HARDWARE OPTIONS FOR PUMP TEST DATA ACQUISITION

by

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INTRODUCTION

The Power and Water Authority (PAWA) of the Northern Territory have engaged the Australian Centre for Tropical Freshwater Research (ACTFR) to provide assistance to them in the construction of a groundwater electronic data collection and analysis system. This report marks the completion of the first stage of the project, the aim of which was to consider the hardware requirements for automatic pump test data acquisition and recording. Later stages of the project will consider options for the displaying, editing and interpretation of this data.

To undertake the work documented herein, suppliers of data-loggers, borehole pressure transducers, water quality monitoring equipment, and flowmeters from all over Australia were contacted; product information provided by these companies has been forwarded to the PAWA with this report. As well, I contacted a number of people from various companies and government departments who have already, at least partially, automated their pump test data acquisition procedures. References to many of these conversations are made below.

It should be noted that although the number of suppliers contacted was extensive, it may not be exhaustive. However more than enough information has been obtained to allow a decision on data acquisition methodology to be made. Following from this a detailed system design can be quickly drawn up and the appropriate items of hardware selected using the brochures and specification sheets provided with this report, or from other information which may be already in the files of PAWA personnel but is not included herein.
SYSTEM REQUIREMENTS

A system is required for the monitoring and recording of water levels in the pumped bore as well as in a number of observation bores. PAWA staff have indicated that the number of the latter may be as few as one, but could be much higher in areas which have been the subject of intense groundwater investigations. The closest observation bore is likely to be no more than 20m away from the pumped bore while the furthest could be 500m or more away. Standing water levels over the Northern Territory can vary from less than 10m to more than 100m. Drawdowns in the pumped bore of 30m are common, and can exceed 50m, though 10m would be the limit in most observation bores.

PAWA staff have expressed the desire that the pump discharge be monitored and recorded along with the bore water level information; these two sets of data taken together represent total data requirements for pump test interpretation. It was also suggested that the possibility be examined of monitoring the temperature and some of the chemical characteristics of the water as well (at least its electrical conductivity), as indications of changes in these quantities with time may be of assistance in gaining a better understanding of the pumped aquifer.

It is intended that the system will allow for pump test data to be examined in the field so that a preliminary interpretation can be made. Also, decisions will need to be made on the basis of data gathered up until a certain time on whether to continue or halt pumping, recovery measurements, etc. Hence it is necessary that electronically stored data be accessible without causing an interference to the logging process, at the pumped bore and closest observation bore at least. Also, it is desirable that the system allow regular checks that all transducers and recording devices are operating correctly.

An obvious requirement is that all parts of the system be physically robust and immune to adverse effects from rain, humidity and high temperature. Ease of installation and use would be desirable. As always, component cost is also an important factor in constructing the system.

A final important requirement is that PAWA staff have ready access to advice from equipment makers or agents. Discussions with users of this type of equipment have reinforced our own experience at the ACTFR that not all equipment is bug-free and that no system will be perfect. Each step in the building of a system will involve some degree of experimentation involving the deployment of some items of equipment in ways that may differ slightly from those in which they have been deployed before. If the equipment is
Australian-made and if its makers are eager to see their gear being used in many different contexts, my experience has been that they will go to some trouble to ensure that its deployment is successful.
SYSTEM COMPONENTS

Bore Water Level Sensors

Types of sensor

Water levels in dams, tanks, weirs, boreholes etc. are measured using a variety of methods, some better suited to particular applications than others. The cheapest way to measure water level variations is to use a capacitative sensor. This is a long tube with a dielectrically coated inner conductor and an exposed outer conductor. Water, being a conductor itself, links the outer conductor to the dielectric coating (normally teflon) of the inner conductor, the length of this water contact determining the amount of teflon dielectric that forms the effective capacitance between the inner and outer conductors. Changes in capacitance are measured and related to changes in water level. The device can be flexible or rigid; the maximum length that I have seen advertised is 6 metres. These items cost between $100 and $800.

Accuracies as good as 3mm have been quoted by manufacturers of these devices, though users will rarely quote below 2cm. Any dirt on the teflon can retain moisture, increasing the effective plate length of the capacitor. Also, metal bore casing may degrade their performance, though I am informed by Jeff Smith of Westdata, that the offset, and not the slope, of the calibration is affected.

Another commonly used method of water level measurement is through the use of a weight and float connected by a string passing over a pulley which drives a shaft encoder. These are extremely accurate devices, offering a resolution of 1 mm or better for any water depth. The float can be made narrow (diameters down to 50 mm are advertised) for use in a borehole. However, when used in a borehole there is always the possibility that the float will rub against the side of the hole, especially if the latter is not quite vertical and the hole is deep. Also, there may be some problem in ensuring that movement of the float is unencumbered in the pumped bore because of pipes, cable etc. The cost of these items begins at about $1000.

The other commonly used method of monitoring water level variation is through the use of submersible pressure transducers. A number of companies manufacture transducers specifically for use in a borehole; there is much variation between these products in quality. Specifically, temperature effects, hysteresis and non-linear specifications need to be compared between brands prior to transducer selection. Price varies between $200 and $10000.
Ultrasonic methods have also been used for measuring borehole water levels. Here a transmitter/receiver is suspended below the water level and the travel time of a sound wave between the sensor, the water surface and the sensor again is measured. To my knowledge, this equipment is not sold or used in Australia. An ultrasonic system would probably be accurate but I would expect that pump noise would be a serious problem in the pumped bore.

Pressure transducers - gauge or absolute

If a pressure transducer is placed below the water surface in a borehole it will measure the hydrostatic pressure relative to some reference. For an absolute pressure sensor, the reference is a vacuum, i.e. zero pressure. For a gauge pressure sensor, the reference is the air in the sensor’s immediate environment. If a vented cable is run from the transducer to the surface, the immediate environment of the sensor will be at atmospheric pressure. If there is a chamber within the transducer’s container which is not linked to the atmosphere, then the reference pressure will be that of the air within the container. The latter will vary with temperature according to the gas law which relates the pressure of a gas to its temperature and volume.

Each of the above methods of measuring pressure has its disadvantages in the current context. If a gauge transducer is used with no atmospheric vent, a temperature correction must be applied to all measurements. The extent of this correction will depend on the volume of the container, excluding any solid pressure-sensing and electronic elements within it; hence temperature must be recorded as well as pressure. If a vent is used, vented cable must be provided. This is expensive, ranging in cost from $1.68 per metre to over $25 per metre. If an absolute sensor is used then the air pressure on the surface must be monitored as well, for this must be subtracted from the downhole sensor’s reading to yield the pressure due to the water alone, from which its level can be calculated. This also means that if a sensor is selected to measure up to, say, 10m depth of water, then at least half of its reading must be subtracted immediately, giving it an effective full scale range of only half its rating. Accordingly, its accuracy and resolution relative to its range are halved, and the number of bits of useful information recorded by the digital data-logger is reduced by one. Also downhole and barometric pressure sensor errors will be added in the pressure subtraction process. Note, however that the greater is the depth range of water that the absolute downhole sensor must measure, the smaller do these barometric reference associated errors become. Hence if a sensor were installed to measure a 50m drawdown, these errors would be reduced from one half to one sixth in a relative sense, though
absolute terms they would be unchanged; fortunately transducer accuracies are fairly uniform, in a relative sense, over a broad range of devices with different depth limits, for a given manufacturer.

The use of vented cable is not without drawbacks. Firstly it is expensive, especially if water levels are deep. This problem can possibly be overcome by terminating the vented part of the cable a few metres above the water level and connecting ordinary cable for signal transmission the remainder of the way up the hole to the data-logger (if the latter is at the surface). The cable join must be such that the vent is not blocked, and it must ensure that no moisture is able to infiltrate and block the vent; the latter could be a problem in the pumped bore. If the join is accidently lowered too far so that the join becomes submerged, water could get into the transducer itself and ruin it (as has happened to Peter Clifton of Mackie Martin & Associates in Perth). Similarly, if the vent sustains a hole (such as in one case of which I was informed where someone melted part of the cable on an exhaust pipe without his knowledge), and water is allowed in, the transducer will, again, be destroyed.

Ian Acworth of the Centre for Groundwater Management and Hydrogeology partially overcomes the problem of expensive vented cable by buying each transducer with only 1m of cable attached. He has different lengths of vented cable which he then joins to the transducer using a special underwater plug. Although he doesn't overcome the problem of having to run large lengths of vented cable to the surface, he does reduce expense by obviating the necessity to buy each transducer with the maximum likely needed length of vented cable attached. Also, if water depths are small, he does not have the excess vented cable lying in the sun getting hot and possibly upsetting its venting efficiency (see below).

Attempts to lower system cost by using the cheaper cable may not be effective, either. Cheaper cable may allow the ingress of moisture, according to Tony Jarvis of Mindata; this will jeopardise the integrity of current and voltage uphole signal transmission (see later).

Another problem, reported by Nick Stathis of QWRC, Ron Bulna of the Western Australian Mines Department, and Geoff Elder of the Rural Water Commission of Victoria, is the effect of cable temperature on its ability to provide an atmospheric reference. I have not encountered this problem myself, but I have been assured that phantom water level variations have been induced in vented cable systems because of solar heating of the black cable, especially if there are restrictions due to kinks or moisture ingress into the vent. The longer the cable, the more likely is this problem to occur. Druck cables, which had a narrow vent, were notorious for this problem, but their agents inform me that the vent is now wider.
Tony Jarvis of Mlndata points out that if downhole cable length exceeds 25m it could suffer damage in supporting both itself and the transducer; this applies to Mlndata equipment and possibly other brands as well. He suggests using stainless steel wire clamped to the transducer to take the weight. If the cable is vented, damage to it could, of course, have dire consequences. I obtained a local price on stainless steel cable: the smallest diameter available in Townsville is 1/16" which costs $1.09/m. I would be surprised if you could not get a better price elsewhere, but it should be noted that this cost, and that of uphole winders, will need to be added to the system cost.

**Signal Transmission**

Whether a sensor is a pressure transducer, flow rate meter, temperature or conductivity probe it must communicate with the data-logger through a cable, unless the logger is built into the same case as the sensor. Signal transmission can be analogue or digital. In the former case some characteristic of this signal is proportional to the magnitude of the property that the transducer is measuring. If the signal is digital a sequence of "on"s and "off"s is transmitted, these encoding a message which may be, for example, an ASCII number representing the magnitude of the property that the transducer is measuring. Most transducers do not make this digital conversion, though loggers communicate with other loggers and computers in this fashion. In the case of analogue data transmission the signal's voltage level, current level or frequency of voltage or current on/off switching may be representative of the property being measured. (Frequency modulation of this type is often called "digital" transmission by the suppliers though this is not really a correct description; however it serves to discriminate logger "analogue" inputs which are for voltage and current signals from "digital" inputs, which can often accept a frequency signal). In the case of digital transmission on/off may be represented by high/low voltage or current or a frequency modulation of either.

If analogue voltage transmission is employed, a cable with three conductors and a shield is normally required to connect a logger to a transducer. One conductor supplies power to the transducer, one is ground, and the third carries the voltage (relative to signal ground) representing the measured quantity; the shield protects the signal from electrical interference. The signal is then fed through a high impedance to an analogue-to-digital converter which produces a number that can be stored. The high impedance is necessary so that the transducer is not "loaded" by the logger, for this would artificially lower the transmitted signal. Also, the resistance of the transmission line must be very low compared to the logger input impedance (to prevent signal loss), necessitating that the latter be large.
The high input impedance necessary for interfacing with analogue voltage transmission lines causes problems where large, high frequency transient electric fields are likely to exist. Unfortunately, in the vicinity of the generator, pump, and its cables, it is probable that such fields will exist. The transducer signal transmission cable acts a little like an aerial and, in spite of precautions such as shielding and keeping individual conductors close together, signal degradation often occurs. Low-pass filtering can assist in removing the unwanted transients, but it cannot be guaranteed to work in all situations.

In analogue "frequency modulated" or "pulse" voltage transmission, a continuous series of voltage pulses is sent whose frequency is proportional to the measured quantity, as was explained above. The logger measures the frequency, or period, of these pulses (by counting either the pulses themselves or a frequency signal of its own gated by them) and stores that value. In this case the input must still have a reasonably high impedance, but a certain amount of noise can be tolerated on the line; in fact transient-induced voltages can be up to about half the line voltage before "on" is misinterpreted as "off" and vice-versa.

Analogue current transmission is commonly employed where electrical interference is a problem: the current carried by the cable varies linearly with the measured quantity. The "4-20mA current loop" is the most commonly encountered variant of this system. Here only two conductors connect the transducer to the logger, these wires supplying both the power to the transducer and carrying the signal current. The logger's input is often a resistor that will convert the current to a voltage that can be sampled by its A/D converter. Fortunately this resistor need have a value much lower than the high input impedance needed for voltage transmission and so electrical interference is greatly reduced as transients are "short-circuited". Quality data loggers can, in fact, reduce this input impedance to zero.

Frequency-modulated current transmission would obviously be the best method of analogue signal transmission combining the noise resistant properties of both frequency and current transmission systems; this option is available for some of the flow measurement transducers encountered while making enquiries for this project. Likewise, digital transmission by modulation of current would also be a safe means of data transmission and is occasionally seen quoted as a transducer output option.

In the present context, as has been mentioned, electrical interference is likely to occur in the vicinity of the pumped bore; hence it is recommended (see later) that the 4-20mA current loop be used there whenever possible unless cable length is very short. In the monitoring bores interference is not likely to be as much of a problem, though it should not be forgotten, especially if signal transmission cable lengths are long.
On the subject of interference, it is suggested that any data loggers in the vicinity of the generator, pump and its cables be housed in a steel box. Steel (because of its iron content) has the ability to block magnetic fields, these often accompanying stray electric fields in electrically noisy environments. Peter Clifton of Mackie Martin has reported that his logger stopped working when placed near an electric power cable on one occasion. I, too, have seen digital equipment malfunction because of magnetic interference; in that case the interference ceased when the instrument was placed in a steel box.

Data Logging

There is a huge range of data loggers available. Variations between units include number of channels, number of bits stored per data item, type of input signal, manner of communication with a computer, power consumption, etc. I do not intend to discuss the full range here, though in the next section I will examine what units are available that may be of use in the context under consideration. However some of the desirable features of a logger for the present application are briefly considered below.

As discussed above, a logger must either be part of, or close to its transducer, or be capable of receiving a current loop input, preferably 4-20mA, this being the industry standard for 2 wire transducer-to-logger communication. It should be noted that a voltage input logger will receive a 4-20mA current input simply by connecting the appropriate resistance across its input terminals, though the bottom 4/20th of the signal is "wasted" because it is never used; resolution is reduced accordingly. (Hence some transducers include a 0-20mA option, though in this case a separate wire is needed for the transducer power supply). Also a number of available loggers that have frequency inputs can be equipped with voltage/current to frequency converters so that their loggers then can interface with voltage and current signals.

The best available pressure transducers that can be considered for the present application quote an accuracy (combining non-linearity, reproducibility and hysteresis) of 0.1% full scale (F.S.). Hence at least a 10 bit sample (giving a resolution of 1 in 1024) is required to make full use of these transducers' capabilities. Capacitance water level sensors quote as little as 0.02% F.S. resolution, requiring a 13 bit logger to match this; however, as mentioned, this accuracy may be too optimistic. Hence it is considered that a 12 bit logger would be sufficient for the present application. A 12 bit logger provides a 1 in 4096 resolution, which is also more than enough for flow rate, electrical conductivity etc. monitoring in the pump test context.
it is necessary to decide whether a system comprising one or a number of loggers is to be employed for monitoring water levels in the pumped bore and observation bores, the discharge rate, and anything else that may need recording. If one logger is used, cables will have to be strung from all measurement points to a central recording facility. The logger will thus need to have as many channels as the maximum anticipated number of inputs, and will need to possess sufficient memory to record these measurements for the maximum anticipated duration of a pump test and recovery exercise. Also, cables may have to be laid out over long distances to faraway observation bores whereby the risk of breakage from animals or vehicles will be high. If, on the other hand, many single-channel loggers are employed, cost could become excessive, unless a very cheap single-channel logger were available. This latter system would also be less convenient in that many loggers would need to be downloaded instead of one. Similarly it would be more difficult to periodically check that the entire recording system was operating properly.

As mentioned earlier, PAWA staff have expressed the wish that the logger(s) be capable of periodic downloading so that data taken up until a certain time can be inspected. With most loggers this will mean that data acquisition has to be halted and then recommenced after downloading has taken place. However unless this operation must take place shortly after the commencement of pumping or recovery, no important data will be lost in this process though, indeed, it would be easier if the logger could be downloaded without having to halt it first and restart it afterwards. The more complex is an operation, the greater likelihood is there of making a mistake, especially if there is pressure to do it quickly. Hence the facility to download without halting and restarting would be desirable.

Most loggers have the ability to be queried as to their current status without interrupting the logging sequence. Hence the amount of memory used, the battery voltage and the current or latest stored transducer value can often be checked by connecting a computer to the logger at any time and asking the appropriate questions.

The amount of memory available varies from logger to logger; some have expandable memories. Some loggers have the ability to conserve memory by only recording a transducer reading if it has changed by a certain, user-defined, amount from the previous reading. This may be a considerable asset in the pump test setting where water levels in the pumped bore need to be recorded at short intervals just after the commencement of pumping and recovery, but at longer intervals at later times, for if the logger is set to constant short-interval recording for the entire pump test duration it may run out of memory prematurely. Of course, it can always be re-programmed to sample at different rates at different stages of the test, but this is inconvenient and, again, raises the danger of
error. Some of the more sophisticated loggers can be pre-programmed to lengthen their sampling interval at specific times giving a "pseudo-logarithmic" sampling scheme.

For most loggers, the logging sequence is commenced and terminated, and data is downloaded, using an IBM compatible PC; a battery-powered laptop would be convenient in the pump test context. Loggers can mostly be programmed to commence sampling at a nominated time, or immediately if desired. In some cases logging parameters can be set using switches or keys on the logger itself, or, in other cases, using a special device to program an EPROM which is then installed in the logger. In the latter case, the EPROM is withdrawn at a later date and read by the same device for its stored data. Other companies manufacture low-priced battery-powered terminals which can set-up and download a number of loggers and ultimately download their stored logger data to a PC at a later time; this saves having to use a more expensive, and less robust, computer for routine field logger communication.

Geoff Elder from the Rural Water Commission of Victoria has conveyed to me a nagging worry that he has pertaining to loggers. Many units that are built to supply power to a transducer, as well as measure its output, only supply power to the transducer for a half second before taking a reading; in this way power is conserved. Geoff has noticed that for some transducer/logger systems this may not provide enough time for the transducer to heat up, and slightly erroneous readings could be recorded. While there is at first no choice but to accept manufacturers' assurances that there are no such errors, the possibility should not be forgotten. I am informed that it is a relatively straightforward matter to reprogram some units to switch on for a longer time prior to taking a reading if this was required.

It should be pointed out that it is possible to set up a signal acquisition system that dispenses with loggers altogether. The Western Australian Mines Department, in conjunction with Westdata, has developed a system whereby transducer data is fed directly into their PC. They do this in two ways: (1) through a data acquisition board that plugs directly into the PC and is thus accessed directly through the computer's bus, and (ii) by conveying digital data from an external A/D converter in serial fashion through the RS232 port. In the latter case they use a commercial software package, Labtech NOTEBOOK to acquire, plot and manipulate the data in real time. As a laptop will not run for more than 5 hours on its internal batteries, such a system would need to employ either a large external DC power source, or a generator; in the case of the WA Mines Dept. a generator is employed. As their computer must be weather protected, it is installed in a caravan which also houses other equipment and the operator. While such a system allows "hands-on" interfacing between the measuring system and the operator, I do not consider it an
appropriate system for the PAWA at this stage, mainly due to its complexity and cost. Such a system would probably require a time-commitment to set up that is greater than that allowed for in the present project. Furthermore, I would be surprised if such a system were not more prone to failure than a more "modular" logger-based system. Also, operators would need to be better trained than for the latter type of system. Further, NOTEBOOK does not allow for log-log or log-semilog plots so that, unless a more suitable package were found, the size of the programming task required to implement the centralized computer based system would be large if it were to be made appropriate for pump test data acquisition.

Discharge Monitoring

There are many different types and makes of flowmeter available, spanning a large range in price. A good review of the principles of operation of the different types can be found in many textbooks; see also the Kent Flow Products Catalogue among the suppliers' information which accompanies this report.

In carrying out a pump test, flow must be monitored as well as recorded. Hence it is necessary that a visual display of flow rate, or some quantity related to it, be available at all times. For recording purposes, the flowmeter used must have an electrical output for interfacing with the logger. If this output is to be transmitted over any distance then it will need to be of current type; if the logger is next to the flowmeter and if the two are somewhat removed from the generator and power cables feeding the pump, then other types of electrical transmission could be tolerated. As it happens, many flowmeters provide the user with a choice between the options of 4-20 mA transmission, or a voltage-based frequency transmission, the frequency being proportional to the flow rate. Many also provide a dial or digital display of either the flow rate itself or a quantity proportional to it.

Some of the more sophisticated flowmeters require 240V power; I have been informed by PAWA staff that the latter is usually available at the pump test site. However, if such an instrument is selected, then experience may show that a power line conditioner is necessary, as many of these flowmeters possess microprocessor circuitry for data processing and display. This would add $400 - $500 to the cost of the unit.

PAWA staff have informed me that discharge rates can vary between 1 l/sec and 100 l/sec. This variability places demands on a flowmeter that are not present in many other applications; a measurement range of 100:1 is beyond that of many available devices. Hence some of the flowmeter hardware may need to be adapted to the anticipated flow rates
of each test. Either the pipe diameter (to maintain flow velocity within measurable limits for velocity-measuring devices) or the diameter of a constriction (to maintain a pressure drop within measurable limits for pressure-drop-measuring devices) will have to be selected for each test on the basis of discharge rate. The expense of this duplication of part of the flowmeter hardware for different flow rates must be taken into account when assessing the overall cost of the discharge monitoring component of the pump test measurement and recording system.

At present PAWA uses a discharge orifice plate and water manometer to measure flow. Here both pipe and orifice plate diameters can be adjusted with flow rate. A simple way of logging flow rate would be to incorporate a 4-20 mA pressure transmitter next to the manometer inlet (cost begins at about $500) and send this signal to the logger. As discussed later, devices are available which incorporate an analogue display, sometimes proportional to the square root of pressure (so as to be proportional to flow rate). Another easy and very cheap method of obtaining a display would be to pass the current signal through a resistor and measure the voltage drop with a voltmeter; the resistor could be switchable for different flow conditions.

More accurate flow rates could be obtained if an in-line orifice plate were used instead of a discharge plate. Here a differential pressure cell would be required (costing at least $500) to measure the pressure difference across the plate and convert this to a 4-20 mA current. Also, dail tubes and venturi tubes could be used, again, together with a differential pressure cell. In all cases the measurement range for a particular set-up is about 30:1 (including the possibility of span adjustment in the pressure transmitter). Differential pressure measurement accuracy is very good; at 0.25% of span for some cells, overall flowmeter accuracy will be set by the orifice plate or other device used to incur the pressure drop. In many differential pressure cells integral damping is carried out to remove pump-induced pressure noise within the pipe. While the overall measurement range of this system is not as good as the 100:1 required for a universal pump test flow measuring system, the cost of the different hardware options required to increase this range (e.g. orifice plates, different diameter pipes) is small.

Another inexpensive option is the turbine flowmeter; however there could be a problem with sand grains causing the blades to stick. Both Mackie Martin and the WA Mines Dept. have used this type of flowmeter. Peter Clifton of Mackie Martin told me that they use a Kent model and it gives them no trouble. WA Mines Dept. used a Bailey turbine meter: it needed encouragement from a hammer to get it going again intermittently. In neither of these cases was flow actually logged, though this does not present a problem as an
electrical output is normally available as an option. An in-line sand filter could also be used in conjunction with them to minimize the probability of sand halting their operation or causing excessive wear.

Vei1 type flowmeters operate on a similar principle; accuracies as good as 1% over a 100:1 range are quoted. Here sticking of blades would not be as likely to occur but the veins could nevertheless be worn down by sand grains; again a sand filter may prolong the life of the instrument. Yet another variant is the paddlewheel sensor. These are normally constructed such that they can be inserted into pipes of different diameter. While their measurement range is not as good for a given set-up as that quoted above, this is compensated for by their ability to be easily inserted into pipes of different diameter.

Some flowmeter types are unsuited to the pump test context. Variable area meters do not handle the flow rate range required; also they rarely have an electrical output. Displacement type meters are certain to become stuck with sand particles. Vortex flowmeters are about the same price as the far superior (for this purpose) magnetic flowmeters, but are less robust and adaptable. Another type of device, in which small holes are drilled into the upstream and downstream sides of a cylinder protruding into the flow path, is susceptible to damage from sand grains.

Magnetic (i.e. electromagnetic) flowmeters are very popular. They have a high accuracy, good measurement range (50:1) and are unlikely to sustain damage from sand grains because no part protrudes into the pipe. They are partially adaptable to different pipe diameters in that the same controller can be used in conjunction with different diameter flow heads for flowmeters provided by most suppliers. An even more flexible item is the insertion magnetic flowmeter which can be inserted into pipes of different diameter; however accuracy and range are not as good.

It is worthy of note that both the South Australian and Western Australian Mines Departments are considering the purchase of a magnetic flowmeter for their pump testing operations.

Ultrasonic flowmeters are of two types. The first type is a doppler type whose principle of operation is like that of a police radar gun. It depends for its proper use on there being enough foreign particles or bubbles in the water for the ultrasonic signal to bounce off. As this cannot be guaranteed in the present context it will not be considered further. The second type produces an output determined by the difference between upstream and downstream travel times. This is accurate and has a high measurement range. Also as no
parts project into the pipe there will be little wear and, as with the magnetic type, no head loss. However these units are expensive. An appealing option for the pump test case is a unit manufactured by Krohne that can clamp onto the outside of pipes of any diameter. While the unit is thus extremely flexible in its use, it is expensive and not as accurate (1-3% accuracy) as fixed flowmeters.

More details of available flowmeters will be provided in the "Suppliers and Products" section of this report. Meanwhile a comment by Gerd Kucher, an engineer from Queensland Water Resources Commission, is worthy of note. He points out that an inherent advantage of systems such as the orifice plate and venturi tube is that they can be "dry" calibrated, i.e. the correspondence between flow and pressure drop (and hopefully electrical output, if the transducer can be trusted) can be worked out solely from the dimensions of the device. This is not the case with more complex units. He told me of a case he had experienced where a number of flowmeters of different types along one pipeline produced a 20% disagreement in flow rate! Suppliers, of course, refute stories such as this saying that connections were wrong or that not enough straight pipe was maintained upstream and downstream of each unit. My feeling from talking with other people who have had some experience with flowmeters is that things are not as bad as 20%, though I have been warned that ultrasonic units may not have been perfected yet.

**Temperature and Chemical Properties of the Discharge Water**

There has been insufficient time in this project to explore the possibilities involved in these kinds of measurements in the same detail with which water level and flow rate measurement methods has been examined. Where suppliers of the latter types of equipment also sell temperature and chemical monitoring equipment (which is mostly the case) I have asked them to send me some information; they have not all complied with this request. In general, sellers of flowmetering equipment can also provide temperature and chemical sensors together with transmitters and display units, the sensors often being suitable for mounting within a pipe or other closed vessel. The gear is often of very high quality and needs to be powered by 240V as it is designed for installation in a factory or chemical process works. On the other hand, makers of inexpensive battery powered loggers often have a submersible temperature and/or conductivity probe that interfaces with their logger. In their design it was envisaged that these probes were to be submerged in creeks or maybe boreholes. A number of manufacturers advertise such products but, upon inquiry, reveal that production is just around the corner.

PAWA staff need to give some thought as to where such probes are to be placed. The cheaper, and hence probably more appropriate ones, cannot be mounted in a pipe of fast-
moving fluid. With FAWA's present set-up of discharge into a 44 gal. drum, out of the bottom of which the water flows into a small channel or flexible irrigation fluming, the obvious place to put any probes would be in the 44 gal. drum, though precautions would need to be taken at low flow rates that measurements are unaffected by the chemistry and temperature of the drum. As for all other types of measurement, signal transmission to the logger should be by current rather than voltage unless the measuring probes and logger are close together and far enough removed from power cables to be considered unlikely to be affected by them.

The most useful chemical property of the water (and the easiest to measure) is normally its ionic content as indicated by its electrical conductivity. A number of inexpensive probes are available or are soon to be released. In principle, the measurement of this quantity is not difficult, though some of the smaller manufacturers appear to have had unexpected delays in getting their units ready for production. Probes are of three types, viz. two-electrode, four-electrode and toroidal. The first two methods are galvanic and the probes will need replacement from time to time as they deteriorate due to rusting or the deposition of other deposits. In the case of the two-electrode probe this will affect the measurement; hence they should not be purchased. The toroidal probe is an electromagnetic device and would be expected to be robust and to have a long life; they are also the most expensive option.

The more sophisticated conductivity measurement systems incorporate temperature compensation (often adjustable for electrolyte type) in order to adjust the reading to a standard temperature, usually 25°C.

The availability and specifications of a number of temperature, conductivity and other chemical probes are described in the next section.
SUPPLIERS AND PRODUCTS

This section contains information provided to me by suppliers in answer to my inquiries on behalf of PAWA. Only products are discussed in detail which are likely to be useable in the pump test context, many of the criteria for use having been set out in the previous section. To keep this report from being excessively long, only the most pertinent information will be presented; PAWA staff can look further into any item that interests them by reading the brochures that accompany this report. These brochures also include information on items considered not so useful and hence not discussed below. Suppliers are discussed in alphabetical order.

Supplier: Bailey Controls Australia Pty. Ltd.
Phone: (07) 846 2688
Contact: Brian Malley

A Bailey differential pressure transmitter without a meter costs $933; a gauge pressure transmitter costs roughly the same. The specifications of these units are similar to those of the same type of product sold by other suppliers; see Rosemount and Kent for a fuller discussion.

Bailey Controls are agents for Krohne magnetic flowmeters. There are two options available here; the flow head can be purchased separately from the signal converter, or "compact" units can be obtained in which the signal converter is mounted directly on the flow head. In both cases the converter is "intelligent" so that, once informed of the pipe diameter, the flow rate in any desired units can be displayed on an LCD display. In both cases the converter can be interfaced with flow heads of different diameter, though the converter needs to be fastened by bolts in the compact units. For the separate flow head and converter systems accuracy is 0.5% over a 30:1 range and 1% over a greater than 50:1 range. For the compact units, accuracy is 1% over a 50:1 range. For both units, signal output can be 4-20 mA current loop or frequency modulated voltage as desired. A DC power option is available though its use may not be feasible as power consumption is high (unless the logger were to switch it on prior to sampling - an arrangement not too difficult to implement in some loggers). Flow head diameters range from 1/10 inches to 24 inches.

For a 4 inch diameter pipe a X1000 type flow head costs $2592; this can be connected to a SC100 AS/MP signal converter costing $1884. A suitable compact unit, the K480, costs $2932. It may be of interest to the PAWA that one of the staff members of the Dept. of Civil and Systems Engineering has just purchased a Krohne compact flowmeter after what he
said was a thorough inspection of its capabilities and those of its competitors. Also the South Australian Mines Department are thinking of buying a Krohne compact unit to incorporate into their pump test system.

Krohne also manufacture high quality transit-time ultrasonic flowmeters with prices beginning at $4092. An interesting unit is the UL600R clamp-on flowmeter. This can be attached to any pipe from 2 inches to 40 inches in diameter. A programmable signal converter displays flow in percent of full scale and outputs 4-20 mA current or variable-frequency voltage. Accuracy is quoted as 1-3% over a 12:1 range. Price is $7197.

Supplier: Centre for Groundwater Management and Hydrogeology, University of New South Wales.
Phone: (02) 949 4488
Contact: Ian Acworth

The Centre for Groundwater Management and Hydrogeology act as agents for Computing Techniques (a British firm) equipment. There are two types of logger available, viz. the single channel CTL1 and the dual channel CTL2. These loggers can be ordered specially to interface with specific types of transducer (including flowmeters) so that engineering units are output, or they can be configured more generally to read a bridge, a voltage (2 different ranges) or a 0-20 mA (three wire system) current. They are robust and protected from the weather, have a low power consumption, and can interface with an IBM compatible PC. They can be programmed to sample with a "pseudo-logarithmic" sampling interval which makes them suitable for pump test monitoring. Their memory capacity is up to 20000 readings per channel at 12 bits per reading.

Their main disadvantage is that they are not cheap. The CTL1 costs about $2000 while the CTL2 is slightly more expensive. An additional cost is the communications software which is worth about $1300.

The Centre sells Druck pressure transducers to accompany the loggers; according to Ian Acworth, it is much cheaper to purchase these transducers through him than through Davidson's, Druck's main agent in Australia. The Centre's pricelist shows the Druck PDCR830 transducer at a cost of about $450, with vented cable costing $6.28/m. Unfortunately, this transducer has a 0-10V voltage output; Ian says that he could probably provide current output units cheaper than Davidson's as well. The cable cost is certainly less than Davidson's price, though one would need to check its venting efficiency before purchase. As mentioned in a previous section, Ian uses an underwater connector to attach his transducer to vented cables of different length. Perhaps this is the "Buccaneer plug"
mentioned in his pricelist at about $40. (An approximate factor of 2 conversion between the Australian dollar and British pound is assumed).

Also available through the Centre is a salinity probe, manufactured by Kent Instruments, costing about $310; this can be attached to a long cable and placed down a borehole if desired. It can also interface with the CTL1 and CTL2 in a manner such that conductivity units can be downloaded directly. However it is a two-electrode probe which, in my opinion, is not reliable.

By the way, of the software mentioned in the brochures, GROWLOG, lan says, is a package used widely in Britain which is not unlike HYDROLOG in Australia. I don't know anything about HYDROLOG, but it is obviously British.

Supplier: Chemical and Petroleum Industries
Phone: (03) 391 7611
Contact: Larry Turner or Kym Williams

Chemical and Petroleum Industries sell Signet instrumentation. Signet equipment represents the cheapest alternative that I know of for measuring flow. The most basic system would comprise a "Rotor-X" paddlewheel flow sensor producing a frequency output fed to an appropriate logger after some basic signal-conditioning. The basic sensor costs about $300 while an appropriate pipe insert adaptor is worth about $40-$100, depending on type and pipe size. Once calibrated, an accuracy of 1% is quoted over a 30:1 range up to about 9m/s velocity; output is linear with flow. I am informed that sand abrasion will not promote premature degradation of the paddlewheel and that when the sensor does eventually become worn paddlewheel replacement is cheap and easy.

If 4·20mA current transmission is desired, a transmitter (and display) can be provided for the Rotor-X, giving a total system cost of less than $1000. Alternatively, a compact 8500 flow transmitter can be purchased for about $610 (varies with pipe size). These units have the transmitter already mounted above the sensor. Their accuracy is quoted as 1% and their range is quoted as 20:1 (up to a maximum velocity of 6.0m/s). A pipe insert adaptor costs between $41 and $63 depending on pipe size. A digital percent flow display can be added, the total system cost then ranging from $823 for a 4 inch pipe to $992 for a 10 inch pipe. However a cost saving could be made, if desired, if PAWA constructed their own display in the manner described in the previous section.

Ideally, each 8500 should be calibrated for installation into a particular pipe size even though each unit is made for a range of pipe sizes (for example the 4 inch unit can be
inserted into pipes down to 1/2 inch diameter using the appropriate insertion adaptor; indeed, the units are cheap enough to allow for duplication for different pipe sizes. However, a further saving could be realized by allowing a particular 8500 unit to be used on different pipe sizes while using the discharge orifice plate to calibrate it in the course of a given pump test; as the devices produce a linear output, only one reading is necessary for calibration. This flexibility could help make up for the fact that its measurement range is not as good as for other flowmeters. I am informed that this latter drawback is particularly important at low flow rates where error rises rapidly once flow is below the lower end of the quoted range (0.3m/s).

An advantage of these Signet flow measuring components is that they are DC powered, requiring 24V. With appropriate wiring incorporating a small relay activated by an appropriate logger, they could be turned on by the logger just prior to sampling; this would prolong battery life immensely. (As most loggers run on 12V batteries, external batteries would need to be supplied for the 8500.)

The Signet "Mighty Mag" magnetic flowmeter costs about $2200; it can provide a 4-20 mA or pulse (i.e. frequency) output and requires a 12V DC power supply. It is of the insertion type, each unit being capable of being mounted into a range of pipe sizes. Accuracy is quoted as 1% over a 60:1 range up to 9m/s. Again, a separate calibration would be required for each different pipe size. A display can be provided if required.

Signet also manufacture analytical instrumentation. Larry Turner does not recommend using the Signet temperature probe as it is considered unreliable at the moment. A conductivity sensor is available for a little over $1000; I was informed that this is a two-electrode device. However further enquiries may prove productive as the catalogue quotes one conductivity sensor as requiring a 4 conductor cable, implying that it is a four-electrode device.

**Supplier:** Combined Instruments Systems (Aust.) Pty. Ltd.
**Phone:** (03) 874 6655
**Contact:** Brett Spurling

Combined Instruments Systems offers a 4-20 mA borehole pressure transmitter manufactured by Ashdown of Britain. Cost is $990 plus $8.00 per metre for vented cable. Neither depth ranges nor specifications were provided but, judging from the Ashdown brochure, quality would be good. Incorporated in the cable is a suspension wire.
Ashdown also manufacture high quality differential pressure cells which would be useful in conjunction with an in-line orifice plate, dial tube etc. These units, like the differential pressure cells offered by most manufacturers, have a 4-20 mA output, a display option, and an option for "square root of DP" output (so that output is linear with flow). Also, again in common with most differential pressure cells, span and zero settings are adjustable with respect to pressure difference so that output current change can be maximized for the expected differential pressure change over the length of the pump test. (I find it difficult to reconcile this ability for adjustment with the fact that these units are advertised as carefully calibrated; perhaps the adjustment devices are marked at their calibration setting.) Also, like most other differential pressure cells, these units possess considerable overpressure protection against pump surging and pulses. Cost is around $1600.

Combined Instrument Systems sell a very attractive flowmetering system manufactured by Great Lakes Instruments. It consists of an insertion impellor sensor together with a monitor/transmitter. The former unit can be inserted into pipes of 3 to 40 inches in diameter and boasts a measurement range of nearly 100:1 for flow rates up to 9m/s; linearity and accuracy are quoted as 1% over this range. The output is connected to an intelligent flow monitor which provides a 4-20 mA or frequency signal to a logger. It also provides an LCD display of flow rate in user-selectable units, as well as a display of total pumped volume; the user enters the pipe diameter and conversion factor he/she desires. With sensors priced from $651 and with the monitor priced at $968, it represents a very powerful and versatile tool. One possible disadvantage is the fact that sand grains may wear down the impellor, though with an application advertised as "irrigation monitoring" this may not be too much of a problem. Another disadvantage is that the monitor requires 240V though I would be surprised if an external battery supply could not be constructed by PAWA fairly easily. If desired, it may be possible that the monitor could be dispensed with and the frequency output of the sensor fed straight to a logger with, perhaps, a little signal conditioning. If so, this would be an extremely cheap flow monitoring option. However I am informed that the monitor's software, by which rotor speed is converted to flow, involves a correction for velocity profile in different pipe sizes; obviously this would not be available if the monitor were bypassed, but it could be done under software control once the data is in a computer.

A note of caution, with respect to both this instrument and the Signet sensors, must be sounded, however. Users of a similar device at James Cook University have claimed that the impellor's ability to rotate becomes diminished with time due to the effects of rust, small particles and human hairs on the bearings. The sensor sold by Combined Instruments endeavours to overcome this problem by employing a "sloppy fit" impellor. They point out that some units have been in continuous use for two years now and no problems have been
reported (though it is unlikely that many users would have tested for calibration drift). Hence if PAWA are interested in a device of this kind it may be worthwhile making further checks on its performance before a decision is made to purchase it.

Great Lakes Instruments manufacture conductivity probes and transmitters. The 3040CIT is a toroidal conductivity sensor incorporating integral automatic temperature compensation to automatically adjust a conductivity reading to a 25°C reference; its measurement range is 0 to 100000 microSiemens/cm. It is worth $559.00. This unit connects, through a 6 conductor cable, to a current transmitter which can interface, through a 4-20 mA current loop, to a data logger. Two types of transmitter are available, a loop-powered version costing $437 and a 240V-powered unit with extra facilities including display costing $996.

Combined instruments market an excellent little data logger called the Rustrak Ranger. This unit is small (hand-held), robust, can be set up without a computer using two keys and a display, and can log up to 4 channels. The display facility can be used for real-time metering of transducer output. Inputs can be 4-20 mA current, voltage, pulsed voltage and others specific to certain types of transducer to which it can be matched to display and download engineering units. The logger downloads to an IBM compatible PC for which downloading and fairly sophisticated data display software is available. This software can also be used for putting logger data into a format appropriate for use by commercial data-handling packages like Lotus 1-2-3 and DBaseII. Cost of the logger plus accessories and software is $2035.

**Supplier**: M.B. & K.J. Davidson Pty. Ltd.
**Phone**: (03) 555 7277
**Contact**: Tanya Curley

Davidson's market a number of items which are of potential use to the current project. They sell two makes of downhole pressure transducer, Data Instruments and Druck. The former transducers cost about the same as Drucks but are about a tenth as accurate. A 0-10m, 4-20 mA Druck downhole transducer sells for $1196.77 including 1m of vented cable; every additional metre of vented cable costs $10.45. As with most pressure transducer families, absolute and gauge transducers are available.

Druck borehole pressure transducers have excellent specifications. Combined non-linearity and hysteresis effects are quoted as 0.1%; temperature induced errors are limited to 0.3% over the entire operating range of -20°C to 60°C. Also the vented cable is advertised as
having a "kerlar strain relieving core" though the length of cable that can be used before extra measures are needed to support the weight of the transducer and cable downhole is not specified.

Of academic interest is a range of DigiQuartz pressure transducers supplied by Davidson's. Unlike most of the pressure transducers discussed in this report which measure pressure by measuring the strain in a diaphragm, these units employ a crystal quartz resonator whose frequency of oscillation varies with pressure-induced stress. They offer an astonishing accuracy of 0.02%! Their price is equally astonishing, beginning at $5000.

Davidson's market Emco flowmeters. Of the brochures that were forwarded to me the device of most interest is the Model MMP-910 Insertion Magnetic Flowmeter. This can be used in any pipe from 3 inches to 80 inches in diameter. It offers a 2% linearity and 0.5% accuracy over a 40 to 1 measurement range; maximum measurable velocity is 6m/sec. A 4-20 mA current output is produced. It costs $7122 for the battery-powered version and $7502 for the line-powered version.

Davidson's are also agents for SFT data loggers; I noticed that PAWA staff had already obtained some information on these units. Tanya Curley suggests that the information may have come from Kinhill, a Sydney company that was collaborating with Davidson's to import these units and then make them under licence to SFT next year. Kinhill have since pulled out of the deal and, at this stage, Davidson's plan to import the loggers next year themselves, and produce them the year after if there is a demand.

It should be noted, however, that some of the data that PAWA has on these loggers in fact pertains to the CTL loggers marketed in Australia by the Centre for Groundwater Management and Hydrogeology; notice from the pertinent brochures that the picture of the SFT PDL200 is in fact identical to that of the CTL2. The reason for this is that SFT is the British agent for CTL and their contract allows SFT to use its name on CTL loggers.

However SFT also makes its own loggers and some brochures are enclosed (it is these which Davidson's will be importing next year). As the brochures demonstrate, these loggers are robust and weatherproof. They can be configured to interface with many different types of transducer, providing an output in engineering units. They can be set up and monitored using a keypad and display built into the logger. They are downloaded to a laptop. However, they are not cheap: a single channel PDL25 (with pulse inputs for flowmeter logging) costs $1577, whereas a PDL27 (a dual channel logger for both flow and pressure recording) costs $1922.
Davidson's are the agents for the Aanderaa range of instruments for remote environmental data logging. Loggers, downhole pressure transducers and temperature sensors are part of the range of products. As the units appear to be expensive I did not trouble Davidson's for a price.

**Supplier:** Dabble Instruments  
**Phone:** (07) 394 1355  
**Contact:** Allan Tyson

Dabble Instruments are agents for Wika. The Wika downhole pressure transmitter for which I was provided with information has very good specifications (linearity 0.1% FS, hysteresis 0.1% FS, temperature effects, about 0.04%/°C). But it costs $2320 for the 0-10m version and the vented cable costs $25/m; hence it must be ruled out of contention.

Another unit provided by Wika for borehole use (which, I am told, is used by the PAWA in Alice Springs; see K. Murphy) costs only $695, with vented cable costing another $9/metre. This also has a 4-20 mA output and can be ordered for a variety of depth ranges. Its accuracy is quoted as 0.5% FS plus 0.1% hysteresis plus 0.02%/°C temperature-effect errors. A more accurate version is available (0.25% plus 0.1% plus 0.1%) costing $900 (plus cable).

**Supplier:** Environdata  
**Phone:** (076) 614699  
**Contact:** Alain Colfs

Environdata build loggers and a suite of sensors for environmental monitoring. Like Monitor equipment (see later), overall power consumption is extremely low and packaging is weatherproof so that equipment can be installed at remote locations and left there for long periods of time (indefinately if solar power is used). The loggers have 12 bit resolution and range from 2 to 16 channels. Input is frequency with a maximum sample rate of 1 sample/minute. The price (in February 1989) varied from $950 for the 2 channel logger to $1870 for the 16 channel version. These loggers are purchased pre-programmed for a particular data acquisition scheme, or the user can set his/her own scheme using IBM compatible software costing another $290. Another program is required for data downloading, this costing $175.

Environdata do not make pressure transducers; they supply Drucks. They can build an interface that will convert the Druck output to frequency for about $120. Their catalogue
includes a conductivity sensor, but I was informed that it is still under development (by another supplier) and that it is probably a two electrode sensor. A barometric sensor is available for $495 while a temperature sensor is available for $185; both have a frequency output.

A request was made for data sheets but none were sent; the above information is gleaned from information sheets already in the possession of the ACTFR.

Supplier: K.D. Fisher & Co. Pty. Ltd.
Phone: (08) 277 3288
Contact: Steve Fisher

K.D. Fisher make Unidata equipment including Starlog data logging systems. As the catalogue shows, they make a wide range of environmental monitoring equipment specifically for these loggers; I am told that this range is still expanding.

Starlog loggers are all multichannel, the 12 bit version (most suitable for the present project) being the model 7000. This has 16 voltage input channels and four counter (i.e. frequency) inputs; units are available with either 64K or 128K of memory. Weatherproof enclosures are available (steel if required). As the logger is built to be adaptable to as wide a range of applications as possible, transducer connections are not via robust plugs but via a field termination unit which can be configured in different ways depending on input signal type. If PAWA purchased a Starlogger they would need to build a more robust junction box preceding the field termination unit in the signal chain.

The field termination unit does allow for design flexibility, however. Resistors can be soldered onto it such that the output from a current transducer can be converted to voltage for subsequent input to the logger. Also, signal conditioning units such as a differential amplifier, a low level thermocouple input amplifier and a Signet flow transducer interface can be soldered to the field termination unit thus becoming part of the system. Like most other loggers, it will communicate with an IBM laptop. The costing of a logging system suitable for the present application is as follows:

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>7000-11 logger</td>
<td>$1398.89</td>
</tr>
<tr>
<td>Field termination strip and frame</td>
<td>$171.00</td>
</tr>
<tr>
<td>Cable to computer</td>
<td>$43.21</td>
</tr>
<tr>
<td>Interface software</td>
<td>$463.79</td>
</tr>
<tr>
<td>Steel weatherproof enclosure</td>
<td>$273.09</td>
</tr>
</tbody>
</table>
The logger is relatively inexpensive. However there are a few disadvantages, none of them overpowering. Because it has a voltage input, and signal conversion from a 4-20 mA output transducer is achieved simply by running the current through a resistor, one fifth of the resolution of the system is lost, as explained earlier; hence use of a 0-20 mA (and hence three-wire) system could be more appropriate. Further, the system cannot be downloaded without terminating the logging sequence and restarting it, though this is not difficult to do; however the system can be checked for correct operation while it continues to log. Also, with its present software the logger does not allow for data compression through storing only if the change from the previous stored value exceeds a certain threshold; with up to 128K memory though, this may not be too much of a disadvantage. The inclusion of counting channels may present an advantage in that some flowmeters provide only a frequency output option.

Mackie Martin in WA have used a Unidata logger in the past for their pump test data acquisition. Their results were mixed. Peter Clifton points out that he was using an earlier model and that the system is probably better now.

Unidata make a downhole pressure transducer with an optional temperature output. At $628.19 (including 15m of vented cable) it is not expensive. However its resolution is quoted at 0.4% and its accuracy over 0 - 50°C is quoted as only 1% (I thus infer a temperature coefficient of a little over 0.01% per oC). This is about half as accurate as Mindata sensors (see later); for a 10m gauge transducer at constant temperature a 4cm error could be expected, compared with 2cm for the Mindata transducer. Also, its output is voltage which is inappropriate for the pumped bore or neighbouring monitoring bores. Note that Unidata also make a barometric pressure instrument for $528.27; it has an accuracy of 1 mbar and a 0 - 2.55V output.

It is noteworthy, though inappropriate for the present exercise, that Unidata sell an impressive bore water level instrument based on the float and pulley principle for a little over $1000. Also available is a rigid capacitance-type water level sensor. With a maximum length of 3m, these units cost up to $753.

Unidata sell a “precision water conductivity instrument” incorporating a toroidal conductivity sensor as well as a linear thermistor temperature sensor. It is configured such that an A/D conversion is made within a signal converter to which the sensors are attached, and the value of conductivity or temperature is displayed as well as transferred digitally to the serial port of a logger. Because of the complexity of this instrument it sells for $2099. It may be worth asking Unidata for a quote on a simpler unit designed to interface directly with whatever logger PAWA opts for, for it looks very good.
Other items of interest from the catalogue are the 6507 temperature probe and the 6512 pressure transmitter. The former costs about $80 and can be used in over 100m depth of water. By its very nature it is a voltage output device. The pressure transmitter also has a voltage output; either gauge or differential forms can be ordered. Its pressure range is such that it could be used to transmit the pressure (difference) from an orifice plate as a record of flow rate. At $400 - $500 it is cheaper than units advertised by most suppliers to do the same job; however it is probably not as well protected against overpressure and would incorporate little damping.

All Unidata equipment is designed to be mutually compatible; all logged transducer outputs are downloaded to a computer in engineering units. The software asks the user during logger initiation what instruments are connected to the logger. Calibration constants stored within the machine are then used to convert transducer voltage or frequency outputs to the units desired by the user.

**Supplier:** Fisher & Porter Pty. Ltd.
**Phone:** (077) 79 3081
**Contact:** Peter Drew

A Fisher and Porter differential pressure transmitter costs $1214. Like most units of this type, span and zero are adjustable. There is an optional output indicator available as well as an optional square root extractor of the output signal.

Magnetic flowmeters are available for pipe sizes between 3 inches and 250 inches. Accuracy is 1% for a measurement range of 10:1 (2% for 20:1) with an option available with twice this accuracy. The converter can be remote or integral; the same converter can be used with flow heads of different diameter. The cost of a 100mm flow head and a standard remote converter with a 4-20 mA output and 240V supply is $3463. If a "smart", microprocessor type converter is used, the total flowmeter cost is $3813. A DC powered option is available.

**Supplier:** Richard Foot Pty. Ltd.
**Phone:** (02) 450 2569
**Contact:** Stan Swatton

I contacted Richard Foot because the name appeared in a directory of manufacturers published by the Australian Hydrographers Association. Having told them of PAWA's needs they informed me that they had nothing suitable. However included with the literature
accompanying this report is a copy of a brochure, from ACTFR files, on a German made logger, the Hydrus, for which Richard Foot is (or was) the agent. Logging of up to 6 input channels is initiated using front panel switches, and most recent values can be displayed on the front panel. Through the use of different analogue cards, it can be interfaced with many different types of sensor; resolution appears to be better than 14 bit. It is robust and weatherproof. However it is expensive ($1825 for a one channel unit without analogue card or interface software), and it is unlikely that customer support will be satisfactory.

Supplier: Geotechnical Systems Australia Pty. Ltd.
Phone: (03) 720 5950
Contact: John Lakeland

Geotechnical Systems manufacture vibrating wire borehole pressure transducers. These transducers have an accuracy of 0.5%, with 0.1% optional; temperature error is less than 0.04% per °C. An attractive feature is that they are cheap (now $250 each plus between $9 and $10 per metre for vented cable). Like silicon strain gauge pressure transducers, they are available for a range of depths.

A disadvantage of the vibrating wire strain gauge pressure transducer is that the wire must be "plucked" by an electrical signal from the logger; frequency of vibration is then measured. The geologger version of the Datataker (see Pacific Data Systems) has this plucking capability, but no other logger that I know of has this function built into it. A possible disadvantage of using this system in a pumped bore is that electrical interference from the pump and power line may upset transmission of both frequency and plucking signals.

Geotechnical Systems also sell piezoresistive strain gauge borehole transducers; these units cost $950. I was sent no specifications for these devices.

Supplier: Insitu

Insitu is an American company based in Wyoming; they have no Australian agents. Geoff Elder of the Rural Water Commission of Victoria has just purchased an Insitu logger. Having combed the world for the ideal pump test data logger he says that this is it. I asked him to forward me some information on the logger but he appears to have forgotten. PAWA staff may wish to contact him themselves for further information. Geoff said he paid about $7000 for the logger.
I notice from the IGWMC publication on pump test software that a company called Instru market pump test software. If it is the same company then the address can be found in that document.

Supplier: Instrument and Industrial Technologies
Phone: (07) 841 1477
Contact: Ian Swift

Instrument and Industrial Technologies market the 'Itabar flow sensor which operates on the same principle as the Rosemount Annubar flow sensor (see later). Like the latter they are inexpensive and flow measurement incurs only a small pressure drop. Accuracy is quoted as 1% and the design is advertised as "non-clog". Prices are about $600 for an 80mm pipe and up to $1400 for a 400mm pipe; to this must be added the cost of a differential pressure transmitter.

An insertion magnetic flowmeter manufactured by Heinrichs is also available. The brochure describing this device is not detailed, but it appears that there are many options to the basic model. It has a 2% accuracy over a measurement range of 40:1. Furthermore the one unit can be used in pipe diameters between 40 and 200mm (or 150 to 1000mm for another unit). The former unit costs $2040, whereas the latter is worth $2760; output in each case is 4-20 mA, though a frequency output is available.

It is not apparent from the brochure whether a display is available; if not, a "percent of full scale" display could easily be constructed by tapping the current loop. It is also not apparent whether flow or velocity is output. If it is the former, and if, as quoted in the brochure, it is "wet calibrated", this implies that each unit can be used for only one pipe diameter if the output signal is to have a known relationship with the flow unless it is calibrated during a pump test against the discharge orifice plate, which presents no difficulty if the response is linear.

Another flowmeter sold by Instrument and Industrial Technologies is an ultrasonic doppler system, made by Greylime Instruments, that mounts on the outside of a pipe of any diameter. Accuracies of 2% are quoted over a measurement range of greater than 100:1. While it would appear to be extremely adaptable because of its external mounting, the specifications indicate that it is factory calibrated to a specified pipe internal diameter. (Again, field calibrations may remove this limitation). Another disadvantage is that, working on the doppler principle, it requires that the water have sufficient impurities to allow ultrasonic reflections; if not, gas bubbles should be introduced. Cost is $2976.
Transit time ultrasonic flowmeters are available, though cost begins at $6000. At the other price extreme, I was told of a low-cost gauge pressure transmitter that could be screwed into a pipe behind a discharge orifice plate; I am still awaiting a price.

Also available from Instrument and Industrial Technologies is a four electrode conductivity probe which connects to a 4-20 mA transmitter. The probe costs about $150 while the transmitter costs around $665; unfortunately the latter requires 240V.

**Supplier:** Kent Instruments Pty. Ltd.  
**Phone:** (077) 72 5575  
**Contact:** Wayne Taylor

Kent Instruments have a Darwin Office: Phone 278 757

Kent Instruments manufacture a range of flow measuring equipment. A Kent Deltapl K Series differential pressure transmitter costs about $1000. This unit has an accuracy of about 0.2%, a continuous span and zero adjustment, an operating pressure range of 15 mbar to 160 mbar and outputs 4-20 mA current; an analogue meter display is optional. This unit can be used in conjunction with a venturi tube, a dall tube or orifice plate. Kent Instruments manufacture these last two items but prices were not sought; however brochures are included.

The Helix 3000R helical vane water meter may be well suited for PAWA's use in monitoring discharge during pump tests. It boasts an accuracy of better than 1% over a flow range of over 100:1 up to continuous flows of 63 l/s (and even higher short term flows) in a 100mm pipe. It can be fitted with a pulse unit that can be fed directly to some loggers (maybe with a little signal conditioning) or it can be connected to a "rate-of-flow indicator" which provides a flow readout in percent as well as a 4-20 mA signal for a logger. Flow can also be determined by timing the revolutions of a circulating needle on the top of the 3000R; a totalizer is also provided. For a 100mm pipe, the 3000R costs $1145 fitted with a pulse unit. The rate-of-flow indicator, which can connect to any size 3000R, costs $1100. It should be noted that this price does not pertain to a Kent rate-of-flow indicator; the Townsville agent recommends another brand as the Kent units are "not competitively priced".

The possibility of damage to the 3000R (or any other impellor or paddlewheel flow measuring device) from sand may be at least partly reduced by bolting an in-line filter upstream at a cost of $224 (for a 100mm pipe). I am informed that 3000R's are installed in bores all over Queensland and that, for a particular unit, the vanes only need to come back to the supplier for maintenance, on average, once every 10 years. As a developed bore will
pump less sand than one undergoing a pump test, this figure probably cannot not be extrapolated to PAWA’s planned use for such an instrument, though it does indicate that damage from sand may not be too much of a problem.

Note that the “Irrigation Meter” displayed in the Kent “Flow Products” catalogue no longer has an analogue flow rate option. However it does have a counter which, together with a stopwatch, will allow for regular, accurate manual samples of flow rate to be taken.

Kent manufacture a range of magnetic flowmeters. The VTC series is for general use and is relatively inexpensive. It can be purchased as a discrete or compact system; in the former case the flow head and signal converter are separated. This series of flowmeters comes in nine sizes from 15mm to 150mm. Accuracy is better than 1% over a 100:1 range; maximum velocity is 10m/s. Output is 4-20 mA current, or voltage pulse (up to 1kHz). No display is available but, as has been mentioned, could easily be constructed by tapping the current loop. The unit requires 240V power; it costs about $2800 for a 100mm pipe.

A particularly apt type of magnetic flowmeter for the present application is the VBC series. With flow head diameters ranging from 50 to 300mm, it is robust and weatherproof, with the flowhead designed for burial. It is also designed for battery operation at low power, battery life being conserved by sampling only at intervals of 1, 5, 10 or 15 minutes (or continuously if desired). Battery life is "in excess of one year from one small submersible 12V alkaline manganese battery". Accuracy is 2% for a 100:1 flow range (up to velocities of 10m/s). Output is frequency (voltage); a digital LCD display shows flow rate or totalisation. The cost, including a 100mm diameter flow head, is $3300.

Kent also make two insertion electromagnetic flowmeters, the VFA and the VPB. These units can be inserted into pipes of 100mm diameter or greater. They are battery operated and, to prolong battery life, the VPB has the capacity for sampling flow at 1, 5, 10 or 15 minute intervals. Accuracy is 2% over a 10:1 flow range up to 3m/s. Output is frequency, voltage or 4-20 mA. Cost is about $6500.

Supplier: Mace
Phone: (02) 638 5166
Contact: Dean Ritossa

Mace’s products are centred on a number of dataloggers which have been built specifically for prolonged use in remote environments. The loggers’ containers are particularly rugged, providing exceptional protection from the elements. The logger that would be of most use to the present project is the Hydromace. This unit will accept input from up to 6 voltage
output transducers and 16 digital output (including frequency) transducers; it will also control 16 digital output lines. It has 16 bit resolution and can communicate with users via telephone, radio or satellite or through a standard RS232 connection to a laptop computer.

The problem is its cost. A two channel unit costs $1600; as well, the communications facility must be purchased at $500, memory must be purchased at $389 and an "external power relay option" costing $200 must be bought to interface with each voltage or current output transducer.

Mace can supply a borehole pressure transducer at $988 plus $20 per metre for cable; they do not make these transducers themselves. They also advertise water quality probes to measure temperature, dissolved oxygen, pH, conductivity, redox and turbidity. A particularly interesting item is their MPP-4 probe assembly: this is a "low power portable and easily maintained head incorporating the four most useful water quality probes: dissolved oxygen, pH, temperature, and electrolytic conductivity". On inquiry I was told that this is an English instrument and that they would ascertain the price for me; I have not heard back yet.

Supplier: Mindata
Phone: (03) 785 3777
Contact: Tony Jarvis, Lawrie Opperman

Mindata are an Australian company which make a range of sensors, loggers and communications equipment. They have recently taken over Southern Cross, who also made hydrological monitoring and recording equipment.

Mindata manufacture rigid capacitance water level sensors, the longest of which is 2m; it is therefore not suitable for pump test use. It is worthy of note, though, that they quote a linearity of better than 0.25% FS, a resolution of better than 0.02% FS and a water temperature effect of less than 0.02% FS per °C. It is most suitably employed in measuring water levels in creeks and tanks.

Mindata produces silicon strain gauge pressure transmitters, the 1200 series. These units are ideally suited for borehole applications. They have a 4-20 mA output, an outside diameter of only 21mm, a linearity of 0.2% FS (0.1% FS if specified) a repeatability of less than 0.1% FS and a temperature induced error of less than 0.01% per °C. Units can be purchased which measure gauge or absolute pressure over water depth ranges of 1.0m up to 500m; if a gauge unit is chosen, vented cable is provided. The transmitter costs $950; vented cable costs $7.50 per metre while unvented cable costs $2.25 per metre. Recognizing the prohibitive cost of great lengths of vented cable, Mindata say that they are
prepared to construct cable joiners by which vented cable can be joined to unvented cable at some location above the water level if a gauge transducer is chosen. This would result in a dramatic cost reduction where water levels are deep; they quote $150 for each such PVC junction box. Alternatively, if absolute sensors are employed, they will supply a barometric sensor for $950. This unit has an accuracy of 1 mbar (about 1 cm of water).

Mindata pressure sensors have a good reputation around Australia, being preferred over Drucks by an ever-increasing number of institutions. They are cheaper and their specifications are nearly as good. A contributor to their present high regard in comparison to Druck may be the trouble that Druck has had with inefficient cable venting.

Mindata sell two kinds of loggers, viz. the Southern Cross Watermaster and the Mindata Model 2000. These units are similar though the latter appears more useful in the present context as it is housed in a more robust container that can be placed inside the casing of a sufficiently wide borehole if desired. Also, the software is more specific to water level monitoring. It comes in versions with up to four channels. For one or two channel units, physical interface with the transducer cable is through robust metal plugs. It is unclear what is done with 4 channel units as there is not enough room for four plugs; perhaps a junction box can be used. In any case Mindata can customize a container to suit a particular application.

The loggers record in 12 bits and have the capacity to conserve memory by sampling only if a sufficient transducer output change has taken place, thus saving memory. The logger is accessed through an IBM compatible computer, including a laptop; it can be downloaded without affecting logging. Borehole pressure transducers are precalibrated, but to make up for possible changes in calibration offset, the user is asked the water level at the time of transducer installation. Heads (though not drawdowns) are transferred to the computer relative to this value in engineering units. The logger is capable of supplying power to any connected 4-20 mA devices from its own internal batteries; these latter may have to be supplemented if there are many transducers and the sampling interval is short. A four channel logger with 32K memory and an internal, rechargeable battery costs $950; a battery charger, RS232 cable and terminal software cost another $210. For big orders, prices may be open to negotiation.

Mindata are about to release a suite of water quality monitoring sensors. Sensors will include temperature, pH, electrical conductivity, DO2, turbidity and redox. For electrical conductivity, two choices of sensor will be available, viz. platinum electrode (they don't say in their brochure whether this will be two electrode or four electrode) and "magnetic domain" (toroidal, I assume). Prices are not yet available. If requested Mindata also
produce a temperature sensor which can be placed down a borehole. The sensor is mounted in a container identical to that holding their pressure sensors; uphole signal transmission is 4-20 mA. I could not get an exact price but I am told that it will be of the order of a few hundred dollars.

**Supplier:** Monitor Sensors  
**Phone:** (071) 95 7222  
**Contact:** James Vale

Monitor Sensors specialize in environmental monitoring; they are developing a suite of low-cost but good quality products for the sensing and long term logging of environmentally useful information. They do not make submersible pressure transducers; they use Mindata's instead if an application requiring them arises. However they do make a solar-powered bubbler water level sensor for just over $1600. They also manufacture capacitance water level sensors to a maximum length of 2 metres costing up to $417; output is frequency.

Monitor manufacture 4 channel, 8 channel and 16 channel data loggers. These have 12 bit resolution, consume very little power and require a frequency input. The 4 channel model costs $834. The 'fast interface' version costs $995; it is possible that this would be more appropriate for the present project. A voltage to frequency converter is necessary to interface with a transducer which supplies voltage or current; this costs $313.

Two other items manufactured by monitor that are relevant to the present project are their temperature sensors ($169) and their barometric sensor ($830); both these devices have a frequency output. Next year a salinity sensor will be available. They are currently developing, in partnership with Queensland Water Resources Commission, an advanced water quality and water movement monitoring system suitable for remote locations and for low maintenance operation.

**Supplier:** Pacific Data Systems Pty. Ltd.  
**Phone:** (07) 391 5077  
**Contact:** George Porter

Pacific Data Systems are one of a number of sellers of the truly remarkable, Australian made, Datataker. The Datataker is a battery powered 13 bit logger with 52 input channels. 46 of these channels are analogue and can be configured to be 23 differential input channels if desired. Each can be configured to accept voltage or current, or to be matched
to certain types of strain or temperature sensors. Digital input channels will read frequency, period, or digital encoded information.

Communication with the Datataker is achieved through the use of any computer that has an RS232 interface. Through the use of a number of simple commands, the device can be programmed to undertake quite complex data capture routines. Because some of these commands can involve decision-making based on the values of digital inputs, the logger could be programmed to be operated in the field by means of user-constructed panel switches if desired. The construction of such a "control box" would be further aided by the fact that the Datataker has 2 analogue outputs and 8 digital output lines.

The amazing versatility of the Datataker allows for its connection, with the minimum of interfacing, to any of the sensors described in this entire section. Furthermore, I am informed by a user of this logger that it allows downloading of data to a computer without interruption of the logging sequence, this being a rarity among cheap data loggers.

The strength of the Datataker may also be its weakness in the present context. Should PAWA purchase a Datataker they will be able to incorporate it into any pump test (or other) data acquisition system that they build. With a little programming the system can be adjusted at any time and the Datataker simply re-configured. However this flexibility means that operator skill may need to be higher than for the more dedicated loggers described elsewhere in this section. Also some hardware in the form of robust connectors may need to be installed in a weatherproof case that can enclose the logger.

The basic Datataker costs $2400. A field version is available for $3000 while the Geologger, a field version incorporating an interface with vibrating wire pressure transducers, also costs $3000. To this must be added the cost of some accessories and software - a few hundred dollars. I am informed that a 10 channel version of the Datataker will be available in January next year costing about $2200. In February or March a 4 channel version will be released which will probably cost between $1600 and $1800.

Two powerful programs are available for facilitating communications with the Datataker and for plotting data (screen or hardcopy). One is DECIPHER, a terminal, graphing, reporting and file handling program developed specifically for the Datataker. The other is Labtech NOTEBOOK, a version of this versatile data handling program having been written especially for the Datataker. NOTEBOOK has powerful plotting routines, and is even able to carry out mathematical inversion to fit an arbitrarily complex model (up to 10 parameters and 10 independent variables) to the collected data. It can also perform real time data analysis. A disadvantage in the pump test context is that the present version does not
allow time to be plotted logarithmically, or so I am told by Ron Bulna, from the Western Australian Mines Department who uses it in his real-time data acquisition system, as explained earlier. DECIPHER costs $195 while Labtech NOTEBOOK costs $1565.

**Supplier:** Rosemount Instruments Pty. Ltd.

**Phone:** (07) 262 8577

**Contact:** Mark Poli

Rosemount have a Darwin Office: Phone 853 753

Rosemount’s range of products include instruments that may be useful in the present project for flow and water quality monitoring.

Of the many options available for measuring and monitoring flow, that which involves least departure from the method presently employed by the PAWA, is to put a tap behind a discharge orifice plate, connect to a pressure transmitter and log the 4-20 mA output of that transmitter. The Rosemount model 1151GP Alphaline pressure transmitter, costing $1054, would be a suitable device for this purpose. An optional analogue indicator can be purchased as well; I believe this costs between $100 and $200. The unit is factory calibrated, though span and zero are continuously adjustable externally. Accuracy is 0.25% of calibrated span, though the overall level of inaccuracy in this flow-measurement system would be determined by uncertainties related to the use of an orifice plate at the point of discharge.

Greater accuracy can be achieved with an in-line orifice plate and a differential pressure cell. Here the model 1151DP transmitter would be suitable. It costs $1140 without an indicator and $1269 with an indicator. Note that the indicator for the 1151DP, does not show flow; it shows pressure difference in percent of full scale.

Rosemount market annubar flow sensors. A small, diamond-shaped tube is emplaced vertically along the pipe diameter. The difference between upstream and downstream pressures along this cylinder (tapped by small diameter ports) is proportional to the square of the flow rate. Accuracy is 1% over a measurement range of greater than 10:1. A device suitable for a 4 inch pipe costs about $1000; the cost of a differential pressure cell would need to be added to this.

Rosemount magnetic flowmeters are purchased as a flowtube and transmitter. The former is available in pipe sizes of 1/2 inch to 8 inches, with a 4 inch unit costing $2255. The transmitter can be connected to any diameter flowtube. Two types of transmitter are available viz. the 8712 and 8722. The latter provides a 1% accuracy over a 10:1
measurement range (20:1 for a 2% accuracy) and includes an analogue display of flow in percent of full scale; flow velocities of up to 10 m/s can be measured. The 8712 is a "smart" transmitter with a measurement range of 30 to 1 for a 0.5% accuracy (120:1 at 2% accuracy). It includes an LCD display of flow rate in user selectable units. Both of these units can be powered by battery if desired, but because of their 15W power consumption, 240V power would be more suitable, unless they were wired to be switched on only when required by the logger.

For conductivity measurement, an attractive system is the Rosemount model 224 toroidal sensor in conjunction with the 1181T transmitter. The system is DC battery powered, has a 4-20 mA output and promises an accuracy of 0.5% FS. It includes a built-in 0-4% temperature slope adjustment and a digital or analogue display. Cost is $820 for the toroid and $1573 for the transmitter.

A two-electrode screw-in conductivity sensor is also available, costing $405; it connects to a transmitter costing $1573.

**Supplier:** Systems Design Services  
**Phone:** (08) 362 8740

Systems Design Services make and sell the Torrens data logger, as well as a range of environmental sensors. The Torrens data logger was designed for semipermanent on-site installation in remote areas and can be equipped for satellite or telephone data downloading; in the latter case a synthesised voice message can be provided to indicate the state of the station. Data storage is provided in EPROM, EEPROM or RAM memory modules. RAM modules are battery backed-up and can be remotely erased. EPROM modules must be manually changed before storage space is filled because once data is written to EPROM they can only be erased by UV light. EEPROM modules offer the advantages of EPROM modules but they can be remotely erased like RAM modules. The logger is extremely robust and is supplied with software that allows for easy communications with the user.

The basic unit costs $2950; this includes a shaft encoder input, rain gauge input, MPU, 64K EPROM, technical reference manual, I/O connection to field test unit, solar regulator and EPROM programmer. To interface with analogue inputs of the type supplied by pressure transducers, a 4 channel A/D board would need to be added to this, costing $500 or $750 depending on whether 14 bit or 16 bit resolution was required; the latter unit also
has a military specification voltage reference. In addition some connectors are required; military specification connectors costing $120-$180 are recommended but this may be a little indulgent.

It is of interest to note that Systems Design Services make a very useful data editor. This can be used not only for actually retrieving data from the Torrens data storage module, but also for screen-based correction and editing of the data. Its use is not restricted to data gathered by the Torrens logger; if the output of any other logger is put into a suitable format, then that data, too, can be handled in the same way.

Supplier: Westdata
Phone: (09) 470 2991
Contact: Jeff Smith

Westdata of Western Australia make a range of logging and sensing equipment that is astonishing for its cheapness. Although some of their equipment has a "home-made" appearance (components are often housed in PVC piping) it is gaining increasing use and is generally well spoken of. Westdata are eager to see their equipment used in new situations and are willing to customize or alter units for specific purposes. As mentioned previously, they have collaborated with the Western Australia Mines Department to construct a pump test data acquisition system which includes real-time display.

Westdata make a number of loggers; the range is increasing all the time. The model 888 can accept 8 analogue inputs and 8 digital inputs, the latter being usable for measurement of frequency or period; the analogue channel resolution is 16 bits. The unit includes a LCD display and keypad so that logging can be initiated without using a computer. Data can be downloaded onto a computer using Westdata software. Cost of the 888 is $940.

A single channel logger is available - the 389; this accepts only frequency inputs. The 389 measures either the frequency or period of an input signal; in the latter case the logger counts its own signal gated by the input signal. The 389 cannot accept a voltage signal directly. As transducer input frequencies may be as high as 32000 Hz, sampling rates for "frequency transducers" are high - as good as 1 per second. For "period transducers" maximum achievable sample rate is about 1 sample per 15 seconds. It should be noted that Westdata capacitance water level transducers are of the former type whereas pressure water level transducers are of the latter type. If it is required that the 389 log voltage, then a voltage-to-frequency converter can be provided for about $40. If it has to log current, the latter can be converted to voltage using a resistor at the input. The 389 costs $216. Unlike the 888, logging is initiated with a computer or 891 field terminal (see below).
Westdata will soon be releasing a 4 channel logger costing about $200; like the 389 it will accept frequency input to each channel.

A useful innovation of Westdata's is the 891 hand-held field terminal. This allows the user to initiate and download up to five 389s; the 891 is then downloaded itself into a computer (e.g. a laptop). Costing $660, it is a far more convenient way to visit a number of field stations than by carrying a laptop to each one.

Unfortunately Westdata logger software is such that loggers cannot be downloaded without halting and then restarting the logger. However this is not too difficult, especially with the 891. Also, it is not possible to inspect the current transducer output, a feature common to many other loggers. Jeff Smith says that this facility could be programmed into the system with little difficulty and so could be ordered if desired. Westdata software does have a data compression facility in that the logger can be asked not to store a sampled value if it has not changed sufficiently from the previously sampled value.

Westdata make a range of transducers, some of which are suitable for the present application. They produce gauge or absolute pressure transducers having an accuracy of something greater than 0.15% FS; temperature effects are not quoted. Like the single channel loggers, these are housed in PVC pipe. They have a frequency output and the logger measures the period of this signal; hence sampling time is about 15 sec minimum. Vented cable costs $1.68 per metre. Because it is two-wire cable and their transducer requires 3 wires (ground, signal, power), the logger must be joined physically to the sensor down the hole. Hence the pressure transducer logger combination is waterproof the two being joined by a screw-type O-ring seal. The vented cable emerges from the logger (housed in small diameter PVC tubing so that it can fit down a borehole) by way of a waterproof gland. The wires within the cable allow for serial communication with the logger from the surface; the logger can be initiated, halted and downloaded while still in the hole.

A present shortcoming of Westdata hardware is that the 891 field terminal will not communicate with any logger through coaxial cable; unfortunately the vented cable is coaxial. Hence communication with the downhole logger must be via a laptop. Jeff Smith says that this shortcoming is soon to be rectified. Also on the Westdata drawing board is a small device for plugging into the uphole end of the cable for inspecting logger status and the last reading taken. In this manner proper operation of the downhole system can be checked intermittently.
Westdata also make capacitive water level sensors which include the longest commercially available (up to 6m). Unlike sensors produced by other companies, the longer ones are flexible so that they can be rolled up before and after use; the 6m probes cost $147. Again, these devices produce a frequency output. Their resolution is quoted as 0.3mm, though if they touch the side of the borehole this will be degraded because of the existence of a film of water, produced by capillary action, between the teflon tube and the side of the hole. Also, any dirt and encrustations on the teflon will likewise degrade performance because of the enhanced probability of moisture retention; users of this device quote an accuracy of 2cm. Western Australia Mines Department are using these capacitance sensors down some of their observation bores as part of their pump test data acquisition system.

Westdata make a salinity probe, a four electrode conductivity device costing $170. I am informed that there were some problems with this when used in estuarine environments due to encrustations on electrodes. Anti-fouling paint was then tried and proved a deterrent to all forms of contamination except "things that crawl". As the latter are unlikely to be a problem in the present context these devices may be useful, though the cell constant may need to be varied to better suit groundwater conditions. Westdata have just received a delivery of toroids and are about to explore the possibility of using toroidal sensors.

Westdata make a submersible temperature sensor worth $45. They also manufacture a barometric sensor, with a quoted resolution of 0.05 mbars, costing $155.

The ACTFR has recently acquired a range of Westdata equipment including 389 loggers, an 891 field terminal, some 10m pressure transducers, some 6m capacitance water level sensors, a temperature probe and some other environmental sensors. At the time of writing the system has only just been deployed in the field and the ACTFR will be pleased to report to the PAWA on its performance; so far the only problems have been (i) excessive delivery time for the transducers, a problem that Jeff Smith attributes to his suppliers of semiconductor strain gauge chips, and (ii) a faulty 389 logger which was replaced immediately. Note, however, that we also have a more expensive Mindata logger and this had to be replaced as well. Similar stories from other users of inexpensive logging equipment abound.

Westdata equipment stands out from the crowd because of its low price. Service is good and the company personnel are always willing to innovate. A nagging worry, though, is how long Westdata equipment will last compared to the more expensive equipment manufactured by its opposition. Only time will tell; I have spoken to a number of Westdata users and none have complained of premature equipment failure. Also, it must be
remembered that in the pump test context accidents can happen to any equipment, whether cheap or expensive; less tears are shed over the breakage of an inexpensive item than an expensive one.
RECOMMENDATIONS

There are many decisions to make in putting together a system for pump test data acquisition. These decisions must be made by PAWA personnel based on the information contained in this report and the accompanying product brochures. This section contains a description of my own leanings based on my present knowledge of field conditions to be expected by PAWA pump test staff. Obviously, those who have experienced these conditions, and who are aware of the many other constraints on these decisions, may wish to review these recommendations.

It should be pointed out that those around Australia with whom I have discussed pump test data acquisition and who have systems of their own, stress the experimental nature of setting up such a system. No system is perfect, and as they gain more experience and different pieces of equipment come onto the market, their perceptions of what constitutes the best system changes. As these perceptions differ from person to person, a large part of the choice of system components seems to be intuition, or previous experience with a particular piece of equipment. The decisions that PAWA staff must make on what to buy in order to automate their data acquisition must be considered in this light. Though decisions should be as well-informed as possible, a decision will only have been proved to be correct after the resulting system has been successfully operational for some time.

Water Level Sensors

The choice here is between pressure transducers and capacitance water level sensors. Obviously, as the longest of the latter items is only 6m, pressure transducers must be used in the pumped bore and close observation bores. Although capacitance sensors have, on paper, a better accuracy than pressure transducers, in practice the performance of the flexible ones which would be used downhole is degraded by dirt, deposits on the teflon tube and the possibility of touching the side of the hole; the latter phenomenon will become a greater problem in deeper holes. Also, their performance is affected by casing. Although Westdata (the makers of the flexible sensors) assure me that the calibration offset and not the scaling if affected, problems could arise if the water level falls through a casing collar or a reduction in casing diameter. Because of all these drawbacks, I prefer to use pressure transducers in all bores.

Gauge or Absolute

If the conditions encountered by PAWA staff were such that the water table was never more than 10m deep, and drawdowns would never exceed 20m, then I would recommend that
gauge transducers and vented cable be employed. Indeed this is the option chosen by most pump test practitioners and PAWA staff may consider that a system should be set up specifically for these conditions if they are common enough. However, with water depths as great as 110m, and, even for shallow water depths, with drawdowns over 30m not uncommon, I have been warned often enough about the problems associated with inefficient cable venting (either on its own or through heating of the cable or damage to it) to conclude that a gauge pressure transducer cannot be guaranteed to work in such conditions every time it is employed. Besides this, the cost of vented cable will become excessive unless a mechanism is set up to vent it down the hole and use unvented cable the rest of the way to the surface. However such a downhole vent cannot be guaranteed never to clog and, where large drawdowns are expected (for example 50m), vented cable length may still be unacceptably large. Hence I recommend that absolute pressure transducers be employed.

As was discussed earlier, the penalties in using absolute sensors are that a barometer must be purchased, software must be written to correct readings, and system accuracy will be cut by a factor of, at most, 2.

**Centralized or Decentralized Logging**

Here the choice is between a single logger with a large number of channels which collects water level information from all the bores as well as flow rate and water quality information, or a system comprising a number of loggers located at strategic sites such that transmission cable lengths are kept short. I prefer the latter system for a number of reasons. Firstly communications to distant observation bores are certain to be broken often by vehicles, animals and people. Secondly, although some multichannel loggers are cheaper than a number of single channel loggers (here, too, it depends on the make), signal transmission would need to be by current if multichannel loggers were used. As only the more expensive downhole transducers are able to transmit current, these would need to be employed, or an uphole transmitter would become necessary to convert a frequency or voltage signal provided by a cheaper transducer to current for transmission to the logging site. In either case the cost advantage of a centralized system would be diminished. A disadvantage of the decentralized system is that increased software complexity may be necessary to collate all the data, but this is, in principle, not difficult and does not, in my opinion, outweigh the advantages of decentralized logging.


**Signal Transmission**

There is no doubt that the pumped bore pressure transducer should not transmit its signal uphole using analogue or frequency modulated voltage because of the probability of electrical interference. The 4-20 mA current loop will probably work though it is suggested that the PAWA experiment with the ACTFR's Mindata system before accepting this conclusion as fact. If a 4-20 mA current loop is not immune to interference then some innovative thinking will be called for as there are no better alternatives on the market.

Frequency transmission would probably be satisfactory for monitoring pressure transducer output in observation bores, with some reservations if power lines are nearby. For the Westdata system, where logger and transducer are mounted together down the hole, it is considered unlikely that there will be electrical interference, for the frequency transmission is over a distance of about an inch.

If the flowmeter is sufficiently far from the pump and if the link between it and its logger is short, frequency transmission would probably be alright, though 4-20 mA transmission would be safer. The same holds for temperature and water quality monitors, though here there seems to be little choice. Even for those industrial type systems discussed in the previous section that have a 4-20 mA transmitter into which the sensor plugs, the link between the sensor and the transmitter will not be current loop with the sole exception of the Mindata temperature sensor. Hence all sensors except this latter one cannot be placed down the pumped bore, and the link between them and the logger, or possibly a current transmitter, should be kept short.

**Pressure Transducer Type**

I suggest Mindata pressure transducers for the pumped bore and the close observation bore. These units are accurate (though not quite as accurate as Drucks), and can be obtained as absolute transducers for ranges 0-20m (i.e. about 0-10m water depth), 0-50m (i.e. about 0-40m water depth), 0-100m (i.e. about 0-90m water depth) as well as other ranges. They are slightly cheaper than Druck units and, being Australian made, there should be help available should any problems be encountered. Also, I am informed that Drucks come with a metre of vented cable whether or not the element is gauge or absolute; hence a way would have to be found of joining this vented cable to unvented cable (if an absolute system were chosen) without permitting any electrical current or water leakage at the join.
For more distant observation bores I suggest that the much cheaper Westdata transducers together with their submersible loggers be used. The specifications are good, the cost is very low and electrical interference should not be a problem. The disadvantages of this alternative will be discussed below under "loggers".

It should be noted that with the use of Westdata systems down the observation holes the case against gauge sensors is not so strong. This is because Westdata vented cable is very cheap ($1.68 per metre) and better vented than most; also it is only slightly thicker than their unvented cable and hence only marginally more cumbersome. In this case cable cheapness does not cause problems with signal quality because the signal is digital and hence, while moisture ingress may affect its amplitude, it will not affect its "message" unless moisture ingress is excessive.

**Flowmeter**

It is probable that PAWA staff are in a better position to make this choice than I am because of their greater experience in flow measurement within the pump test context.

With some reservations I suggest using the Signet 8500 paddlewheel flowmeter. The main advantages of this unit are that it is cheap, appears to be quite robust, is battery powered and transmits 4-20 mA current. Also, a particular sensor can be used on a variety of pipe sizes though, unfortunately, no one sensor can be used across the entire range of pipe sizes employed by the PAWA (ranges are 1/2 - 4 inches, 5-8 inches and 10-up inches). The disadvantages of this instrument are the possibility of abrasion of the paddlewheel, the possibility of bearing deterioration, and the fact that the measuring range is only 20:1 in a particular flow setting. If this instrument were used, it would be important that discharge orifice plate manometer readings be intermittently recorded for both in-test calibration of the flowmeter, and to monitor any change in the latter's characteristics, over time.

If this alternative is not chosen then I would consider further the Great Lakes Instruments insertion paddlewheel sensor marketed by Combined Instruments, the Kent 3000R helical vane flowmeter (with or without the rate-of-flow indicator), the Signet "Mighty Mag" magnetic flowmeter or the Kent VBC magnetic flowmeter. Again, whatever instrument is chosen, the discharge orifice plate should be retained in case of flowmeter malfunction and as a check on flowmeter calibration. Also, depending on the type of flowmeter chosen, it may be desirable to adjust the span and zero of the electrical output as soon as the pump is switched on so that the logger is able to record flow rate variations with a high resolution. If this is the case, the manometer may be needed to set flow rate correctly upon the pump being switched on.
**Water Quality and Temperature**

The cheapest alternative here is to place a Westdata temperature and conductivity sensor in the drum or some other containment into which the water discharges prior to flowing away through a channel or irrigation fluming. As the electrical output of the Westdata temperature sensor is frequency, the logger to which it is connected would need to be closeby; also, the water container should be well removed from the pump and its power cables. For the conductivity sensor, a Westdata four electrode or toroidal sensor (if in production) should be considered; if these are not optimized to groundwater conductivities, I am sure that Westdata would be happy to make the necessary adjustments.

In a situation where greater temperature accuracy is desired, or where it may be desirable to monitor flow from different aquifers into a pumped bore (requiring perhaps multiple temperature probes) then a Mindata downhole temperature sensor is suggested, this being the only unit available that will transmit current.

**Loggers**

It is suggested that a 4 channel Mindata logger be employed to receive signals from pressure transducers in the pumped bore and the closest observation bore. The other two channels could be used for different purposes at different times. For example one channel could be used for monitoring water level in another close observation bore. One may be used for monitoring temperature through a Mindata downhole probe, or it may be used for monitoring flow rate by receiving the flowmeter signal. The Mindata logger is well priced, can supply power to 4-20 mA transducers from its own power supply (which can be supplemented by an external supply), its logging status and the current transducer readings can be inspected using a laptop at any time, and the logger can be downloaded without affecting logging operations so that results up until a certain time can be plotted and inspected whenever desired. For a simple pump test set-up involving the monitoring and recording of water levels in up to three bores, together with the recording of flowrate, only this one logger would be required, as long as barometric correction was not required or was done under software control through manual reading of a barometer. Alternatively, a Mindata barometer could be purchased and plugged into one logger channel; see below.

As mentioned, the Mindata logger can provide power to downhole pressure (and temperature) transducers. Where a 4-20 mA device is supplying its own power (as will probably be the case with the flowmeter), there will need to be correct interfacing between the two. This matter will have to be discussed with Mindata if this option is chosen; it
should be possible, with many of the flowmeters described, for the logger to switch them on prior to sampling thus conserving flowmeter power. Another matter which needs to be discussed with Mindata is software flexibility for allowing different types of transducer (e.g. pressure, temperature, flow and possibly barometric) to plug into the logger at different times.

In more complex pump test situations where there are observation bores further afield it is suggested that Westdata submersible loggers be used. These have the advantage that they are cheap; this is a big advantage if there are many observation bores. They have the disadvantage that logging must be halted before downloading can take place, but, in the course of a pump test, it may be more important that the response of the pumped and close observation bores be closely monitored and intermittently plotted than that of the observation bores: it should be noted however that it is not difficult to halt, download, and then restart Westdata loggers. Another disadvantage is that, with the present state of Westdata equipment, the 891 field terminal cannot be used to start and stop logging and gather data. I suggest that, as it has been promised that this is about to be changed, Westdata be asked to include this change in any equipment they supply us. It would also be worthwhile encouraging them to speed up development of the promised hand-held unit for monitoring status and latest transducer reading of the downhole loggers. While neither the 891 nor the status monitor are essential, communication being possible in the equipment's present state by using a laptop, depreciation of the latter could be minimized by the use of a field terminal.

For temperature and water quality monitoring it is suggested that a Westdata multichannel logger be employed, preferably the soon to be developed four channel logger. The reasons for this are (i) it would interface with the cheap Westdata temperature and conductivity probes, (ii) these loggers are inexpensive, and (iii) three brands of logger on the one site may present disadvantages in terms of user training, software construction and manufacturer back-up. Some suitable container for the logger incorporating connection plugs may have to be constructed.

Another possibility which is worth considering is to allow a Westdata logger to interface with a frequency output flowmeter; this could be either a dedicated single channel unit or the same one that is being used to record water temperature and conductivity. A significant cost reduction in many types of the flowmeter can be achieved if a current output is not required and a pulse output is provided instead. For example, the Signet Rotor-X flow sensing element could be used instead of the 8500, or a Kent 3000R would not require a rate-of-flow meter. In these cases the flowmeter output could be frequency divided to a level
where very accurate measurements of period (and hence flow) could be made with a Westdata 389 logger operating in the period mode.

**Barometer**

A Westdata barometric sensor connected either to a single channel Westdata logger or to the multichannel logger monitoring water properties would be cheaper than, and as accurate as, any other alternative for barometric recording. Alternatively, if PAWA staff foresee that pump tests involving a pumped bore and only a single observation bore will be a common occurrence they may wish to purchase a Mindata barometric sensor. While this alternative is more expensive, it will allow for the use of only one logger in this simplest of pump test setups (the 4th channel would monitor the 4-20 mA output of a flowmeter).

**Software**

The system suggested above is modular and hence can be as simple or complex as the occasion demands. It is designed to be as easy to install and use as possible while preserving accuracy, flexibility and cost.

A set of software will need to be written to allow for information from all parts of the system described above to be pooled into a coherent form suitable for plotting and mathematical analysis. It is not intended to discuss the software details in this report, though its capabilities will need to include some of the following features. Assuming that the system is as outlined above:

1. both Mindata and Westdata logging outputs will need to be read;
2. if Westdata loggers are downloaded and restarted, subsequent logger records will need to be joined into a single record pertaining to one hole;
3. if a transducer is moved down during a test to accommodate greater-than-expected drawdown, this shift in logger readings (either Mindata or Westdata) will need to be corrected for;
4. data gathered up until a specific time should be able to be plotted for inspection, with the responses of a number of bores being plottable on the same graph;
5. water levels taken manually or flowrates measured with the discharge orifice plate should be usable for transducer or flowmeter output calibration.
A Comment

The hardware recommendations made above are based on information supplied in manufacturers' brochures and by manufacturers themselves, or their agents, during telephone conservations. When it is decided to proceed with the purchase of the abovementioned, or any other, items more detailed inquiries will need to be made to confirm information and prices supplied herein and to solicit any other information required for complete system design prior to purchase. The above recommendations are thus made subject to a favourable outcome to these further inquiries.

OTHER CONSIDERATIONS

Transducer Calibration

For many loggers, the transducer current or frequency readings are converted to head or drawdown as the data stored in the logger is downloaded; the transducer calibration constants (which may vary slightly from transducer to transducer) are stored in a file on the downloading computer. In the case of the Mindata logger, I gather that the calibration slope is assumed invariant and the effect of offset variation from unit to unit is allowed for by enquiring of the user the water height (according to any datum) when the transducer is installed; all logger outputs are then appropriately adjusted. In the Westdata case, the transducer can be entirely re-calibrated each time it is installed, for both slope and offset.

Transducer calibration drift can be monitored by comparing logger output with manually measured water depths. In fact if this latter information is taken while a pump test is underway, then the transducer can be calibrated against drawdown in the course of each pump test. Hence an operator procedure that allows for the measurement of water levels in all bores before a pump test begins, then just before the pump is switched off and again just before the transducers are removed from the hole, will provide enough information to ensure that, provided transducer linearity is according to specifications, the logger-recorded water levels are correct in spite of any possible drift in the transducer calibration constants over time. Naturally, the facility for using manually-gathered water levels for such continuous transducer calibration will need to be built into the software.

It may be of interest to PAWA staff to know that the ACTFR has a transducer calibration facility for water depths of up to 10 metres. This has been found useful in monitoring transducer and logger performance as well as in checking linearity specifications.
Flowmeter Calibration

Many users of flowmeters treat their specifications with suspicion. Furthermore, especially with mechanical meters, wear of moving parts may affect accuracy. Hence, as mentioned above, it is strongly suggested that the orifice plate and manometer be retained on any system PAWA use for discharge of pumped water. This will allow a continuous check to be made on flowmeter performance and to monitor any changes that it may undergo from pump test to pump test.

If PAWA do not have their own flowmeter calibration facilities it may be of interest to them to know that the ACTFR possess calibration facilities for flow rates of up to nearly 100 l/s.

Computers

A data logger needs to download its data into a computer. Most environmental loggers are battery powered and consume very little current so that they can stay operational for long periods. Many have the capacity to withhold the contents of their memory even after the batteries have failed either because data is stored in EPROM or in lithium battery backed RAM. Hence loggers can be brought back to the office for downloading after their deployment is complete.

PAWA personnel have indicated that they would like to process at least some of their pump test data in the field. Hence a field computer will be necessary both for logger (or field terminal) downloading and for data plotting and processing. For field downloading purposes it would be best if the computer were battery-powered. Some form of laptop is the obvious choice; these normally have internal batteries which will keep them going for about five hours. For processing, a computer of at least XT power with a hard disk would be advisable. If 240V power is available at the campsite whenever this computer is likely to be used, this machine does not need to be a laptop. It should be noted that power line conditioning may be required to filter out spikes on the line feeding the computer from the generator. A suitable unit is the Arlec CUS 80250 costing $157.25 (wholesale) though there are many other similar devices around.

A savings in cost could be achieved if the processing and downloading computer were one and the same; laptops are available with hard disks and XT (even AT) power. However as I have left the task of costing and assessing computer requirements to the PAWA, I do not know how great is the price advantage of a single XT laptop with hard disk over a PC single-floppy-disk laptop plus an XT or AT transportable computer with hard disk. If the price difference is not too great then I would lean toward having the two computers; if the laptop
broke down the central logger could still be downloaded into the other computer in an emergency, as there will normally be power at the pumpsite. Also, as the computer used for field downloading of loggers may be subject to some rough treatment and exposure to the possibility of accidental damage, it may be cost-effective in the long term if this machine were as inexpensive as possible.