuitry is specially developed and handled by the software such that should any wire become damaged or any connector become defective, the software makes visual notification through the PC screen and appropriate action is taken to re-divert signals such that the system continues to work. Defective connectors can be replaced easily because they are attached to the wires around the periphery of the site.

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