Salinity Control using Air Displacement Pumps at Lake Toolibin

The contents and specifications herin are subject to change without prior notice

Contents

More information can be found on our website: www.airwellpumps.com

Air Displacement Pumping:

There are many ways of moving water from one spot to another, using a variety of energy sources to power them. In an ideal application electrical power would be conveniently located to the water source, and the water itself would be clean, pure and available in copious quantities. Unfortunately this is not always the 'real world' scenario, hence the development of alternative methods. Compressed air is a particularly useful means of transferring energy. Air can be compressed at an existing power source, and carried long distances through MDPE polyethylene pipe with little loss of pressure, saving costly power installation at the bore head, whilst allowing the compressor to be used for multiple pumps, or other local purposes. The development of the air displacement pumping method has enabled many industries to utilise water sources that are distant from electrical power, those that are low producing or contaminated, or a combination of all.

An air displacement pump does not run at high pressure, and operates by completing a fill/empty cycle, whereby a submerged vessel is allowed to fill with water and then pressurised with air to push the water away. No buckets or pistons are required, as the pumping is achieved by compressed air acting directly upon the surface of the liquid. There are several manufacturers making air displacement pumps with varying degrees of success and quality. Where Air-Well differs from the others is the thought and design that has gone into how the vessel fills and empties. Traditionally the vessels have been cycled purely on a time basis, so the pump is given so many seconds to fill, and then so many seconds under pressure to empty. They were manufactured from a variety of materials, and used 'off the shelf' valves made for general purposes to regulate the flow of water and air. Time base is a very simple method, and is successful in some applications, although there is no automatic regulation of the operation, so in low production applications where optimisation of water recovery is paramount, they were not ideal. Another method is to use a float within the pump to activate an inbuilt air valve that automatically switches air into the pump when it's full, and then switches it off when the pump is empty. An excellent idea in principle, but the complicated valving required is susceptible to sticking and clogging in applications where there is suspended material or grit in the water. It also means that the pump requires regular pulling out for maintenance, a hindrance most users hope to avoid. Air-Well developed a pump vessel that incorporates the automatic features that are so useful whilst replacing the complicated float and valves with rugged high flow, hard wearing ball check valves and a level sensing probe. The resultant vessel has limited moving parts, and is virtually maintenance free.

The Air-Well Pump

The basic bore pump consists of a 316L grade stainless steel tube, generally 2m long and 100mm in diameter. The design of the Air Well pump allows it to be manufactured in various lengths and diameters. The tube is enclosed at each end. At one end is a non return valve allowing the submerged vessel to fill with water, and at the other, a second valve preventing the return of the expelled water. The valves are our own design, incorporating special features that give exceptional ability to handle silt and sand, combined with a very simple, and maintenance free construction. This is accomplished by providing a hard, clean seat for a polyurethane ball to close on. The seat is in a raised position away from the bottom of the pump, and is kept clean by the natural circulation of the water as it enters.

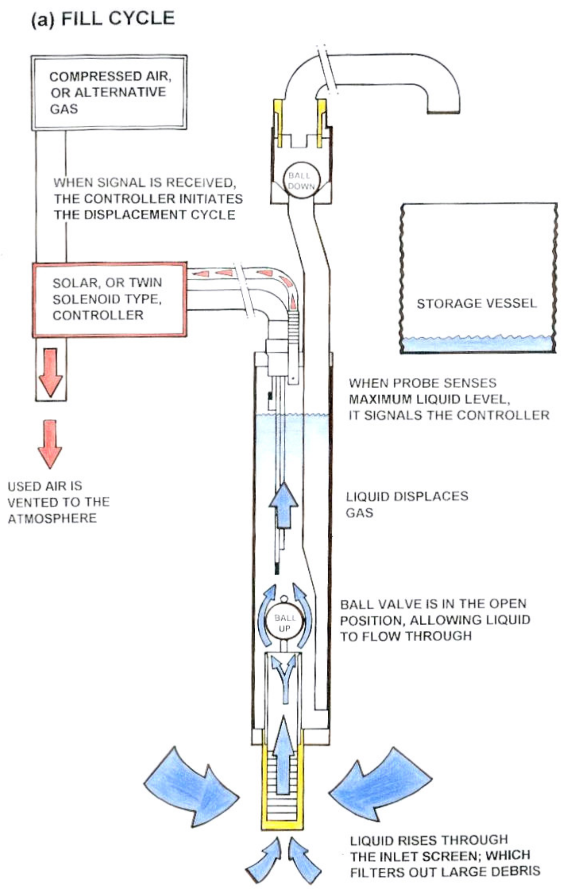
Within our most popular pumps there are two conductivity probes; one long enough to reach the bottom of the pump, and one short one. This is the key to the automatic

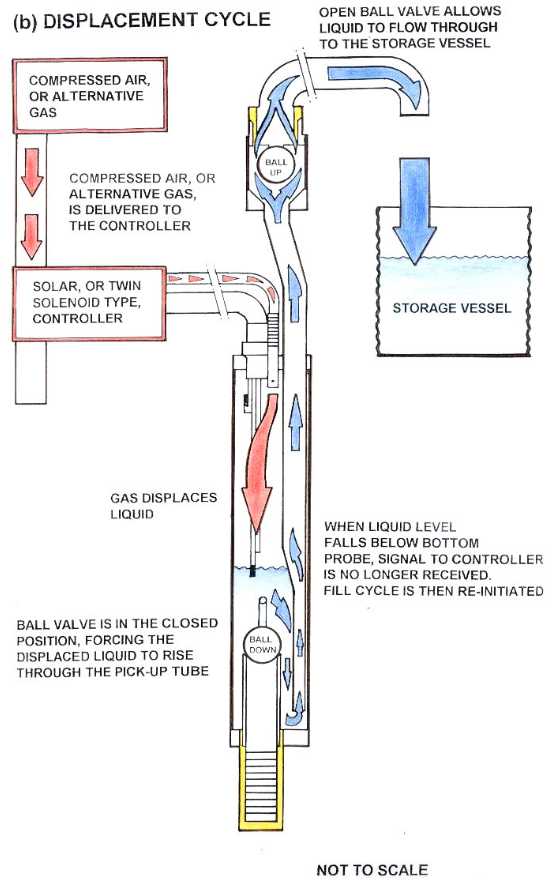
function of the pump. The cycling process is made possible by the ability of water to conduct electricity. Contact is made when the water rises to the height of the short probe at the top of the pump, and contact is broken when the water level falls below the probe at the bottom of the pump, (both probes become dry). An electronic circuit in the control unit at ground level detects this making and breaking of water contact, and subsequently changes the state of a 3-way solenoid valve, alternately admitting compressed air into the pump, forcing the water up the delivery pipe, and then exhausting the air from the pump, allowing it to refill. The result is that the Air-Well Pump will only cycle when a 'full' or 'empty' signal is received, regardless of whether this is every few seconds, minutes, hours, weeks or years. No air is used when the pump is filling, making the system as energy efficient as possible. The air usage chart on page 19 shows the approximate volumes of air required to pump water from various depths over a 24 hour period.
The control unit stands on a post at the head of the bore. Typically, besides carrying the 3-way solenoid valve for the air and the electronic control circuit, it also houses a maintenance free, dry cell battery to power the system. The lid of the enclosure is a small solar panel to keep the battery charged. There are variations on this, as has been used at Toolibin, and we will go into more detail about this system later. However, to get an understanding of the air-Well system, I will continue with a description of standard equipment.
Prior to June ‘97 an Air-Well controller used a conventional solenoid valve that required power to keep it open. It should be noted that the newer IMPULSE style controller, as the name implies, only requires a short power pulse (60 milliseconds) to change its state from fill to empty cycle and similarly, to change from empty to fill. It is this style of operation that allows us to use a valve of far heavier construction and yet far less power consumption than previously. The advantages to the user include a smaller solar panel and battery, longer battery life, much simplified operation and a much more robust valve, that's more tolerant to the effects of contamination from the water being pumped. The fact that the new controller is microprocessor based has also allowed for greater control and improved reliability. What is has achieved is to put all the maintainable parts where they are convenient to work on – above ground.

The water delivered by an Air-Well system comes in surges, not a continuous flow like that of an electric submersible pump. Depending on the diameter and length of the pump, and hence its internal volume, different quantities of water are discharged per cycle. See chart on Page 17 for pump volumes per cycle.

The degree of reliability achieved with an Air-Well system is largely dependent on the suitability of the air compressor to the task. With smaller applications where the total water head is low (under 40 meters), and water pumping volumes are also low (less than 10,000 litres per day), good results can be achieved with lower cost compressors, particularly if de-rated in speed from standard. This is achieved by changing the drive pulley on the motor to a smaller diameter. However, where a more demanding pumping situation is required, a quality compressor must be employed to achieve the system reliability that should and can be expected

Helpful diagrams to understand stages of the pump cycle





As the water enters the vessel through the natural method of equalising pressure inside and outside the vessel, air within the pump is forced up the airline, exhausting to atmosphere through the exhaust valve until the top probe becomes wet, providing a pump full signal to the control circuitry.

On receiving the full signal, the exhaust valve is closed and the pressure valve opened, allowing compressed air into the pump. The compressed air displaces the liquid up the pick up tube, past the non-return valve, and on to the tank. When the water clears the bottom probe, both probes are now dry, giving a pump empty signal to the control circuit, closing the pressure solenoid and opening the exhaust solenoid, allowing the pump to refill.

The two ball check valves in the pump are made from hardwearing urethane on stainless steel seats. Their raised position allows the movement of sand and grit through the pump without causing any harm to the internal components, and not clogging up in bores of reasonable flow.

In the beginning

The involvement of Air Well pumps Pty Ltd in the Lake Toolibin project began with an approach from Dr Richard George of the Department of Agriculture.

Dr George had become very familiar with our companies activities during his time at Merredin Dry Land Research Institute.

Dr George described to us a project that would require the drilling and equipping of approximately 10 bores with pumps over an area of a lake (spread of pumps approx. 2500 metres by 1500 metres). The purpose of this work was to prevent the salt water table from rising any further and ultimately to reduce the water table to a depth below the lake floor, allowing the regeneration of the native lake bush cover. The salt water was to be disposed of by pumping to another lake, one already very badly salt affected and beyond help, that was some 7Km away.

It was anticipated that the pumped water would be very saline and therefore potentially highly corrosive. At the early design stage there did not seem to be an appreciation of the high levels of contaminants such as iron in the water, and this was not given as much attention regarding pipeline design as in hindsight it might have.

Why air displacement

Before the involvement of Air Well pumps in this project, two standard electric submersibles had been trialed in two bores for some time. The operating conditions proved very harsh on the electric submersibles and their poor performance contributed to the looking for alternative methodologies.

The Air Well pumping system was considered for this project for a number of reasons. The most obvious of these was the fact that the bores were spread over such a wide area. As previously described, an Air Well system uses easily reticulated compressed air as its energy source, not mains electrical power. That is to say that rather than distributing mains power to every bore site, the power was taken to one location to power a large air compressor. (The power, in fact was already at this central site). From this one compressor, compressed air could be reticulated to all bore sites using low cost HDPE pipe. In the instance of this particular project, individual airlines of 16mm Class 12 poly were run from the compressor to the bores. The cost saving in the distribution of air over electrical power on the project is considerable, probably in excess of 75%.

The Air Well system had another benefit in that it self adjusts for different flow rates. A standard Air-Well pump can operate from no flow at all, right through to about 1 litre per second.

Although it was not deemed to be a requirement at the design stage, another ability possessed by the Air Well system would become very beneficial in practice – the ability to handle large amounts of grit.

After much discussion, a design philosophy was decided upon that involved the use of direct displacement air operated pumps, although it would not be until the following year that Air Well pumps Pty Ltd became the successful tenderers for the provision and installation of the hardware.

Some urgent works needed

Concern was raised about the likelihood of the lake becoming flooded before the works could be completed, prompting some preliminary works to be carried out by Air Well pumps personnel on the lake floor whilst conditions were the driest experienced for some years.

Drilling of the first six production bores and sundry monitoring bores was completed by Flockhart Drilling. Air Well pumps provided steel pipe posts to Flockhart Drilling so they could be grouted in over the bore casings. These would become the principal support for raised well completions at a later stage, facilitating access to the bores when the lake is full of water. As part of this first works Air Well pumps laid airlines, water pipes and signal cables from all 6 production bores back to the proposed site of the transfer pump station.

The main bore pumping stage

Over a year passed before we were back on site for the next stage of the project, after being awarded the bulk of this tender.
The original operational concept developed by Air Well pumps involved the use of a large storage tank at the proposed transfer pumping station. The Air Well air displacement pumps would deliver the water from all bores back to this tank. A separate electrically driven transfer pump would take water from this large tank and transfer it to the other lake via a HDPE pipeline. This is the correct use of all technologies. Although it is possible for an Air Well system to pump the water all the way to the other lake 7 km away, it is more efficient, faster and generally more appropriate to use a two-stage approach. Use air displacement to collect the water to one site and electrically driven pumps to transfer it over the long distances.

Regulatory problems arose with the design and construction of the proposed concrete tank, so it was dropped from this stage of tendering, but allowed for in all planning. This stage of the project therefore saw us complete all aspects that were required to recover water from the lake and deliver it to the site of the proposed tank. The bores that were to be equipped at this stage became known as bores Nos. 1, 2, 3, 4, 7 and 8.
The walk decks around the pumps were completed, the pumps were installed and connected with their controllers at each bore and connections to the previously installed pipes and cables were completed. A shed to house the compressors and control system was constructed with provision for the proposed water transfer pump.

The transfer pump and water pipe to the other lake were not included in this part of the tender, partly because of the problems with the storage tank but largely because there was still a hope that something could be done with the saline water rather than having to pump it to the other lake.

The Mains Power issue

From a practical perspective, one of the most difficult aspects of this project was the lack of adequate mains power. The site is 45km away from its nearest major town and the only power available was single phase, transmitted on relatively light conductor and had already come a long way.
Prior to this project, Air Well pumps had had some exposure to a locally designed power conversion system called “Polyphase”. This system allows 240VAC or 480VAC single phase to be converted to 415VAC three phase. We had found them to be sufficiently successful enough to propose that the technology be used on this project. To operate a unit sized to provide sufficient power for our needs it is necessary to have adequate transformers on the HT poles. Two 25Kva transformers were fitted in parallel for this purpose. After some inevitable tweaking the converter has proved to be very successful.

The shed was fitted out with everything required to allow the pumps on the lake to function and have their performance monitored. The fit out includes power metering, a mains switchboard, 480-volt single phase to 415 volt three phase power converter, two air compressors, an air receiver and the air distribution and pump-monitoring panel.

At the completion of this stage of the project we were able to power up the power converter, which in turn allowed the operation of the compressors, activation of the pump controllers via the central control panel and water to be pumped to the proposed site of the storage tank (adjacent to the compressor and control shed). All systems were checked and commissioned, including the feed back signal from the individual pumps to the control centre for individual pump monitoring.
Each time the bore pump goes on to 'pressure', whereby the water is being expelled from the pump, an indicator lamp on the corresponding relay in the control panel comes on and stays on until the pump goes to 'exhaust', whereby it refills. This indicator relay provides the signal to both the electronic counter in the control panel, and to the radio telemetry system in its own enclosure, that the bore pump has completed a cycle. It also acts as a useful tool to monitor how long the pump takes to complete a cycle (or if the pump is cycling at all), and enables an approximate volume pumped/day to be calculated. Potential problems with individual pumps can be recognised without actually going out on the lake by comparing these figures with those previously known.

The project once again remained at this stage while decisions were made regarding various aspects of the projects completion.
Air Well pumps had completed what it was contracted to do and was keen to be involved in the projects completion. To this stage the project had followed almost entirely the recommendations proposed by Air Well pumps Pty Ltd based on the technology and experience that we had at the time.

The final stage

The next and final stage of the project was to construct a storage tank, install an electric transfer pump and install the 90mm HDPE water pipe that had been purchased by CALM for the transfer pipeline.

On reading the tender documentation for this part of the project I found that to comply fully with the letter and intention of the tender, we would arrive at a dollar figure three fold of one that I believed was necessary for the task or one that would be accepted by the principal as reasonable. As Air Well Pty Ltd was not prepared to provide any goods or works short of what was specifically requested in the tender documentation, an approach was made to the tender principal to see if a non-conforming tender would be accepted. As it was responded that non-conforming tenders would not be considered in the presence of a conforming bid, Air Well pumps saw little point in submitting a non-conforming bid. Air Well pumps therefore did not submit a tender for the final stage of this project.

With the full benefit of hindsight, it is unfortunate that the originally proposed large storage tank did not eventuate as part of this final stage of works, I am sure that this would have resulted in the reduction or elimination of the problems associated with the transfer pump. These problems being mainly retained gas and large quantities of grit. At the time, when it was suggested that the large tank was becoming too expensive and difficult to organise, and would be replaced with a small tank inside the compressor shed using a variable speed control on the transfer pump to regulate outflow, I did not foresee this to be a problem. The extent of the poor water quality and levels of grit in the water were not known at that stage. The presence of a tank full of extremely saline water inside a shed housing compressors and instrumentation has subsequently had problems.

First system expansion

As part of this final stage Air Well Pumps Pty Ltd was contracted to add two more pumps to the existing six. The two electric submersibles that were still in place would be replaced with air displacement pumps to match the others and be incorporated in the monitoring and control system. These are known as bores 9 and 10.

Recent additions

As part of a more recent drilling and bore completion programme bore No.14 has also been fully incorporated in the system making a total of 9 air operated pumping bores.

Problems encountered

Contamination

The principal problem, of course, is the poor quality of the water. This is mainly caused by moderate amounts of iron reducing bacteria. Although our experience in other bacteria producing bores has been very successful in slowing down bacterial growth, there is no practical way without the addition of third party equipment to prevent the build up. The effect is to gradually block aspects of the system in contact with water with a red coloured build up. Some bores are significantly worse than others, with Bore No. 8 being by far the worst. It is currently out of service because the water discharge pipeline away from it (300m of which has been replaced) blocks so fast with bacterial build up that it has been impractical to keep it clear.
No long-term damage can be caused by the contamination of the Air Well pumps themselves, they simply block and have to be cleaned out and reinstalled, which in itself is a relatively straight forward process. The affects on the rest of the system are more permanent with the gradual blocking of discharge pipe work and the damaging affects on the electric transfer pump.
The air controllers at each bore suffered from this bacterial build up at first, before quick exhaust valves were added to the system. By preventing contamination getting to the main control valves, this new valve has reduced the problem to a very predictable and manageable service routine.
As many of the bores produce significantly more grit and other suspended material than was expected, the additional material tends to combine with the bacteria to form a harder build up, reducing the effectiveness of pigging the lines.

If we were to do this project again today, our current model valves would have far fewer problems with this type of contamination. One of the biggest areas of improvement within our product range since we installed this project is how to design around many of these contamination problems. Since this project, we have been involved in many similar situations, particularly with mining companies, and have gained considerable practical experience in this area.

Corrosion

The issue of corrosion has not been particularly significant when the quality of the water is taken into consideration. After several years of operation it became evident that the bronze component at the top of each pump and the inlet screen were not going to be suitable, as they were being ‘eaten away’. As with the bacterial problem, the speed and significance of the corrosion of these components varied from bore to bore. These components are being replaced (with all but two pumps having the bronze components replaced) with acetal and are showing no signs of wear at this stage. The 316-grade stainless steel, which makes up the majority of the down hole aspect shows limited effects of corrosion in some bores, with a few minor repairs being made to the stainless steel in the worst cases. The use of brass or bronze in this type of application can be beneficial, as it often acts as a sacrificial anode, reducing the corrosive attack on the stainless steel. Where the bronze has been replaced with non-corrosive components, there has been no significant increase in the deterioration of the stainless steel.
The 304-grade stainless steel wire ropes used to support and retrieve the pumps has deteriorated where in contact with the water, and most have now been replaced with 316 grade.

If we were to do this project again today, we would probably offer pumps manufactured from Duplex grade (SAF 2205) stainless steel. Although more expensive, based on the performance of 316L, they would almost certainly not be susceptible in this environment. However, with the amount of corrosion that has been experienced so far it is, debatable whether any real benefit would be gained against the increased initial expenditure.

Retained gas

On this site we have experienced gas bubbles in the pumped water, almost to the stage of being carbonated. This is quite unusual in this type of application, although is often encountered on pollution recovery sites were we recover hydrocarbons. The most practical and cost effective way to get rid of this is to problem is to pump the water into a large tank and allow it to settle, and positioning the transfer pump away from the tank filling point.
With such a small tank within the compressor shed there is insufficient time available for the gas to escape and therefore it becomes a problem for the electric transfer pump.

If we were to do this project again today, revert to having a large storage tank, which would also allow any grit to drop out of suspension as well.

Sizing of airlines

Each air displacement pump has its own 16mm Class 12HDPE airline to it from the compressor shed. Under normal circumstances we use a larger main airline and branch of it to each separate bore. On this project, separate airlines were run to each bore due to the likelihood of the lake filling with water and isolation of a given pump becoming too difficult.

If we were to do this project again today, we would certainly use a larger airline to at least the two furthest bores, if not to all. As the air reticulation exists at present, we can’t quite get enough air to bores 1 and 8 to pump at their full potential. 20mm HDPE to these two bores would have been the correct size.

Air compressor reliability

The reliability of the air supply is directly related to the reliability and performance of the Air-Well pumping system, as the reliability of the electrical supply affects many aspects of the performance of the compressors. By using the telemetry figures generated from the pumping system, graphing out those figures enables a snapshot of how the system is performing. Typically, when a pump fails, it can be seen clearly as its own cycle rate, and hence flow rate, falls. This is often associated with a rise in flow from other pumps, generally the deeper ones. When all pumps register a demise in flow, it is directly attributable to the air supply, and may be just a reduction in operating air pressure, or compressor failure. Apart from the remoteness of the site creating a sometimes erratic power supply, the performance of the air compressors has left a lot to be desired when compared to similar projects that Air Well pumps have been involved in.

If we were to do this project again today, we would increase the ventilation in the compressor shed over the amount that exists and normally thought necessary, and we would over specify the compressors in both volume and pressure terms.
We would make it very clear to the suppliers of the compressor equipment what the duty for the compressors would be and invite them to make a reliability guarantees based on measured air production and performance. Ideally the air compressors would be connected to the remote telemetry system, allowing the operating status of the compressors can be recorded remotely at all times.

Successes and improvements

In the life of the project so far, there has not been a failure of any control aspect of the Air Well system. There has been no replacement or repair of any electronics and no problems with signal cables to and from pumps. There have been no air leaks and no attention given to the Air Well distribution centre in the compressor shed.
All problems experienced in this project to date have been associated with, iron bacteria, corrosion or compressor outages.
Due to the extreme bore water quality the regular maintenance required on the controller air valves must be viewed as routine.
The pumps have performed well in general, and, as can be seen from graphical representations of the telemetry figures and the physical rehabilitation on the lake, the system is lowering the saline aquifer. With all operating pumps except 9, which has lowered the aquifer to the pump anyway, all pump performance figures when viewed over a period of time show a gradient downward. This represents a decline in the available pumpable water, hence, less water in the immediate facility. The Air-Well pump will only slow down if the recharge rate of the bores decreases. After lengths of inactivity at any of the bores, when pumping recommences, all pump rates are higher than when the pumping stopped because the bores and surrounding areas have had a chance to recharge.
Although not all pumps have performed to their optimum, some thought could go into whether all of the pumps need to be set quite as deep. If the pumps were lifted, improvements in the possible flow rates would be improved, possibly increasing their effectiveness.

If we were to do this project again today, we probably would not run any instrument or low voltage power cables to the bores. Miniature radio transmitters have become economic and so efficient that all aspects of monitoring currently employed on this project can now be done better via radio (as with our mining customers). Because there have been no problems with the current methodology in this project, it is improbable that it would make the system any more reliable, but installation and potential for problems would be significantly reduced. At the time the system was designed our 24-volt AC powered controllers (via instrument cable) were much stronger and more reliable than our solar powered version. Subsequently that is what was selected. The current design of solar controllers manufactured by Air-Well is far and away more reliable and efficient than any of their predecessors, and would therefore be the recommended option of today. This would take out cabling across the lake, eliminating a potential problem.

Air-Well Pumping System – Hardware Specifications

Air-Well Pump Body

Dimensions:	102mm Diameter, 2m long
Displacement capacity:	13.8 Litres/cycle
Construction Materials:	316L stainless steel, Bronze, urethane & Acetal

Controlling the System:

At the bore;

Power Supply:	12VAC/12VDC Air-Well regulated Power supply. 5A fuse protection
Control Enclosure:	Painted alloy,
Solenoid Valves:	Twin Asco
Count Relay:	Omron LY2 12VDC signal relay

At the Control Shed;

Control Enclosure:	Rittal AE range - Painted Steel housing;
Power Supply:	240VAC/24VAC multi tap transformer
Air Manifold	Brass, includes air isolation tap for each bore
Counting/Indication	Omron LY2 with LED, Omron digital counter

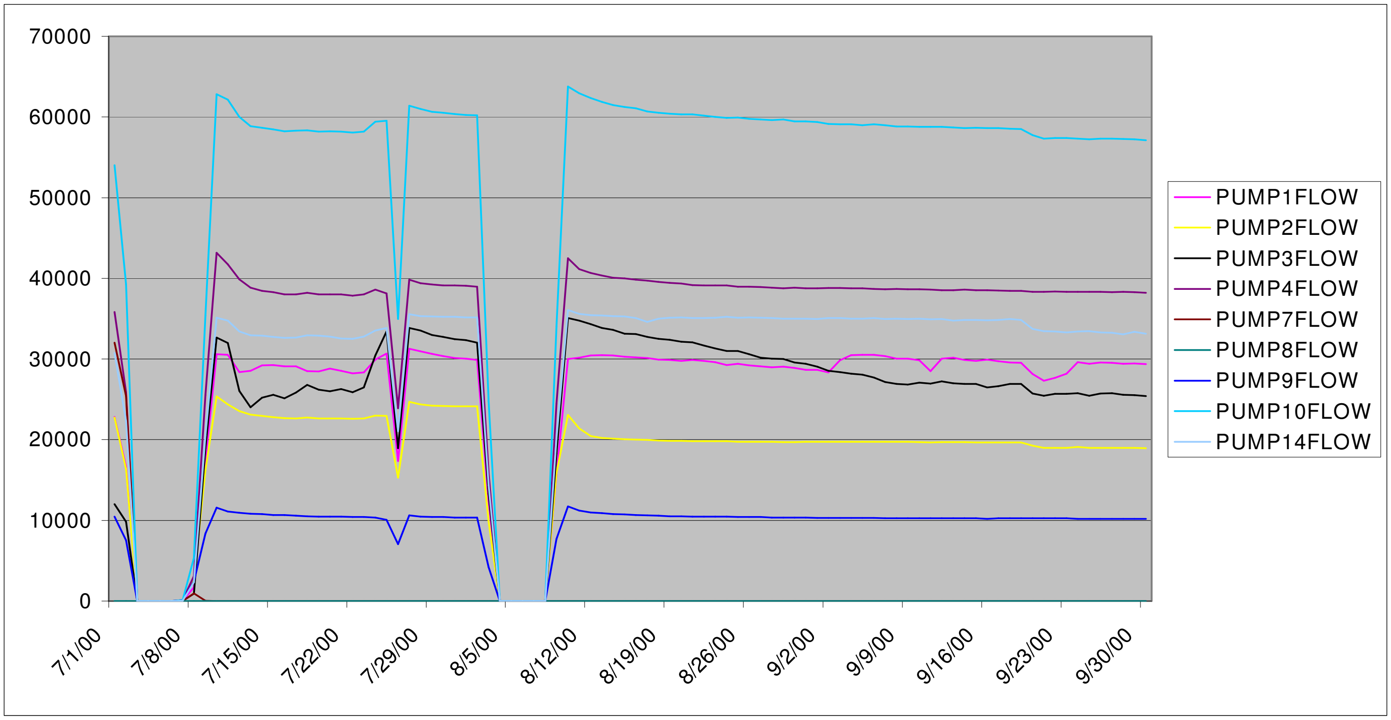
Interconnections

Electrical	3 x 2.5mm Irrigation Cable in 16mm conduit
Airline	Individual 16mm Class 12 HDPE
Water	Class 9 HDPE – various diameters-as follows

Water Pipe Sizes between Bores:

1 and 2, 7 - intersection, 8 - intersection, 10 and the shed, 14 and 9 = 50mm HDPE
2 and 3 = 63mm HDPE
3 and 4, 4 and 9, intersection and 9 = 75mm HDPE
9 and transfer tank (under floodway) = 90mm HDPE

Graphical pump performance

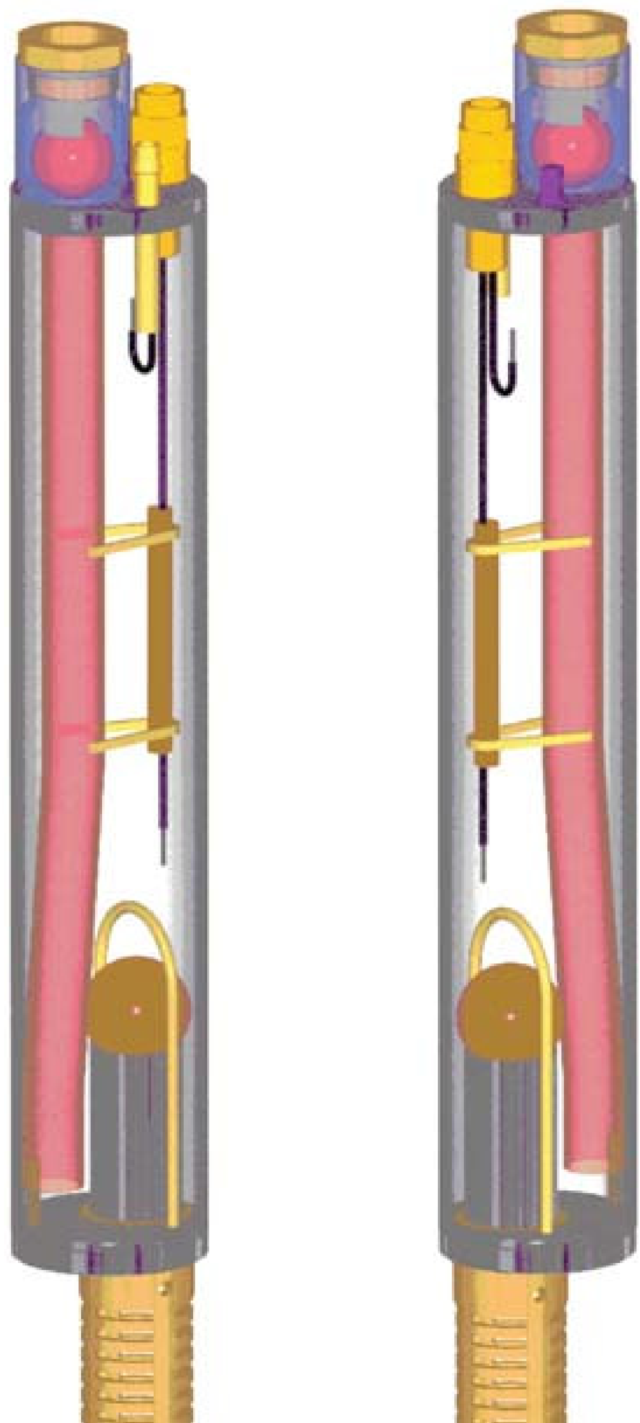


From the graph, we can easily identify what is happening on the lake. Whenever there is problem with the air supply, all pumps are affected. After a period of not pumping, we can see that the recharge of water in the area around the bores allows the pumps to increase their flow rate, taking several days to get back to where they were. All bores show a gradual reduction in fluids pumped during the period, highlighting the lowering of the groundwater.

Pump setting depths on commissioning

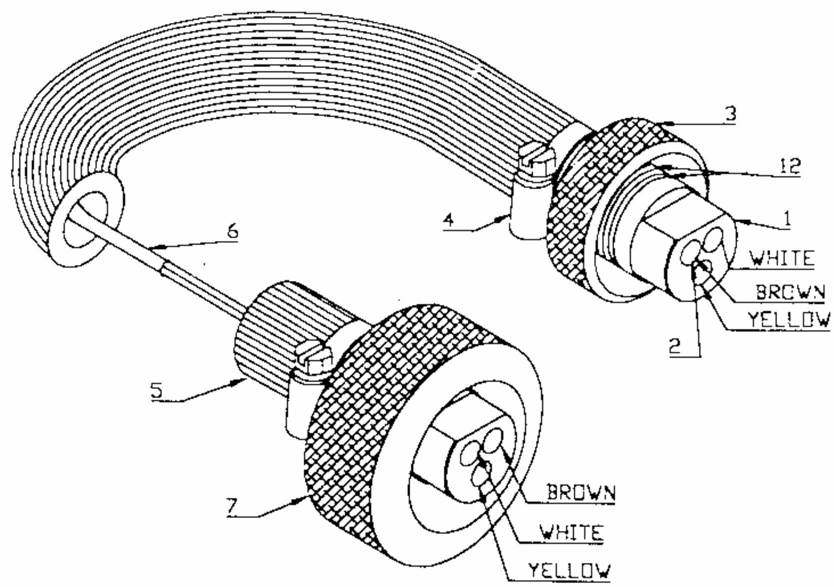
Pump	Bore Depth	Pump Depth (top of pump)	Distance to Transfer Tank	Tower Height
1	51.2m	33m	1471m	2.3m
2	28.7m	29.5m	1169m	2.2m
3	43.9m	42m	791m	2.3m
4	34.4m	32.3m	436m	2.3m
7	39.7m	38.3m	763m	2m
8	41.2m	33.8m	859m	2.1m
9	32.6m	33m	120m	2.4m
10	?	30m	80m	None
14	?	35m	560m	2.2m

3D View of Pump Assembly

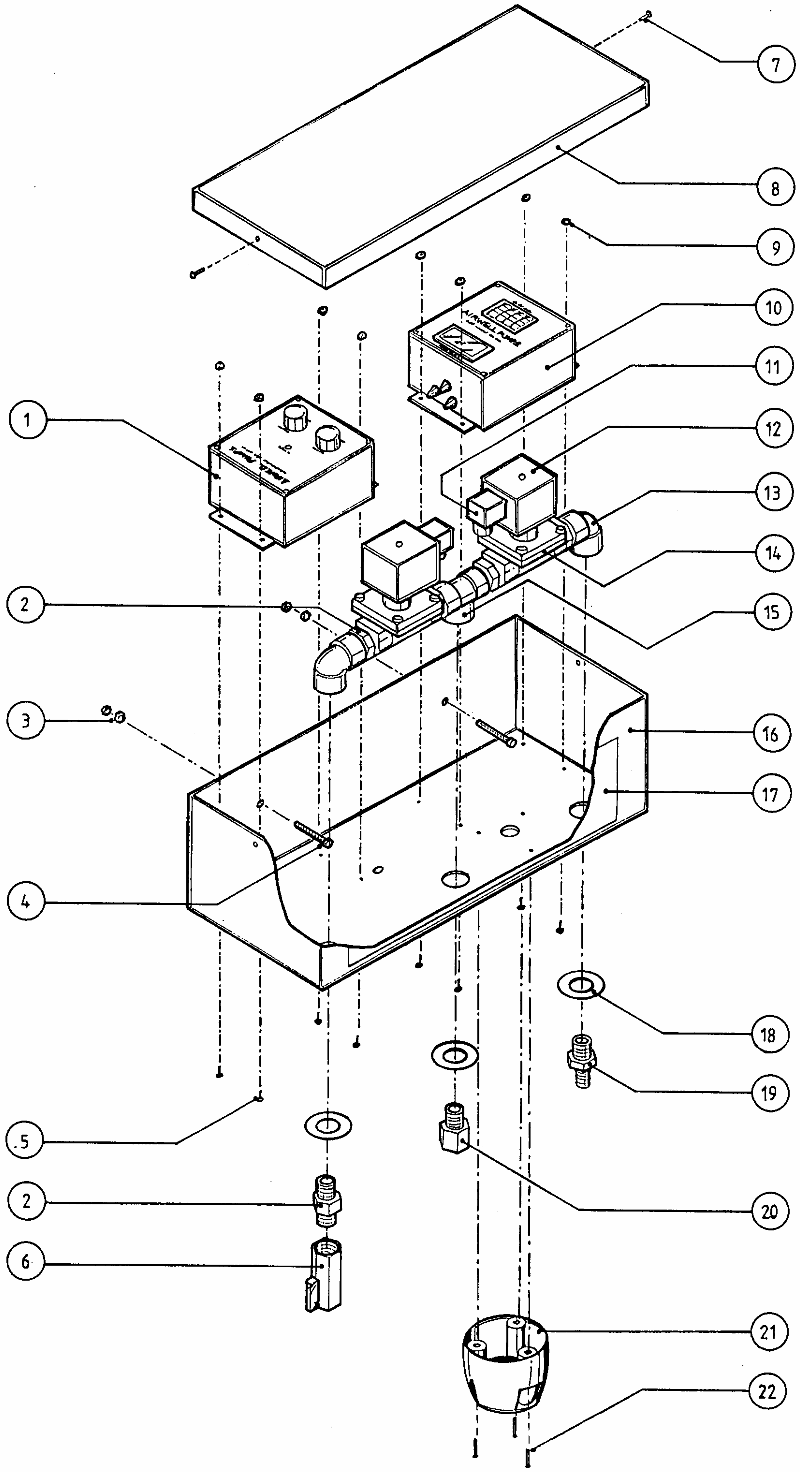


The Cable Kit

Connects the pump to the local controller, providing signals to the electronics, indicating when the pump is full and empty.



Twin solenoid controller
At the head of each bore is the pumps own controller, interpreting a full and empty signal from the pump and activating the solenoids to pressurise the pump to expel the liquid, then exhaust the pump, allowing it to refill.



The twin solenoid controller operated from a 24VAC supply, and at the time of design was the most reliable version offered by Air-Well. This diagram does not show the relay that was incorporated to send a signal back to the control shed, providing a pulse each time the pump cycled.

Formula for Calculating Daily Flow Rate

Using a stopwatch, commence timing cycle when air first blows off (end of pumping cycle, start of filling cycle), and continue to time until it blows off again. Similarly, by timing the period when the indication light on the control panel relay comes on goes off and then comes on again. This will give you the total time for the filling and emptying of the pump (its Cycle).

Displacement per Cycle is as follows:

Pump Diameter	*Pump Length*	Volume per Cycle
2" (51 mm)	0.5m	0.62 litres
2" (51 mm)	1 m	1.4 litres
2" (51mm)	2 m	3 litres
3" (76 mm)	2 m	7 litres
3.5" (89 mm)	1 m	4.8 litres
3.5" (89 mm)	2 m	10.5 litres
4" (102 mm)	1 m	6.7 litres
4" (102 mm)	2 m	13.8 litres
6" (152 mm)	1 m	14.9 litres
6" (152 mm)	2 m	31.5 litres

a) Pump displacement _____ litres, divided by time (seconds) and multiplied by 86,400 gives you the amount of litres displaced in one 24-hour day.

b) The more water above the pump, the faster the filling time.

c) The higher the operating pressure the faster the system will discharge the water contents.

d) Quick exhaust valves can sometimes be fitted with benefit to allow pump to be filled quicker.

Air Pressure required to over come a specific Head

Bore	Head		Airline	Pressure
Feet	**Metres**		**KPA**	**PSI**
328.0	100	=	1020	147.9
311.6	95	=	969	140.5
295.2	90	=	918	133.1
278.8	85	=	867	125.7
262.4	80	=	816	118.3
246.0	75	=	765	110.9
229.6	70	=	714	103.5
213.2	65	=	663	96.1
196.8	60	=	612	88.7
180.4	55	=	561	81.3
164.0	50	=	510	74.0
147.6	45	=	459	66.6
131.2	40	=	408	59.2
114.8	35	=	357	51.8
98.4	30	=	306	44.4
82.0	25	=	255	37.0
65.6	20	=	204	29.6
49.2	15	=	153	22.2
32.8	10	=	102	14.8
16.4	5	=	51	7.4

NOTE:

The pressures on the above chart describe the amount of pressure required to reach equilibrium. No flow will occur with pressures less than these amounts. Pressures of greater than these amounts are required to achieve a flow. The amount of extra pressure required over the above amounts is equal to the friction created at that given flow rate.

Air Requirement Chart

WATER FLOW RATE	Volume of Air Required - Per Pump							
1.388 litres/sec	6.32cfm	10.21cfm						
5,000 litres/hour								
1,100 gallons/hour								
26,400 gallons/day								
1.111 litres/sec	5.06cfm	8.17cfm	11.67cfm	15.55cfm				
4,000 litres/hour	5.07cfm	8.47cfm						
880 gallons/hour								
21,120 gallons/day								
.833 litres/sec	3.79cfm	6.12cfm	8.75cfm	11.65cfm	14.83cfm			
3,000 litres/hour	3.8cfm	6.36cfm	9.36cfm	12.6cfm				
660 gallons/hour								
15,840 gallons/day								
.555 litres/sec	2.52cfm	4.08cfm	5.82cfm	7.77cfm	9.89cfm	12cfm	14.72cfm	
2,000 litres/hour	2.53cfm	4.24cfm	6.24cfm	8.4cfm	10.8cfm	13.68cfm		
440 gallons/hour	2.7cfm	4.56cfm	6.88cfm	9.6cfm				
10,560 gallons/day								
.277 litres/sec	1.25cfm	2.03cfm	2.9cfm	3.87cfm	4.93cfm	6.08cfm	7.33cfm	8.68cfm
1,000 litres/hour	1.27cfm	2.12cfm	3.12cfm	4.2cfm	5.4cfm	6.84cfm	8.36cfm	10.04cfm
220 gallons/hour	1.35cfm	2.28cfm	3.44cfm	4.8cfm	6.32cfm	8cfm		
5,280 gallons/day								
.139 litres/sec	0.61cfm	1.01cfm	1.44cfm	1.92cfm	2.45cfm	3.02cfm	3.66cfm	4.34cfm
500 litres/hour	0.63cfm	1.06cfm	1.56cfm	2.1cfm	2.7cfm	3.42cfm	4.18cfm	5.02cfm
110 gallons/hour	0.67cfm	1.14cfm	1.72cfm	2.4cfm	3.16cfm	4.0cfm	4.98cfm	6.04cfm
2,640 gallons/day	0.59cfm	0.84cfm	1.48cfm					
.069 litres/sec	0.29cfm	0.5cfm	0.72cfm	0.95cfm	1.2cfm	1.5cfm	1.82cfm	2.14cfm
250 litres/hour	0.32cfm	0.53cfm	0.78cfm	1.05cfm	1.35cfm	1.71cfm	2.09cfm	2.51cfm
55 gallons/hour	0.34cfm	0.57cfm	0.86cfm	1.2cfm	1.58cfm	2.0cfm	2.49cfm	3.02cfm
1,320 gallons/day	0.29cfm	0.42cfm	0.74cfm	0.99cfm	1.26cfm	1.6cfm	1.94cfm	2.28cfm
BORE DEPTH	**32 Ft**	**65ft**	**98ft**	**131ft**	**164ft**	**196ft**	**230ft**	**262ft**
	10m	**20m**	**30m**	**40m**	**50m**	**60m**	**70m**	**80m**

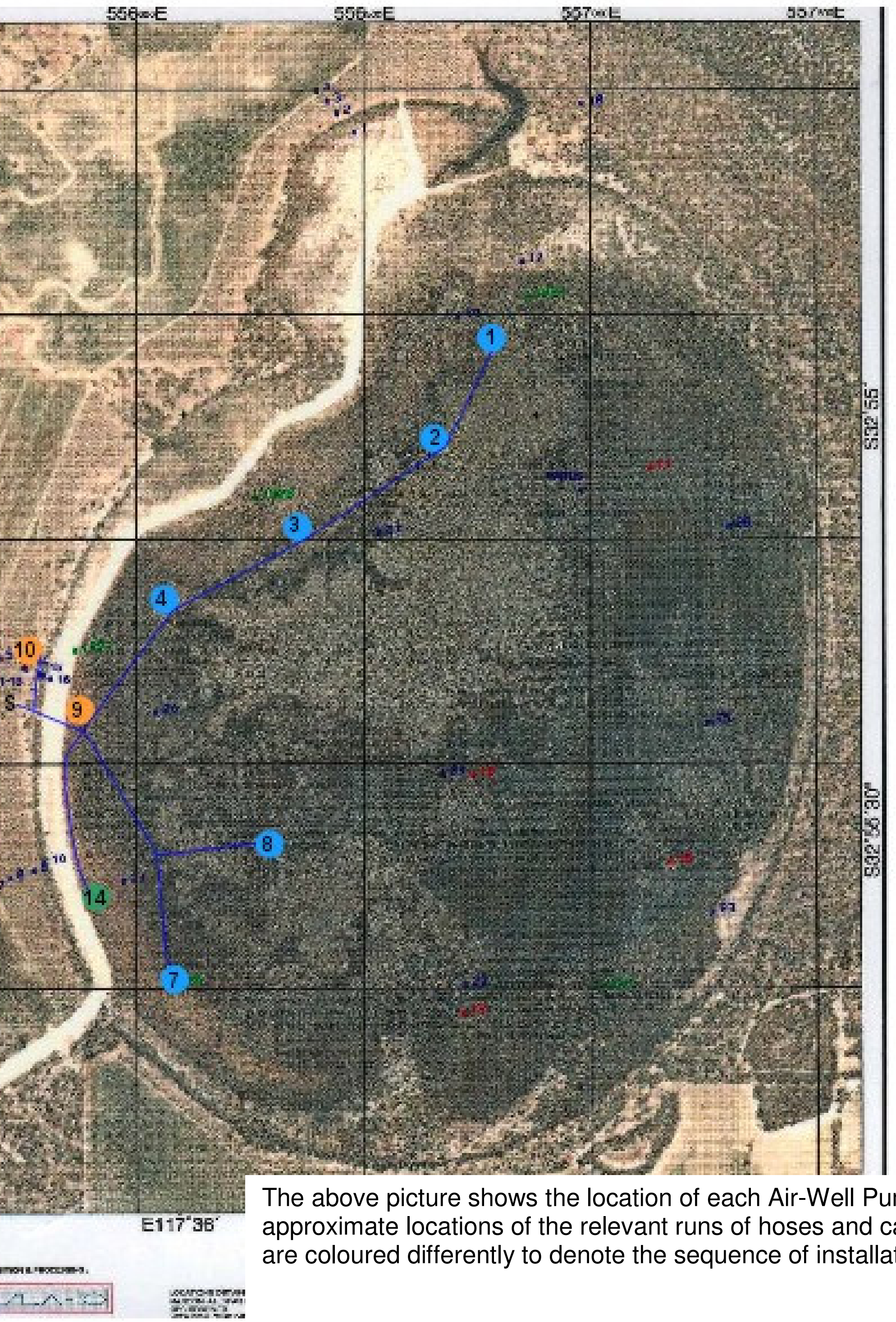
Pump Size

102mm (4") x 2m
89mm (31/2") x 2m
76mm (3") x 2m
51mm (2") x 2m

1CFM = 0.47 lts/sec
1 litre/sec = 2.11CFM

The figures in this chart are conservative, so figures calculated on actual application figures often give lower air requirements.

Position of Air-Well equipped bores on Lake Toolibin



The above picture shows the location of each Air-Well Pump currently on the lake, with approximate locations of the relevant runs of hoses and cabling. The pump locations are coloured differently to denote the sequence of installation.