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SOLAR POWERED REVERSE OSMOSIS DESALINATION FOR REMOTE COMMUNITIES

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The Remote Area Developments Group of Murdoch University has been investigating the technology of Reverse Osmosis powered by photovoltaic panels. A small RO unit featuring energy recovery has been tested while connected to a solar panel. Compatibility of power supply and power demand has been achieved with the use of an inexpensive pump optimiser, eliminating the need for batteries or electronic controllers. Daily pumping durations have been extended dramatically by the use of a robust, maintenance free solar tracker. The Group is developing a larger unit with the aim of producing up to 1000 L/day of fresh water from two solar panels.

INTRODUCTION

Many inland community water sources have salinities in the range of 3000-6000 ppm, making it unsuitable for drinking water supply. Nitrate and fluoride are also often found in concentrations higher than the recommended standard (National Health and Medical Research Council, 1987). In places where surface water sources are not available or are limited, rainfall is low and groundwater salinity is high, the only possible supply of drinking water is from desalination.

Solar distillation was, until recently, the world's leading desalination technology. Its appropriateness for remote community water supply however is questionable (Walker, 1982). Reverse osmosis desalination has now superseded distillation and has been applied in the provision of drinking water worldwide (Silver, 1984).

Reverse osmosis is a pressure driven membrane separation technique which has traditionally required pressures of 40 atmospheres or more. Recently, low pressure membranes have been developed which operate at 10 atmospheres or less and, though not suited to seawater desalination, are ideal for the treatment of brackish water allowing a high production rate and a lower energy demand. The process has, however, remained a highly technical one requiring skilled supervision and ongoing maintenance. Its appropriateness for application in remote communities is therefore doubtful. Further, its energy demand, even with low pressure membranes, has made its adaptation to solar power an extremely expensive option.

The Remote Area Developments Group (RADG) of Murdoch University has been investigating the process with a view to adapting it for remote applications. The criteria for successful adaptation are seen as, 1. Simplicity, 2. Low cost, 3. Low maintenance and 4. Robustness.

DEVELOPMENT STRATEGY

The Reverse Osmosis Hardware

The amount of water treated per membrane is restricted to 10 - 15% as higher recovery ratios lead to rapid membrane deterioration. Large plants use several banks of membranes connected in series to achieve recovery ratios of 80 - 90%, leaving a highly concentrated brine which may be very difficult to dispose of. Additionally, the last few membranes in series are treating quite concentrated salt solutions. Without chemical pretreatment (complexing agents and pH control) many sparingly soluble salts commonly found in groundwater (eg. $CaSO_4$) can exceed their solubility and precipitate out of solution as a scale which fouls the membrane (Heitmann, 1990). Post treatment dosing is also required to adjust the pH back to drinking water standard.

Very small units, typically run from generators, may use only one or two membranes and so achieve recovery ratios of only 10 -20%. They require a much lower degree of pre and post treatment and brine disposal is much less of a problem (Keefer *et al.*, 1985). The brine is only slightly more concentrated than the feed but there is a lot of it, as 80 -90% of the feed is rejected. Accordingly, for every litre of fresh water produced, up to 10 litres of feed water has to be pumped up to the system pressure. In terms of the hydraulic energy requirements the process is quite wasteful and makes adaptation to solar power a very expensive option. Also, since the system pressure and recovery ratio are determined by a throttle valve on the reject line, regular supervision and adjustment would be required to cope with the varying supply of power from the solar array.

Great savings in energy can be gained by using this still pressurised waste stream to assist in the pumping of the feedwater. An example of an energy recovery system in production is shown in Figure 1. The switching valve has opened the pressurised waste stream to the back of the piston for the pumping stroke. With a flow of 90% of the total pumped flow and in excess of 90% of the pumped pressure working on the back of the piston, the motor provides only a fraction of the total energy needed to pump the system to pressure. Further, as the recovery ratio is fixed internally, no adjustment is required as power from the solar array fluctuates during the day. The accumulator evens out the flow across the membrane which would otherwise deform under the pulsed flow of a single cylinder pump.

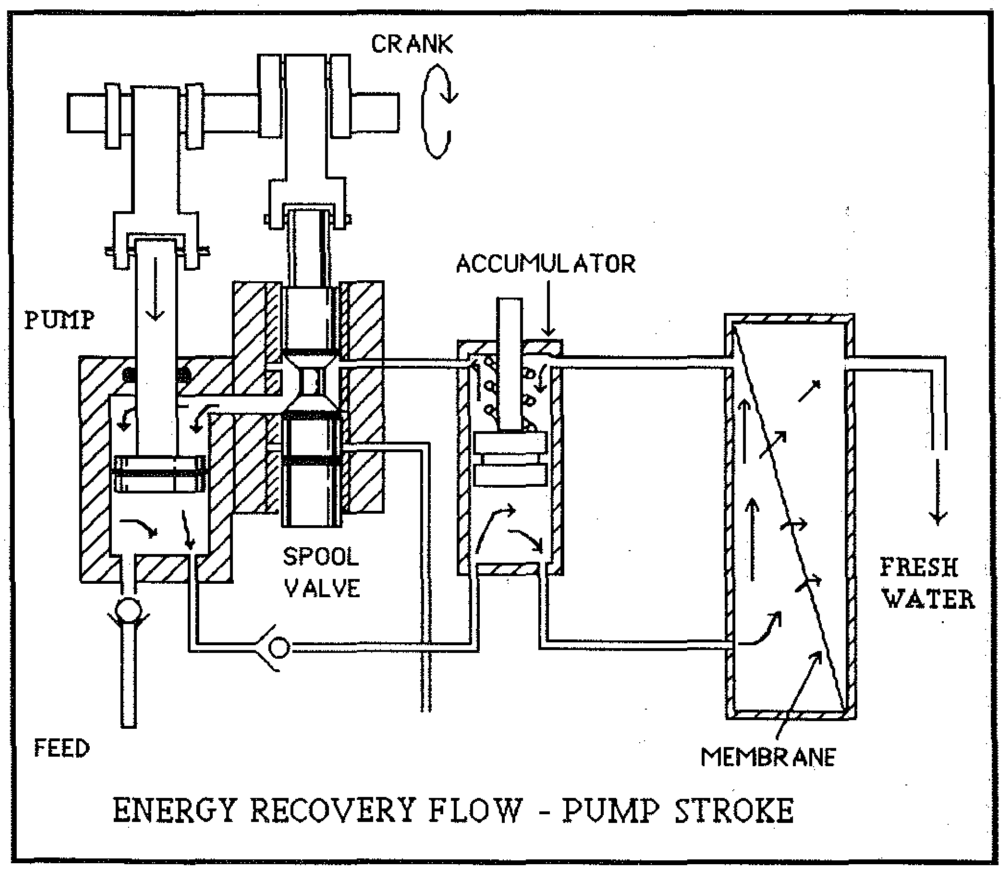

Figure 1. The spool valve opens the pressurised waste flow to the back of the pump piston.

In Figure 2, the switching valve allows the waste stream, now at atmospheric pressure, to be expelled while feed water is being drawn into the pump.

The two main handicaps with this system are the fixed recovery ratio and the pulsing of water through the membrane. The fixed recovery ratio means that devices can't be optimised to suit bore water quality. It should be possible to use higher recovery ratios on reasonable quality water and

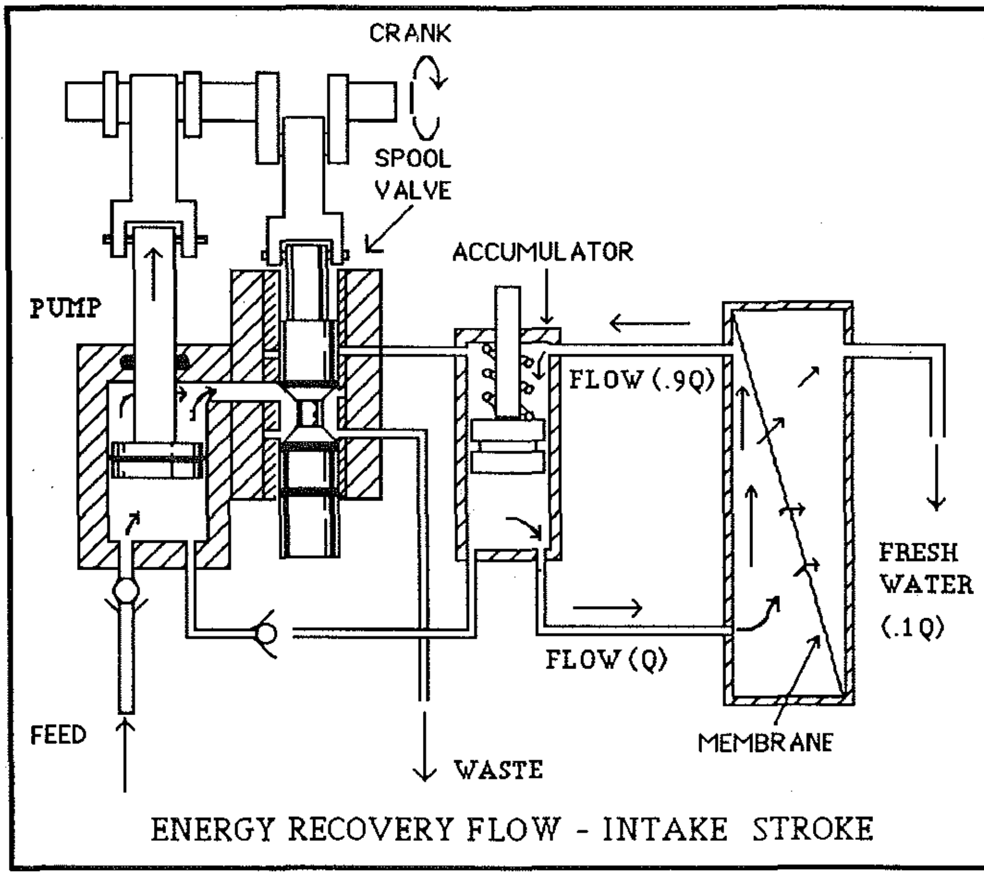

Figure 2. Water flow returned to the pump is 90% of total water flow (Q).

thus obtain higher volumes without aggravating membrane fouling. The single acting simplex pump inevitably causes pulsing through the membrane. The membrane is spiral wound and pulsing causes adjacent membrane layers to rub against the web-like intervening layer. This rapidly decreases membrane life. The pulsing is partially controlled by the accumulator but this becomes less effective for larger pumps. In fact it is usual to use a triplex pump for larger flow rates to avoid this pulsation. This naturally becomes an expensive and complicated option.

The RADG group has been developing a simple pumping system using double acting pumps to deliver an even flow, and energy recovery to reduce the power requirement. By scaling up the smaller field units instead of scaling down a larger plant, we hope to retain the simplicity of the former and avoid the costly and operator intensive control systems of the latter.

In the majority of cases, the salt removal efficiency does not need to be very high. Salinities of 3000 - 6000 ppm need only be reduced to 1500 ppm to meet the required standard for drinking water (National Health and Medical Research Council, 1987). Ongoing testing of the new range of low pressure membranes will continue to determine the best combination of flux rate, removal efficiency and cost.

Solar Tracking

A Perth company, Solar Track Pty Ltd, has invented a robust and reliable solar tracker which has only two moving parts - the two bearings. The solar tracker operates purely on the weight difference between the two half-shaded copper cylinders, each partly filled with liquid Freon. When one cylinder heats up more than the other, more Freon evaporates which forces the liquid Freon below it into the other cylinder. The weight difference rotates the tracker, keeping up with the sun all the time. A patented device in the upper shade gives the tracker a kick back last thing in the evening. As the panels cool, gravity takes over and the tracker rotates back to face the east, patiently awaiting the dawn.

Pump Optimisation

Solar panels don't produce power like a battery does. A battery provides the power at its designed voltage, say 12 V, and provides the current that the motor requires, say 4 A. The output from a solar panel is dependant on the strength of the sunshine (insolation) and power is provided in a range of Voltage/Current combinations that comprise its I/V curve. With a slowly revolving single cylinder pump, the current draw varies dramatically over the crank cycle, so the output from the panel will be shooting backward and forward along the I/V curve, only rarely encountering its zone of maximum power. Further, if the insolation level drops it may not be possible to find a point on that curve and the motor will stop.

A Perth company, Solar Focus, produces a Pump Optimiser which keeps the voltage output up so that the output from the panel is always near its maximum (Figure 3). It then delivers the required current to the motor, making up any power deficit by varying the voltage. The principle differs from full size Maximisers (Maximum Power Point Trackers) which actually track backwards and forwards along the IV curve to maintain the point of maximum power. They may be more efficient than an Optimiser but they are five times the cost.

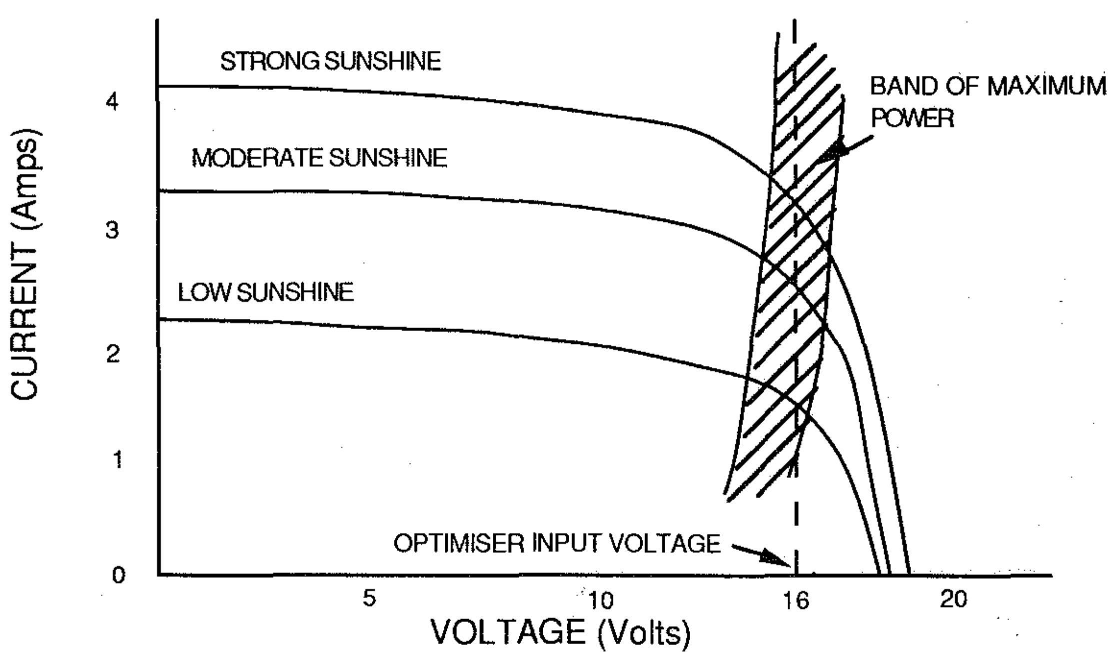

Figure 3. Input voltage is selected to keep the power production of the array near its point of maximum power. Output voltage is delivered according to the current demand of the motor.

Miscellaneous Controls

Unlike most larger scale reverse osmosis plants, it is anticipated that no other control mechanisms will be required. It should be stressed that every control mechanism requires some power, is a source of failure and adds to both the capital and maintenance costs. In keeping with this philosophy, the pump is connected through the optimiser directly to the solar array and not through a battery bank. Batteries are only 70% efficient, so 30% of the power from a solar array is lost if batteries are used (Van Overstraeten and Mertens, 1986). Further, since only a fixed amount of solar energy is available per day, it is considered more efficient to store that energy as water than to store it as chemical/electrical energy.

EXPERIMENTAL WORK

While the development work on the prototype was in progress, a small commercially available desalinator was tested for its adaptability to solar power. The 'Powersurvivor" is a 12V unit designed for the boating market with a 5 L/h capacity and a high pressure membrane suitable for desalinating seawater. The unit was installed in a test facility on Murdoch campus and connected to a 55W solar panel via a solar pump optimiser. The panel was mounted on a solar tracker and both the tracker and the optimiser could be disarmed to evaluate their performance.

RESULTS

The typical summer production pattern of the 'Powersurvivor' coupled to the solar panel is shown in Figure 4.

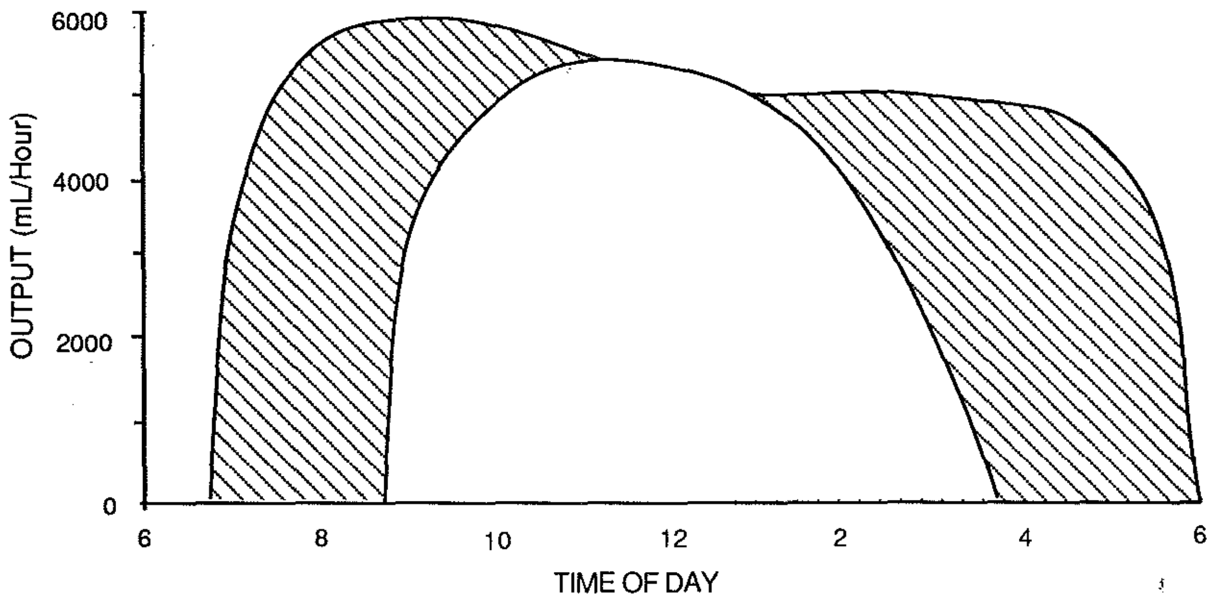

Figure 4. The hatched area represents the increased production of fresh water resulting from the use of solar tracking and pump optimisation.

The tests demonstrated the benefits of the solar tracker and the optimiser on production rates. The tracker in particular produced a significant increase in production while allowing a rapid startup in the morning. The optimiser showed its benefits in keeping the unit working well through marginal conditions such as early morning, late evening and, as earlier tests showed, through periods of light cloud. The power provided by the panel in the mornings is also delivered in a high current, low voltage form by the optimiser and so gives the pump the required starting torque. The tracker and optimiser together nearly doubled the production of fresh water. From these results, it is likely that the maximum daily duration of production (in January in Perth or October in the north of the State) will be 11 to 12 hours. The maximum production rate from the Powersurvivor is approximately 65 litres from a day which recorded 12.7 hours of bright sunshine. Using the system adopted by Legge (1987) we can assume a production rate of 55 litres from an average Perth summers day of 10.7 hour of bright sunshine. Similar production rates could be expected for Alice Springs in January.

COMPUTER MODELLING OF PROPOSED UNIT

A computer model which takes into account energy recovery has been constructed and by using the flux rates of a commercially available low pressure membrane, a production rate of 83.7 L/h is expected in summer bright sunshine conditions. The experiments conducted on the Powersurvivor demonstrated the extremely long duration of pumping that can be achieved using a solar tracker and solar optimiser. Twelve hours of pumping in Perth would therefore produce 1000 L/day from just two solar panels.

A comparison of the production rates of previous solar RO desalinators is shown in Table 1 and demonstrates the advances that have occurred in recent years.

PROJECT	YEAR	POWER (W)	PRODUCT (m^3/d)	ENERGY CONSUMPTION (kWh/m^3)	RATE (L/d/W)
Peterson	1979	2750	1.5	14.7	0.55
SERIWA	1983	1200	0.7	13.7	0.58
Powersurvivor*	1989	55	0.065	10	1.2
Prototype**	1990	110	0.288	4.6	2.6
Projected**	1991	110	1.0	1.3	9.1

* = features energy recovery

** = features energy recovery and low pressure membranes

Table 1. Power consumption based on the nominal size of the solar array used. The Peterson and SERIWA units used fixed arrays and energy consumption is based on an assumed eight hour production cycle, whereas the next three use solar trackers which extend the pumping cycle to twelve hours. Figures are based on the maximum summer production.

CONCLUSIONS

Solar powered reverse osmosis has the potential to make a significant contribution to the health and well-being of remote communities whose water sources are not to the required drinking standard. Solar panels are maintenance free, have a life expectancy in excess of 15 years, are clean, quiet and environmentally sound. Their only failing has been their comparatively high capital cost. The use of energy recovery on the reverse osmosis plant can reduce the number of panels required to one quarter of that normally required. To this end, RADG's goal is to develop the technology to produce up to 1000 L/day of fresh water from brackish water sources, from the power of only two solar panels, with the aid of, 1. energy recovery of the waste stream, 2. low pressure membranes, 3. solar trackers, 4. pump optimisers and 5. Australia's abundant sunshine.

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ON-SITE BACTERIOLOGICAL TESTING OF WATER IN REMOTE ABORIGINAL COMMUNITIES

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This paper provides brief details on an investigation currently underway into the use of self-contained bacteriological testing kits in remote Aboriginal communities. In addition to testing the technical applicability of various kits, a pilot scheme which trains local members of the community in usage of kits is being undertaken. If the pilot training scheme is successful, it is hoped that training in kit usage will form an advanced module in the Environmental Health Worker (EHW) Training Programme, which is taught at Pundulmurra College, Port Hedland.

Brief descriptions of current water sampling procedures and kits being trialled are given below.

CURRENT SAMPLING PROCEDURE

The Water Authority of Western Australia has responsibility for the monitoring of water quality for Aboriginal communities in remote areas of the State, such as the Pilbara, Western Desert and Kimberley regions. At present, water quality monitoring is achieved by collecting a sample from a source once a month, and chartering an aircraft to deliver this sample to a central testing laboratory, located at the Queen Elizabeth II Medical Centre, Perth. Chartering is necessary because the sample must arrive at the laboratory within 24 hours to be valid.

Only a limited number of communities are tested at present, as indicated by the attached summary of water testing schedules for the Pilbara and Kimberley. It should be noted that most of the communities which are not tested are very small (30 or less people) and can be totally uninhabited during the hot season.

Coliform counts and detection for amoebae are performed for all samples, and samples showing high background growth counts are examined for salmonella.

The current procedures for analysis of water samples from remote areas detailed above have various drawbacks:

- A large number of small communities which do not get tested.
- It is difficult to guarantee that samples arrive within the necessary time period. If samples are delayed, another sample must be collected. This does not protect the community effectively and is costly.
- The system has little flexibility, and can break down in emergency situations, such as when there is an outbreak of water-related illness, flooding, etc.
- Water Authority inspectors often do not have sufficient time to carry out other tasks on site such as routine maintenance, checking of facilities, etc., because aircraft must leave promptly to ensure delivery within 24 hours.
- It typically takes 5 or 6 days to analyse a sample and get the result to an inspector using the current system. Thus, if contamination is discovered, it is likely that much of the community will have been exposed before any warning can be given or remedial action taken.
- High costs. In particular, charter of an aircraft once a month costs about $16,000 per annum.

Use of a portable, self-contained testing kit by local members of the community would address these shortfalls, allowing more effective water quality monitoring at significantly reduced cost.

WATER TESTING KITS

The range of kits being trialled at present is detailed briefly below. It should be noted that it is not practical to assess for amoebae and probably salmonella on-site, and thus portable testing kits should generally be viewed as an augmentation rather than a substitution to current sampling procedures. However, NH & MRC guidelines on Desirable Quality for Drinking Water in Australia point out that:

> "...it is far more important to examine numerous samples by means of a simple test than occasional samples by a more complicated test."

Also, the use of a delayed incubation technique, described below, would make transport of samples much simpler and more economical. This is also being investigated as part of the study.

Delagua

The Delagua Water Testing Kit was developed on behalf of the charity organisation Oxfam by the Robens Institute, based at the University of Surrey, England.

The kit uses a membrane filtration technique and on-site incubation to find faecal coliform count only. The kit was developed primarily for use in developing countries, and employs resterilisable petri dishes and media bottles.

Training needs are significant.

Colilert

The Colilert kit uses an adaptation of the most probable number technique, requires a separate incubator, and allows enumeration of total and faecal coliforms.

This kit is particularly easy to use, but is bulky and comparatively fragile.

Millipore

The kit is similar to the Delagua kit, but does not use recyclable materials. Construction is significantly more robust than the Delagua kit, and this is reflected in the price of the kit, which is almost double that of the Delagua kit.

Incubator can process samples at 37 and 44 degrees centigrade simultaneously.

Training needs are similar to Delagua kit.

Delayed Incubation Technique

Samples are filtered on-site and then treated with a preservative, which keeps sample valid for 72 hours, allowing cheaper and simpler transport to central laboratory.

Bottled Sample

Transport of 200 ml sample to central laboratory within 24 hours (current approved method). This is being undertaken in conjunction with on-site methods, to allow comparison of results.

PRELIMINARY FINDINGS

The study will not be completed for several months, but preliminary findings can be summarised as follows:

- EHW workers have been trained in usage of the Delagua kit. Major aspects requiring attention are techniques of sterilising reusable equipment, and the need to time various steps in the experimental procedure, as EHW's do not commonly have access to a watch or clock. The need for training in resterilisation techniques could be avoided by use of the Millipore kit or development of 'one use' petri dishes, etc., for the Delagua kit. The need to time various steps is being further investigated, addressing:

  - the permissible margin for error based on time allocations of various experimental stages;

  - the incorporation of a simple timing device into kits;

  - the description of timing needed in terms which are meaningful to Aboriginal peoples.

- The flexibility of having a kit on-site is proving to be very useful. Kits have shown within 24 hours, and at very low cost:

  - that a newly commissioned UV disinfection system is functioning correctly, allowing fitters to leave the site knowing that the unit is functioning;

  - that a soak thought to be safe to drink from by a community was as polluted as another soak which the community regard as unfit to drink. This may be a way of educating the community which water sources are safe to drink, although how to present this to the community meaningfully still requires some careful thought;

  - that a bore which is currently being recommissioned for use by an outstation community requires shot dose chlorination to remove faecal contamination. This bore would not have been tested or treated using current established procedures;

  - that water from a sewage treatment pond satisfies Health Department criteria for irrigation.

It is emphasised that all findings noted above are provisional and require further investigation before they could be regarded as conclusive.

WATER QUALITY ANALYSIS
COVERAGE OF ABORIGINAL COMMUNITIES
PILBARA - APRIL 1991

Monthly Analysis	Jigalong	
	Yandearra	
	Warralong	
Quarterly Analysis	Punmu	
No Analysis	Milyakirri	
	Well 33	
	Parnngurr	
	Kuta Kuta	
	Camp 61	
	Billanooka	
	Walgun	
	Robinson Range	
	Pundawarrie	
	Ngurrawaana	
	Gurradunja	
	Strelley Nomads	Mijijimaya
		Callawa
		Coongan
		Carlindi
		Lalla Rookh
		Strelley
	Wapet Road Bores	
	(Wayside Bores)	

In the Kimberley there are an estimated 200 communities which have no water quality monitoring at present.

No.	Description	Time Taken	Volume	Faecal Colonies	Colonies per 100 ml	Average	Comments
1	Water	9.37	100	zero	zero		Non-faecal colonies too numerous to count.
2	Tower	9.49	100	zero	zero	zero	
3	Salt Lake	10.25	100	###			Community reportedly drink from this soak.
4	Soak	10.30	100	###	###	###	
5	Soak near	11.00	100	###			Community do not drink this water.
6	Watertower	11.05	100	###	###	###	
7	Dun Soak	11.40	50	###			Community do not drink this water.
8		11.45	50	###	###	###	
9	Tap, pre	12.20	100	1(nfc 2)			Water contains colony forming units and cannot be considered safe to drink.
10	UV unit	12.25	100	0(nfc 8)	<1	<1	
11	Start-up	12.30	100	0(nfc 0)	(nfc 3-4)	(nfc 3-4)	
12	Tap, post	1.00	100	0(nfc 0)			Comparison of pre and post UV samples indicates that UV unit is sterilising water effectively.
13	UV unit	1.05	100	0(nfc 0)	0(nfc 0)	0(nfc 0)	
14	start-up	1.10	100	0(nfc 0)			
14	Solar powered	1.40	100	0 (nfc 23)			Water contains colony forming units and cannot be considered safe to drink.
15	bore, Airstrip	1.45	100	0 (nfc 28)	0 (nfc 25)	0(nfc 25)	
16	Control Medium only	-	-	0	0	0	Medium sterile.

= colonies too numerous to count.
nfc = non-faecal colonies.

WATER QUALITY ANALYSIS - JIGALONG AREA 13/6/91

No.	Description	Time Taken	Volume	Faecal Colonies	Colonies per 100 ml	Average	Comments
1 2	Robinson Range PVC Cased Bore	12.55pm 1.00pm	100 100	87 80	87 80	83	2 processed by Michael Humes. Colonies much better developed after 24 hours at ambient temperatures. Zero non-faecal colonies (nfc).
3	Robinson Range Tap	1.40pm	100	1	1	1	Not same source as PVC bore. Mark Jeffries processed sample, 8 nfc.
4	Jigalong Mains Chlorine at 0.4 mg/l	2.15pm	100	zero	zero	zero	1 nfc. External contamination?
5 6	Primary Treatment Pond	2.50pm 2.55pm	10 10	### ###	### ###	###	### = too numerous to count.
7 8	Secondary Treatment Pond	3.05pm 3.10pm	10 10	123 no result	1230	1230	Significant improvement in quality. Usable for irrigation? Membrane adhered to top of petri dish, no result.
9 10	Outfall of third Treatment Pond	3.25 3.30	10 10	6 12	60 120	90	Very significant improvement in quality.
11 12	Walgum Bore	4.15 4.20	100 100	### ###	### ###	###	Community are fixing up bore will be drinking this water in less than a month. Contacting WAWA and Environmental Health Worker.
14	Control	-----	-----	zero	zero	zero	Medium not contaminated.