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PHOTOVOLTAIC WATER PUMPING FOR LIVESTOCK IN THE SOUTHERN PLAINS

by

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Summary:

Providing clean, environmentally safe water for livestock in sufficient quantities continues to be a major concern for farmers and ranchers. A photovoltaic water pumping system designed for remote locations began pumping water (0.25 L/min) when the solar radiation intensity exceeded 300 W/m^2. Flow increased linearly with radiation intensity and reached a maximum flow of 4.5 L/min at an intensity of 900 W/m^2. Daily water volumes pumped ranged from high of 1,671 L/day to a low of 504 L/day and averaged 1,105 L/day.

Keywords:

Solar Energy, Solar Power, Water, Pumps

PHOTOVOLTAIC WATER PUMPING FOR LIVESTOCK IN THE SOUTHERN PLAINS[1]

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ABSTRACT

Providing clean, environmentally safe water for livestock in sufficient quantities continues to be a major concern for farmers and ranchers. Abundant water in remote locations is needed to insure that grasslands are grazed evenly. A photovoltaic water pumping system designed for remote locations was operated to determine the performance and reliability of the system and components. The system began pumping water (0.25 L/min) when the solar radiation intensity exceeded 300 W/m^2. Flow increased linearly with radiation intensity and reached a maximum flow of 4.5 L/min at an intensity of 900 W/m^2. Maximum flow was dependent on using the correct controller adjustment as well as the radiation intensity. Daily water volumes pumped ranged from a high of 1,671 L/day to a low of 504 L/day and averaged 1,105 L/day. This pump would provide water for approximately 25 beef animals.

INTRODUCTION

Traditionally man has supplied water for his domesticated livestock by using springs, flowing streams, and handdug wells. One of the early uses of solar power in the form of wind power was to pump water from shallow wells using bucket pumps [Fraenkel, 1986]. In the late 1800's, the American multibladed windmill was developed to pump water from deep wells. These systems provided a year-around water supply and allowed settlement of the area known as the Great Plains. With the deployment of electrical utility systems into rural America, many of these mechanical windmills have disappeared. Many windmills have been in use for over 50 yrs and are simply worn out. Farmers and ranchers are seeking replacements for these windmills for remote water pumping. Additions of remote water pumps to the electrical grid are being discouraged by electric utilities because of the high cost of maintenance of rural electric lines. A high connect fee often exceeds the cost of other fuel alternatives.

An adequate year-round water supply is still a major stumbling block to livestock grazing in many arid regions. Ranchers have found that if sufficient watering places are not provided, livestock do not move to areas of the pasture where grass may be abundant. Cattle will graze

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about one kilometer from a water supply; therefore, several water supplies are needed in most large pastures. Many ranchers continue to haul water for livestock in remote areas.

Livestock animals require various amounts of water depending on their size and weight. Chickens and turkeys require the least amount of water with cattle and horses requiring the most. Table 1 contains a range of water use data for various livestock with smaller amounts applying to smaller animals or cool weather use and the larger amount applying to larger animals or hot weather use. The amount listed for dairy cattle includes the water used for cleaning the milking barn. For most remote locations, water storage for 3 to 5 days is usually provided. If water is stored in an open tank, then the amount of water lost to evaporation must be considered in determining the volume of water needed to meet the demands of the livestock.

Many farmers and ranchers depend on surface waters that are polluted and harmful to the health of their animals. Water can not be pumped because often times energy and labor for servicing engine-driven pumps is unavailable or too costly. The availability and cost for new electrical grid service are often prohibitive. New developments with solar photovoltaic water pumping systems have provided a new potential for pumping water in remote areas. A solar photovoltaic water pumping system for remote areas has been evaluated by the USDA, Agricultural Research Service, Bushland, TX. The objectives of the evaluation were 1) to measure the system performance of a photovoltaic water pumping system; 2) To determine the daily water pumping volumes at various pumping depths; 3) to evaluate the reliability of photovoltaic water pumping systems; and 4) to evaluate the effectiveness of passive tracking systems.

DESCRIPTION OF PHOTOVOLTAIC PUMPING SYSTEM

The system consisted of a photovoltaic panel (PV) array, mounting apparatus, controller, pump, and electric motor. A schematic of a pumping system is shown in Fig 1. PV arrays are comprised of multiple panels containing 30 to 40 individual solar cells, rated at approximately 50 W; and usually wired in 12 or 24 V configurations. For this study, two 53-W panels were wired in series to produce a nominal output of 24 V. The panels were mounted on a tilting frame that allowed the surface to be rotated back and forth to keep the panel surface perpendicular to the sun. Two liquid filled cylinders were used to move the tracker by heating the fluid and causing the hot liquid-gas mixture to move from the hot side (towards sun) to the cooler side (away from sun). The manufacturer claims 55% more energy is collected with the tracker [Zomeworks[3], 1991].

The submersible motor was a DC electric motor rated for 24 V and had a peak current draw of 3.1 A and was mounted directly to the pump. The pump was a diaphragm type pump constructed of marine bronze and stainless steel. The pump-motor combination weighed 6.4 kg

[3] The mention of manufacturer's names is made for information only and does not imply an endorsement, recommendation, or exclusion by USDA-Agricultural Research Service.

(14 lbs) and the outside diameter was 96 mm (3.8 in). The pump-motor combination was 273 mm (10.75 in) long. The pump fit easily inside of 102 mm (4 in) diameter pipe which is often used for small well casing. Fig 2 shows the head-flow and head-current relationships for the pump. Curves representing the manufacturer's data and curves from data measured by USDA are given. The measured flow was slightly higher than the flow presented by the manufacturer, but the two currents were identical.

A controller was used to boost the current to match the load requirements in low sunlight, boost the voltage for maximum pump output when the sunlight was good, and provide voltage regulation of the PV array around its maximum power point [Solarjack[3], 1992]. The controller increased the voltage in low sunlight to above 16 V so the pump would operate, thus providing small amounts of water. In excellent sunlight, the controller limited the voltage at 24 V and increased the current to increase the flow.

The pumping system was operated for several months at the USDA Conservation and Production Research Laboratory, Bushland, TX. The Laboratory is located at a latitude of 35°11' north and a longitude of 102°5' west, with an elevation of 1164 m (3819 ft). The pump was operated at simulated pumping depths of 20, 30, and 40 m. Pumping depths were simulated using a back pressure regulating valve and pressure tank to maintain the desired pressure. Water pressure was measured with a pressure transducer and flow was measured with a turbine meter equipped with an electronic output. All data were sampled every 2 sec and the averaging interval was 1 min. Data were recorded on a personal computer systems using a data acquisition board. The 1 min averages were stored for further processing and real time data were displayed on the monitor. All equipment used was commercially available. For more information on the data acquisition hardware and software, see thesis by Hui Qian [1994].

RESULTS

Incoming solar radiation was measured with a pyranometer mounted directly on the tracking rack. The pyranometer was always at the same sun angle as the PV panels to insure that a correct measurement of incoming radiation was recorded. A 3-day average incoming radiation intensity for August, September, October, November is shown in Fig 3. The intensity level for August was lower because the moisture content in the atmosphere was higher in August resulting in more radiation being reflected; thus reducing the intensity level. The intensity level was about the same during the other months. The effect of shorter days is clearly seen in these data. Data were recorded from 7:45 am to 5:45 pm to reduced the volume of data stored. This time period accounted for over 98% of the pumping volume.

The average flow rate during the same four months described above is shown in Fig 4. The flow for August reflects the lower radiation intensity, but shows the effect of longer days. Some of this reduced flow may be attributable to the lower efficiency of PV panels with increases in temperature. With an increase in temperature from 25°C to 75°C, the output voltage of the PV panel drops by 4 volts [Solarjack, 1992]. This reduced voltage could easily account for the lower pumping rates for August. The low pumping rate for September was probably caused by a miss-adjustment of the controller. Several attempts were made to adjust the controller per manufacturer's instructions during this period. The controller was correctly adjusted in early October and these data verify the criticalness of a correct controller adjustment.

Data from clear days during the four months were combined and binned using solar radiation bin widths of 75 W/m^2. Fig 5 shows the relationship between radiation intensity and voltage output from the PV panel. These data show the effectiveness of the controller to boost the voltage when the radiation is low and to limit the voltage when it exceeds 24 volts. Similarly, Fig 6 shows the relationship between radiation intensity and water flow rates. Water flow began at about 300 W/m^2 radiation intensity and reached a peak flow of about 4.5 L/min. Considering the radiation data from Fig 2, this pump will pump at a rate of 4 to 4.5 L/min for 6 hrs during October and 9 hrs during August. This defines the maximum pumping rate for this pumping system because few days are perfectly clear. Although not shown here, the various pumping heads of 20, 30, and 40 m had less effect on pumping rates than radiation intensity and controller adjustments.

Estimated average daily pumping volumes for each month are shown in Fig 7. These rates were calculated using a regression prediction from Fig 6 and the average monthly solar radiation measured at Bushland. The monthly radiation data base was determined from 19 years of pyranometer measurements (level surface with no tracking). As expected, the summer months provided the most water while the winter months the least; ranging from a high of 1671 L/day to a low of 504 L/day. The yearly average was 1105 L/day, which compares to the 1294 L/day given in the manufacturer's product literature (Solarjack, 1992). One reason for this difference between our estimates and the volume given by the manufacturer is that our long-term radiation measurements were made on a fixed horizontal surface. This pump would provide water for approximately 25 beef animals.

SUMMARY

A photovoltaic water pumping system was operated for over a year at Bushland. TX to determine the performance of the system and each of the components. The system began pumping water when the solar radiation intensity exceeded 300 W/m^2. At this intensity, the flow was usually between 0.25 and 0.50 L/min. Flow increased linearly with radiation intensity and reached its maximum flow of 4.0 to 4.5 L/min at an intensity of 900 W/m^2. Maximum flow was dependent on using the correct controller adjustment as well as the radiation intensity. Daily water volumes pumped ranged from a high of 1,671 L/day in June to a low of 504 L/day in December and averaged 1,105 L/day. This average water volume compares to 8,600 L/day for a mechanical windmill [Clark and Mulh, 1992]; however, the mechanical windmill cost about twice as much as this solar pumping system.

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TABLE 1 Daily Water Requirements for Various Livestock [Neubauer and Walker, 1961].

Animal	Liters/Day
Beef Cattle	40 - 50
Dairy Cattle	60 - 75
Sheep & Goats	8 - 10
Swine	10 - 20
Horses	40 - 50
Chickens (100)	8 - 15
Turkeys (100)	15 - 25
Evaporation	800 - 1200

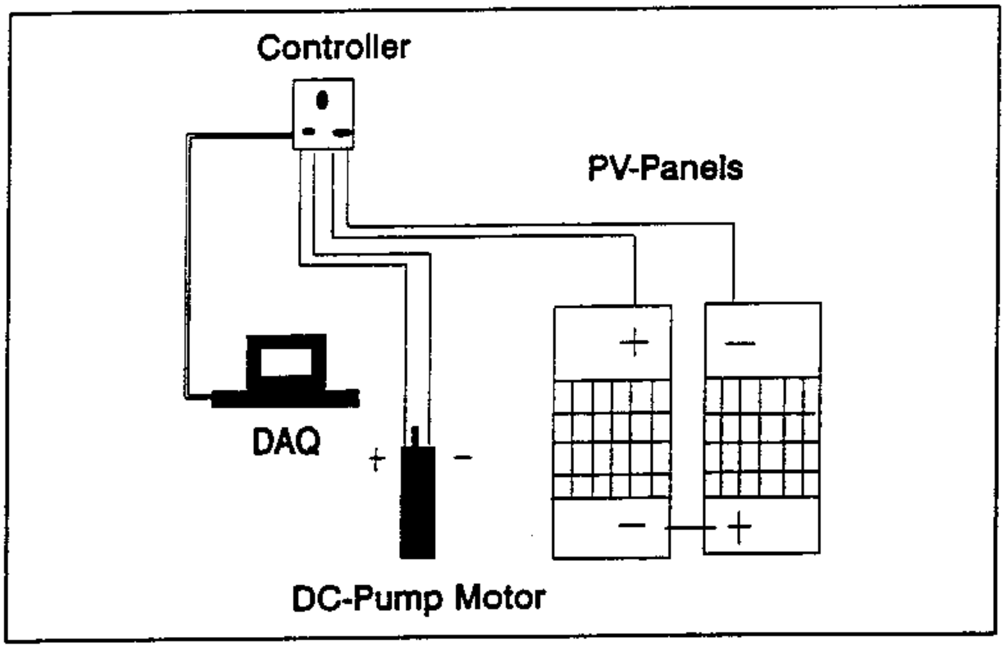

Fig 1 Schematic of photovoltaic water pumping system as tested at Bushland, TX.

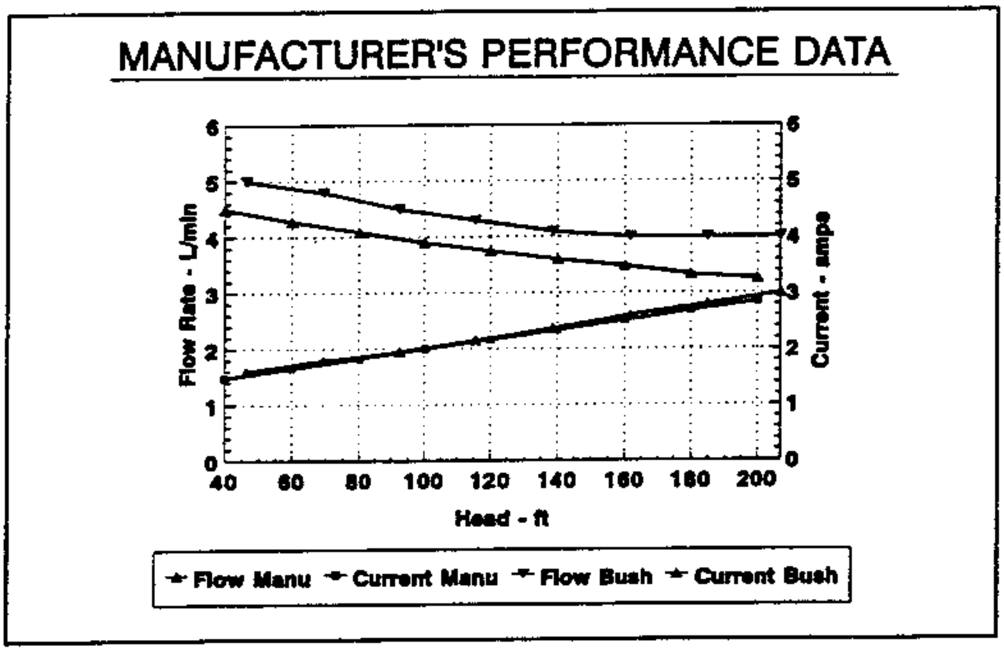

Fig 2 Comparison of manufacturer's published performance data and performance data collected at Bushland.

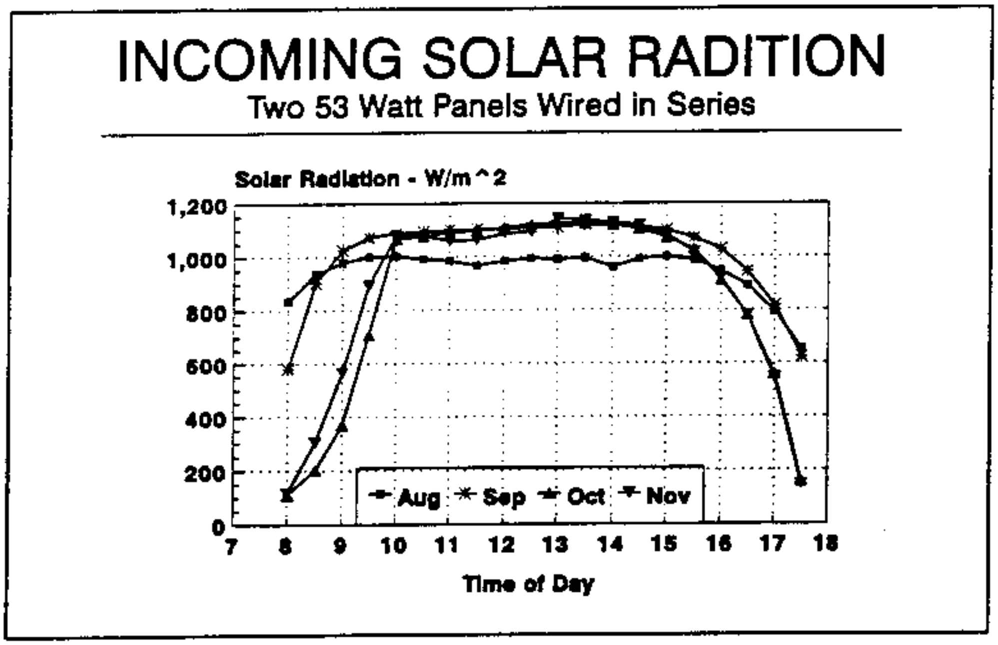

Fig 3 Averaged measured solar radiation intensity on PV panels for three days during August, September, October, and November 1994.

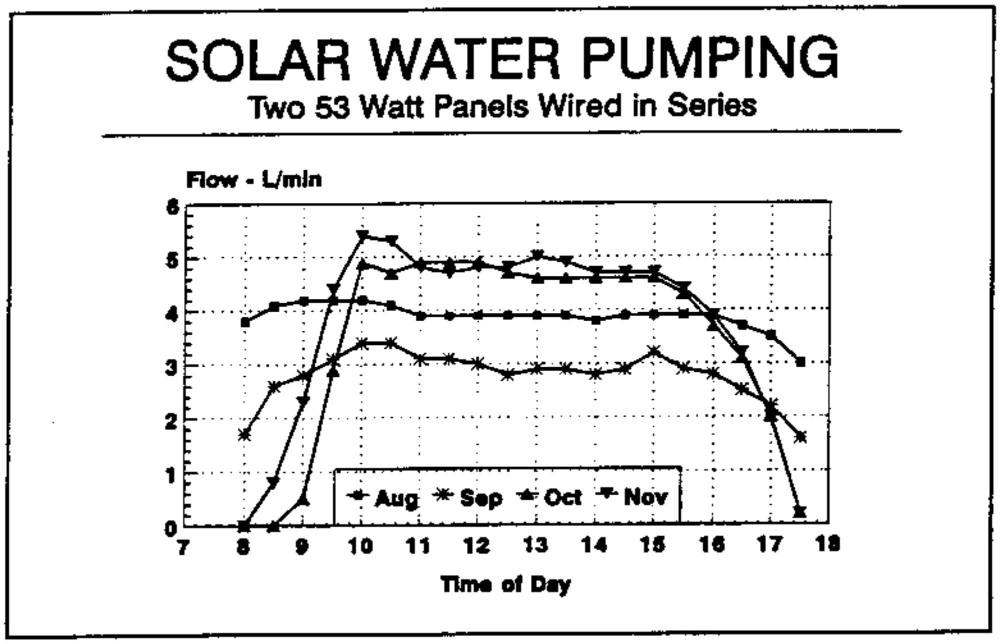

Fig 4 Average water flow rates for each 30-min period during three clear days of pumping in August, September, October, and November 1994.

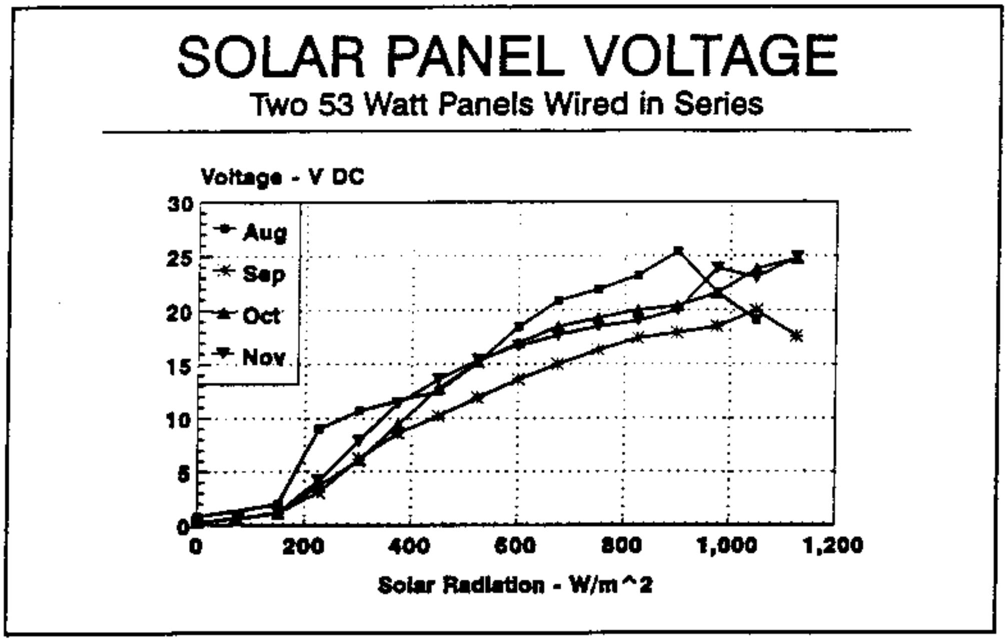

Fig 5 Measured voltage as a function of solar radiation intensity for three clear days in each month.

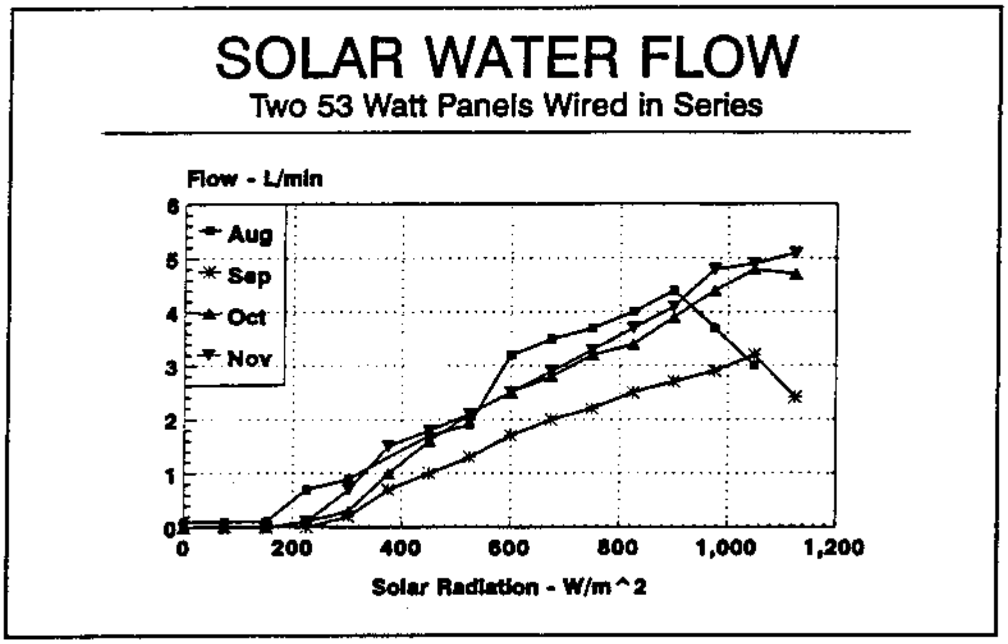

Fig 6 Average water flow as a function of solar radiation intensity for three clear days in each month.

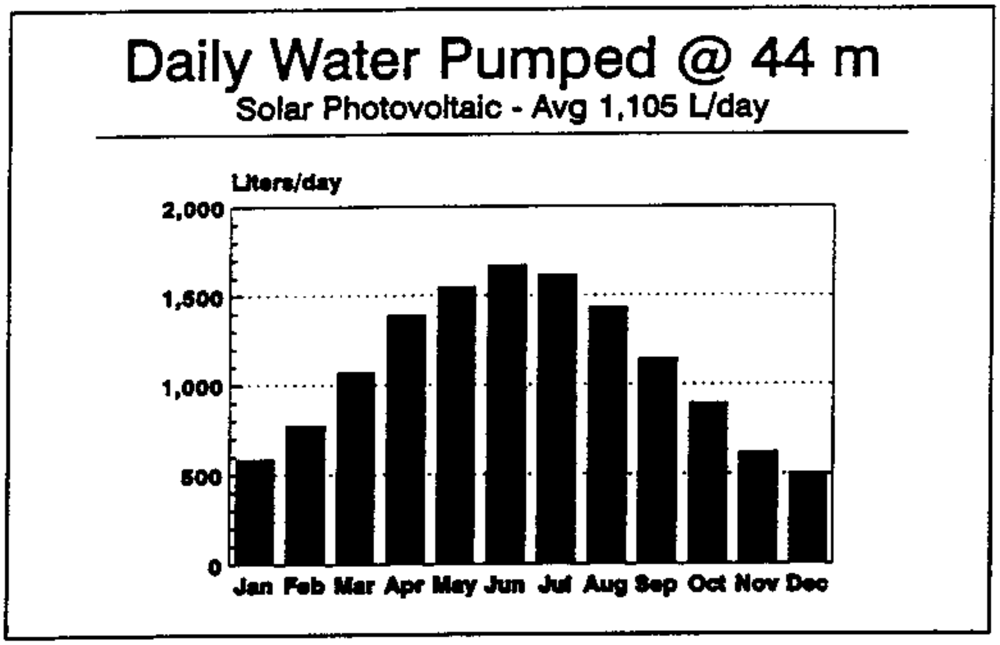

Fig 7 Estimated average daily volume of water pumped using a photovoltaic pump when the pumping head was 44 m (140 ft).