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ICE CONTROL IN LAKES BY PHOTOVOLTAICS POWERED WATER CIRCULATION

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ABSTRACT

A photovoltaics powered submerged water circulator, known as the Wardun "Sunstirrer" was developed and field tested. The system was used for ice control in a small, British Columbia lake (latitude 50°N), for water oxygenation (fisheries) reasons.

The system consisted of a photovoltaic array (rated at 375 watts in peak sunshine), a rechargable battery bank and a very free running, low speed, low energy consumption water circulator. Laboratory measurements showed that over the normal range of operating speeds (240 - 300 rpm) the power consumption was extremely low (23 - 38 watts) and the water flow rate was good (25 - 32 litres sec^{-1}).

A program of field testing was undertaken in Winter and early Spring. A data logging system monitoring field information showed that the hours of strong sunshine at the site (2.9 hours/day average) in February were more than adequate to keep the system in operation.

1. INTRODUCTION

Many of the most productive lakes in Canada are hostile to fish species such as trout because of the winter kill problem. During the winter an ice cover seals off the water body from oxygen exchange with the atmosphere, and the addition of new water to the lakes by river inflows is small because runoff is small. The lake becomes depleted in oxygen, and eventually the fish die from suffocation.

One procedure that has been successfully used in treating these lakes is forced water circulation using airlift pumps. These pumps contribute oxygen directly to the water body, and more important, cause a substantial ice-free patch to be created in the lake through which air exchange with the atmosphere can occur. Because of the inverted temperature gradient in lakes during the winter (0°C water near the surface, 4°C water at significant depths below surface), a pumping system may be used to bring 4°C water to the surface to melt the ice cover, (Lackey and Holmes, 1972).

The routine operation of this technique has been well established in British Columbia by Fisheries Research Section, BC Ministry of Environment, using air lift pumps powered by compressors (Ashley 1983). However finding a suitable and cost effective energy source for the compressors (rated at 1 - 7.5 kW) has been an intractable problem. The lakes of concern are usually far from the main electricity grid, and the cost of conveying and storing diesel fuel at the site is usually very large.

Although photovoltaics powered pumps have been extensively tested for medium-high head, low flow applications (Halcrow 1983, Derrick et al 1982, Ward and Dunford 1984, Pulfrey et al 1986), their application to ultra low head, large flow water circulation was novel. A modest amount of solar power from photovoltaic panels may be obtained in the Winter at latitude 50°N, and the location of many of the lakes with fish winter kill problems was in areas with relatively sunny, low precipitation climates.

The advantages of using (1) an approximately constant power system driven via rechargable storage batteries or (2) a "sunshine only" direct driven system were difficult to assess. A decision was made to construct a very low power consumption pump, and to drive it with rechargable batteries. The system designed and constructed consisted of an 8 panel (nominal 375 watt) array, a number of totally sealed lead acid batteries, a permanent magnet DC motor, and a very low friction propellor pump turning at low speed. Because of the careful electrical and mechanical design, the pump consumed only about 25 watts at its design speed, and was capable of moving a substantial flow of water.

The system was installed and operated at Menzies Lake, near Merritt, British Columbia during the winter months, and water temperatures, solar radiation, battery voltage and other operating parameters were measured. Our paper focusses on the design, laboratory testing and field evaluation aspects of the pump.

2. SYSTEM DESIGN

Initial calculations indicated that it would be possible to circulate 25 litres/sec of water (the design flow selected by Fisheries Research and Development Section) using about 35 - 45 watts provided the velocity was kept small. A fairly large diameter, low speed propellor was required and thus an electric motor running at low speed was needed to drive the propeller. In the interests of reliability and compactness a submersible unit was conceived, with the motor and propeller near each other in a single housing.

Information on available sunshine in the interior of southern BC in the winter showed that an average of about 2 hours of strong sunshine per day would be available in January. Using photovoltaic panels rated at 12 volts and 3 amps in optimum conditions (ARCO M75 Panel), the number of ampere hours available/day from an eight panel array, configured as 4 parallel strings of 2 panels (24 volt system) was:

$$\text{No. of ampere hours} = \text{No. of strings} \times \text{Output per panel} \times \text{No. of hours of sunshine}$$

$$= 4 \times 3.0 \times 2$$

$$\text{No. of ampere hours/day} = 24$$

With this current going into batteries and being used to operate the pump when the sun was not shining, the fractional running time for a 36 watt system was computed. The current required was 1.5 amps, that is 36 ampere-hours/day.

$$\text{Thus: Percent Time running} = \frac{\text{Power Available}}{\text{Power Required}}$$

$$= \frac{24}{36} \times 100$$

$$= 67\%$$

Plans were made to construct an electronic duty cycle switch, to allow the system to function at various fractions of the total time.

For energy storage to carry the system through a meteorological weather cycle (typical duration 4 days), the battery capacity was:

No. of ampere hours for batteries =
Amps Consumed x Required time x low temperature factor
= 1.5 x 4 x 24/0.7 = 206 Ah.

Three parallel strings of two, 12 volt Watchman II Sealed Deep Cycle Batteries, manufactured by GNB Batteries (Canada) Inc, were used, rated at about 65 Ah each for small discharge currents.

3. PROTOTYPE CONSTRUCTION

A Baldor DC permanent magnet motor rated at 1 hp, 180 volts and 1750 rpm was selected for driving the propeller. Operation of the 180 volt motor at 24-32 volts enabled the required low speeds to be obtained, without need for a gearbox or pulley speed reduction.

A very free running spring loaded rotary shaft seal was purchased and this seal together with two bearings formed the support for the propeller drive shaft. A rubber bushing direct drive coupling was used between the motor and propeller shaft. The Baldor motor was partially dismantled and machined down so that it would fit inside a 6 inch diameter PVC pipe. The propeller housing and the motor housing were bolted together and sealed with a large "O" ring seal. This unit, together with the 10 inch (254 mm) cast aluminium propeller, and the streamlined cover formed the prototype pump (see Figure 1).

The top cover of the pump was transparent plastic, and enabled a check to be made on the adequacy of sealing. A support hook, the electric line and an air valve were all attached to the plastic top cover. The air valve enabled the pump to be inflated to a pressure greater than the water pressure at the proposed depth of submergence of the pump. This ensured that the pressure inside the housing exceeded the pressure outside, so that no water could leak in.

The final pump design was called the Wardun WD 20 "Sunstirrer".

An electronic duty cycle controller was designed and constructed to operate the pump. The switching element was a power field effect transistor. Switches allowed timer periods of 5, 10, 20 40, 80, 160 and 320 minutes to be selected and duty cycles of 10, 20, 30, 40, 50, 60, 70, 80, 90 or 100% of total time to be selected. The Controller included built-in override circuits, so that the pump would cease operation below a preset low voltage, and go to 100% operation above a preset high voltage.

4. LABORATORY TESTING

A 12 inch (30.5 cm) cowling was bolted around the propeller (see Fig 1). The pump was lowered to about mid-depth in a 2½ m deep, large volume test tank in the floor of the University of British Columbia, Civil Engineering Hydraulics Laboratory. An Ott laboratory current meter was attached above the propeller in the gap between the motor housing and the cowling.

The pump was run at four values of speed, controlled by the applied voltage. The speed increased from about 180 rpm to 360 rpm as the voltage was increased. Measurements of water velocity were made, and measurements of current and voltage to the motor were recorded.

Values of power supplied, power out of motor and power imparted to water were computed as follows:

$$\text{Power out of motor} = \text{Power supplied} - \text{Power lost}$$

$$= (\text{Power supplied}) - (\text{friction loss} + i^2R)$$

$$= iV - (0.25V + 3i^2)$$

in which
V = supplied voltage
i = supplied current
R = resistance of motor windings (3 ohms)

$$\text{Power imparted to water} = \text{Power associated with dynamic head}$$

$$= 1/2\, \rho\, Q\, u^2$$

in which
ρ = density of water
Q = flow rate (volume per unit time)
u = velocity of flow

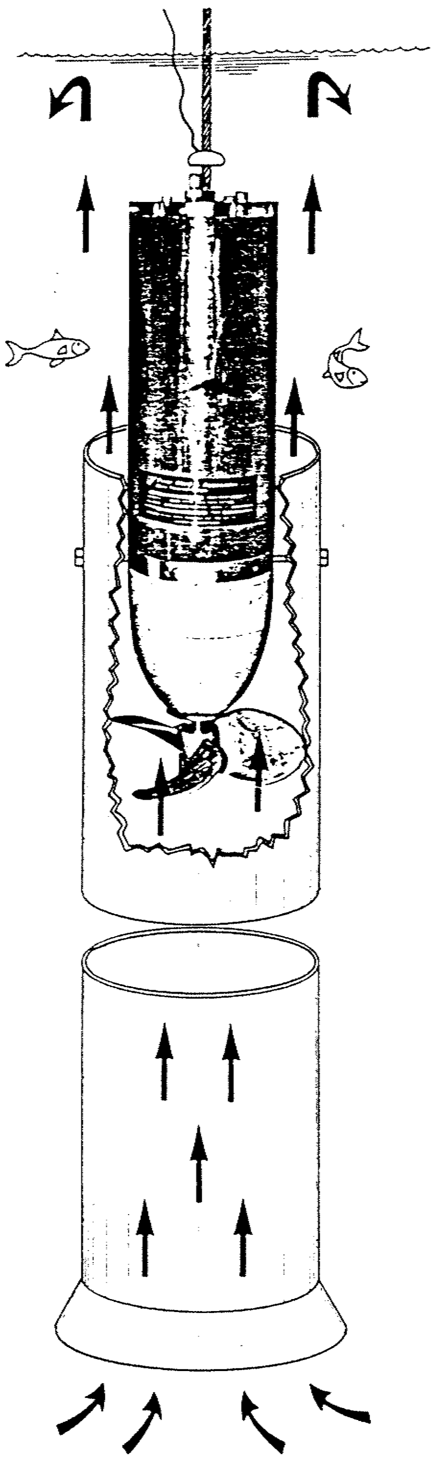

Fig. 1. Wardun WD 20 "Sunstirrer" Pump with 12 inch (305 mm) Intake Tube

Values of power were computed with these equations for each value of voltage and are listed (see Table 1). The motor efficiency is in the range 48 - 72%, a good range considering the fact that the motor was being used at only 1/70th to 1/12 of its design power. The pump efficiency was in the range 20-24% - a reasonable range considering significant losses must have occurred in the gap between the propeller tip and intake tube.

Initial problems of water leakage were overcome using the pressurization idea described in Section 3. At the planned operational voltage (25 volts) the pump drew a current of 0.91 amps and produced the design flow (approximately 25 litres/sec). Subsequent measurements in the field at low water temperatures (about 4°C) showed that the current drawn was 1.00 amps at 25 volts. This was a very satisfactory finding because the current was significantly smaller than the original design current of 1.5 amps, and meant that the pump would easily be able to exceed its design performance.

5. FIELD TRIALS AND RESULTS

Plans were made by BC Ministry of Environment, Fisheries Research and Development Section to carry out field testing at Menzies Lake, British Columbia (about 20 km south-east of Merritt). Menzies Lake has a surface area of 3.7 hectares, a volume of 209×10^3 m^3 and a maximum depth of 15 m. A 2.5 m x 2.5 m raft to carry the solar panels, pump and batteries was designed. The raft was in modular form, and could be dismantled for road transport. The battery compartment was designed to be well submerged in water, in order to ensure that the batteries were kept at a temperature no colder than the water temperature. Space in the raft was also allocated to housing the Microscout data logging system. The Microscout system is a microprocessor controlled data system that stores information in solid state memory for later retrieval. The system (manufactured in Richmond, B.C.) is versatile and will work in the field in winter conditions for periods of 3 months or more.

The Microscout was readied for field operation and a total of six data recording channels were prepared, as follows:

Channel 1	Water Temperature	°C
Channel 2	Water Temperature	°C
Channel 3	Water Temperature	°C
Channel 4	Solar radiation monitored by small PV panel	mA
Channel 5	Charge current from main PV array	mA
Channel 6	Battery voltage	v

The equipment was transported to Menzies Lake by road, and assembled. A rectangular hole was cut in the ice (which was about 0.6 m thick). A 4.9 m long, 0.3 m diameter galvanised sheet-iron pipe (the intake tube) was attached below the pump, and the whole unit lowered through the opening in the ice. The rod supporting the pump was attached to the raft so that the top of the pump was about 1.4 m below the water surface. The pump intake was then about 6.5 m below the water surface, enabling relatively warm (3.7°C) water to be available at the intake for pumping.

TABLE 1 EXPERIMENTAL PERFORMANCE DATA FOR WARDUN "SUNSTIRRER" PUMP, MEASURED IN LABORATORY

POWER SUPPLIED			MOTOR POWER		POWER IMPARTED TO WATER				EFFICIENCIES	
EMF	Current	Power	Power lost in motor	Power out	Current meter revs.	Velocity	Flow	Final Power Delivered	Motor	Pump
volts	amps	watts	watts	watts	n	m.sec-1	l.sec-1	watts		
18.75	0.59	11.1	5.7	5.3	5.74	0.355	18.0	1.14	0.48	0.21
25.1	0.91	22.8	8.8	14.1	8.1	0.485	24.6	2.89	0.62	0.21
31.2	1.21	37.8	12.2	25.6	10.7	0.626	31.7	6.20	0.68	0.24
37.7	1.62	61.1	17.3	43.8	12.2	0.707	35.8	8.93	0.72	0.20

Electrical connections between the photovoltaic array, the batteries and the motor were made, and the system set on an 80% duty cycle, with a 40 minute period (approx. 32 mins. on, 8 mins. off). The current drawn by the motor was measured as 1.00 amps, with a battery voltage of approximately 25v. The solar powered pump was then ready for operation (see Fig. 2).

(Channel 1) and the water at 9 m (Channel 3) was the same temperature (3.7°C), and the water at 4.5 m (Channel 2) was 3.5°C. Calibration in melting ice prior to the field trip had indicated that the accuracy of the temperature probes was good (about ± 0.1°C). After 1 day's initial operation a hole in the ice of about the same diameter as the raft (2.5 m) had been created, and the raft settled into the water and became free floating.

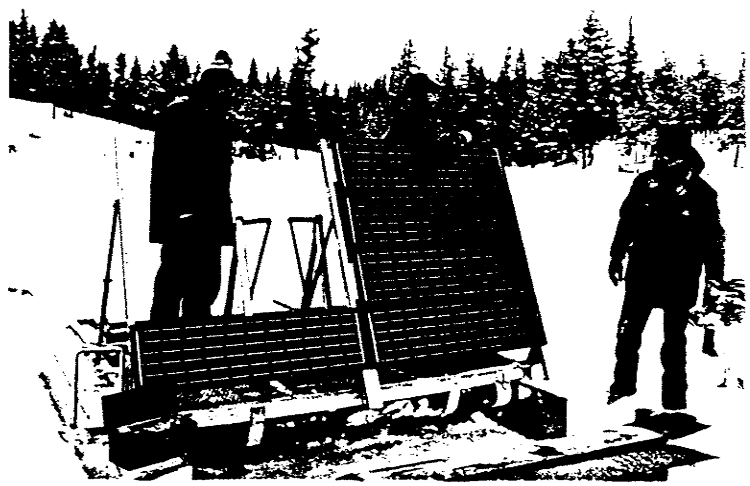

Fig. 2 Photovoltaic Powered Water Circulator (Wardun WD 20 Sunstirrer) **and Support Raft**

The Microscout system was set up, with temperature probe 1 placed in the exit flow from the pump, and probes 2 and 3 at submergence depths of 4.5 and 9 m respectively. Channels 4, 5 and 6 were also connected, and the system set to sample at 1 hour intervals starting at 12.15 hours, 12 February. Initial measurements of water temperature showed that the water being pumped

The system was visited after 10 days' operation, by which time a substantial ice free patch (about 6 m diameter) had been formed (see Fig. 3). During the 10 days' operation temperatures had been very cold indeed, with a four day period when night temperatures averaged -24°C and day time temperatures averaged -15°C. About 40 cm of snow fell during the period, with 19 cm falling during a single storm on

14 - 15 February. The Microscout was downloaded at 10.15 hours on February 22nd, and restarted about 1 hour later. At the date of writing (April 10) the whole system was continuing to work satisfactorily, and an ice free patch of dimensions 20 m x 25 m had been created around the pump.

Daily averages and totals for the days of sampling are shown (see Table 2). These are based upon hourly readings. An example listing for one day of operations is also presented (see Table 3).

The battery voltage after 10 days operation indicated that the batteries were still 1/3 to 1/2 charged on this date, despite a five day period when almost zero current was supplied to the batteries because of a major snow storm.

The water temperature of the water pumped (Channel 1) decreased a very small amount (from 3.7°C to 3.5°C) during the initial 10 day period. The water temperature at 9 m depth (Channel 3) decreased a negligible amount in the same period. Data from the photovoltaic monitor panel (Channel 4) indicated that a daily average of 1.91 ampere hours of electricity had been obtained during the 10 day period. With a peak monitor panel current of 0.65 amps in bright sun, the average hours of bright sun during the period are 1.09/0.65 = 2.9 hours. If further measurements at this time of year confirm the result, then there is significantly more bright sunshine available than were used in the design calculations (2 hours per day assumed).

TABLE 2 DAILY AVERAGE READINGS OF WATER TEMPERATURES (CHANNELS 1 - 3), PV PANEL OUTPUTS (CHANNEL 4 - 5) AND BATTERY VOLTAGE (CHANNEL 6)

	DAILY AVERAGES AND TOTALS					
DAY	Chn# 1 deg C	Chn# 2 deg C	Chn# 3 deg C	Chn# 4 AH	Chn# 5 AH	Chn# 6 volts
Feb 12,86	3.7	3.5	3.7	1.0	11.7	26.0
Feb 13,86	3.7	3.5	3.7	4.0	58.4	27.8
Feb 14,86	3.6	3.5	3.7	2.3	31.6	27.2
Feb 15,86	3.5	3.4	3.6	0.2	0.0	25.4
Feb 16,86	3.6	3.4	3.6	1.1	0.0	25.1
Feb 17,86	3.5	3.4	3.6	1.5	0.0	25.0
Feb 18,86	3.6	3.3	3.6	1.9	0.8	24.9
Feb 19,86	3.6	3.3	3.6	2.5	0.6	24.7
Feb 20,86	3.5	3.2	3.6	2.4	18.8	25.2
Feb 21,86	3.5	3.2	3.6	1.8	37.7	25.7
Feb 22,86	3.4	3.2	3.6	0.4	0.0	25.2

TABLE 3 ONE DAY'S DATA SET - HOURLY READINGS OF WATER TEMPERATURES PV PANEL CURRENT AND BATTERY VOLTAGE

Feb 13,86	0:15:	3.5 deg C	3.5 deg C	3.7 deg C	0.0 mAMPS	0.0 mAMPS	25.4 volts
Feb 13,86	1:15:	3.8 deg C	3.5 deg C	3.7 deg C	0.0 mAMPS	0.0 mAMPS	25.2 volts
Feb 13,86	2:15:	2.6 deg C	3.6 deg C	3.7 deg C	0.0 mAMPS	0.0 mAMPS	25.4 volts
Feb 13,86	3:15:	3.8 deg C	3.6 deg C	3.7 deg C	0.0 mAMPS	0.0 mAMPS	25.1 volts
Feb 13,86	4:15:	3.1 deg C	3.6 deg C	3.7 deg C	0.0 mAMPS	0.0 mAMPS	25.2 volts
Feb 13,86	5:15:	3.9 deg C	3.6 deg C	3.8 deg C	0.0 mAMPS	0.0 mAMPS	25.1 volts
Feb 13,86	6:15:	3.7 deg C	3.4 deg C	3.8 deg C	0.0 mAMPS	0.0 mAMPS	25.2 volts
Feb 13,86	7:15:	3.9 deg C	3.6 deg C	3.8 deg C	0.0 mAMPS	0.0 mAMPS	25.1 volts
Feb 13,86	8:15:	3.8 deg C	3.6 deg C	3.8 deg C	25.0 mAMPS	0.0 mAMPS	25.3 volts
Feb 13,86	9:15:	3.9 deg C	3.6 deg C	3.8 deg C	188.0 mAMPS	2470.0 mAMPS	27.1 volts
Feb 13,86	10:15:	3.9 deg C	3.6 deg C	3.7 deg C	527.0 mAMPS	8060.0 mAMPS	32.6 volts
Feb 13,86	11:15:	3.7 deg C	3.5 deg C	3.7 deg C	621.0 mAMPS	9060.0 mAMPS	33.3 volts
Feb 13,86	12:15:	3.7 deg C	3.5 deg C	3.7 deg C	663.0 mAMPS	9660.0 mAMPS	33.5 volts
Feb 13,86	13:15:	3.7 deg C	3.5 deg C	3.7 deg C	657.0 mAMPS	9510.0 mAMPS	33.4 volts
Feb 13,86	14:15:	3.7 deg C	3.5 deg C	3.7 deg C	591.0 mAMPS	8500.0 mAMPS	33.2 volts
Feb 13,86	15:15:	3.6 deg C	3.5 deg C	3.7 deg C	454.0 mAMPS	7150.0 mAMPS	32.9 volts
Feb 13,86	16:15:	3.6 deg C	3.4 deg C	3.6 deg C	271.0 mAMPS	4020.0 mAMPS	32.0 volts
Feb 13,86	17:15:	3.6 deg C	3.4 deg C	3.6 deg C	6.0 mAMPS	0.0 mAMPS	26.4 volts
Feb 13,86	18:15:	3.6 deg C	3.4 deg C	3.7 deg C	0.0 mAMPS	0.0 mAMPS	26.1 volts
Feb 13,86	19:15:	3.6 deg C	3.5 deg C	3.7 deg C	0.0 mAMPS	0.0 mAMPS	26.0 volts
Feb 13,86	20:15:	3.7 deg C	3.5 deg C	3.8 deg C	0.0 mAMPS	0.0 mAMPS	26.1 volts
Feb 13,86	21:15:	3.7 deg C	3.5 deg C	3.7 deg C	0.0 mAMPS	0.0 mAMPS	25.8 volts
Feb 13,86	22:15:	3.8 deg C	3.5 deg C	3.7 deg C	0.0 mAMPS	0.0 mAMPS	26.0 volts
Feb 13,86	23:15:	3.8 deg C	3.5 deg C	3.7 deg C	0.0 mAMPS	0.0 mAMPS	25.8 volts

Fig. 3 Whole System After 10 Days Operation

6. CONCLUSIONS

A prototype photovoltaics powered pumping system (the Wardun WD 20 "Sunstirrer") was designed, built and field tested. The pump was built using a new, direct drive principal using a DC permanent magnet motor. This enabled an efficient power transfer from electrical energy to mechanical energy to water circulation power to be achieved, minimising the cost of the photovoltaic panels.

An open water patch 20 ft (6 m) across was created after 10 days operation at Menzies Lake (near Merritt, BC). This was a surprisingly large opening in the ice (which was 0.6 m thick) in view of extremely low temperatures during the period. Water temperatures and solar radiation data were measured. Solar radiation during February was more than had been anticipated, and the pump used less power than anticipated to circulate a flow of 25 litres sec^{-1}. With minor modifications the system would be capable of circulating $1\frac{1}{2}$ to 2 times the present flow. In addition we believe it may be possible to dispense with the batteries and use a directly driven (sunshine only) pumping system. This would pump vigorously (at 10 -20 times the present power) in full sunshine, and shut down completely in low light conditions.

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8. REFERENCES

1. **Ashley, K.I.,** "Hypolimnetic aeration of a naturally entrophic lake : physical and chemical effects". Can. Journal of Fisheries and Aquatic Sciences 40 (9), pp. 1343-1359, 1983.

2. **Derrick, A., McNelis, B., Starr, M.R.,** and **Wright, D.E.,** "The state of the art of commercially available, small-scale photovoltaic pumping systems", Proc. 16th Photovoltaic Specialists Conf., pp. 194-198, IEEE: New York, 1982.

3. **Halcrow, W.** et al., Small scale solar powered pumping systems: The technology, its economics and advancement", Main report to the World Bank, UNDP Project GLO/80/003, June 1983.

4. **Lackey, R.T.,** and **Holmes, D.W.,** "Evaluation of two methods of aeration to prevent winterkill". Prog. Fish Culturist 34 (3), pp. 175-178, 1972.

5. **Pulfrey, D.L., Ward P.R.B.** and **Dunford, W.G.,** "A Photovoltaic-Powered System for Medium Head Pumping", Solar Energy (in Press), 1986.

6. **Ward, P.R.B.,** and **Dunford, W.G.,** "Solar Powered Groundwater Pumping for Medium Heads", Challenges in African Hydrology and Water Resources (Proceedings of the Harare Symposium), IAHS Publ. No. 144, pp. 249-258, 1984.