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GLOSSARY

Grid-connection	cabling and interface (possibly requiring a transformer) to connect electrical equipment at a remote site to the nearest mains power lines
Micro-hydro power	small scale hydro electric installation, of less than 100kW rated power.
Mono-crystalline (PV module)	the active part of a solar electric (photovoltaic) power system, where photons are converted into electrons, is the semiconductor material. The most common form consists of thin slices of silicon substrate cut from a single silicon crystal. Such cells are known as “mono-crystalline” and are the most efficient means to convert sunlight into electricity
Pointing lock-gate	a pair of lock gates hung like conventional doors or gates from each side of the lock basin which when closed form a pointing “Vee” in the upstream direction.
Pump-out	installations on the river or canal bank for emptying and receiving the sewage from river craft
PV – solar photovoltaic	a semi-conductor based device with the property of producing electricity when light falls on its active surface, the electricity production being generally in proportion to the intensity of the light
PV Module / Array	a PV module is the basic building brick for a solar PV system; it is a single panel consisting of glazed and weather-sealed solar cells. A set of solar modules can be mounted as an “array” on a frame and wired so as to sum either the current or the voltage from the individual modules to the required level.
Vertical lock-gate	a form of lock gate that slides up and down vertically like a sluice gate or guillotine; these are made of steel and counterbalanced and they are raised and lowered by a mechanical drive mechanism which may be manually or electrically actuated. These gates are most common in Anglian Region of the Environment Agency and are generally paired with a pair of pointing lock gates at the upstream end of the lock.
Wind turbine	common term for a windmill which generates electricity

EXECUTIVE SUMMARY

IT Power Ltd were commissioned in March 1996 to examine the feasibility of using alternative energy sources to provide power for navigation services. The study examined the technical, financial, and environmental viability of different river sites and different energy technologies, culminating in a design study for a specific project to electrify a lock gate drive using a solar photovoltaic power supply. Additionally, decision-making guidelines were prepared to assist Environment Agency staff in assessing navigation sites, energy requirements, and options for instalment.

The study considered the power requirements of vertical lock gate drives, pump-out facilities, electric boat-charging, emergency telephones, and lighting units. The agreed top priority was to focus on the powering of vertical lock gates.

All but one vertical lock gate on the Ouse were found to be electrified already, while all the Medway sites had locks with pointing gates. Therefore the focus of site studies was on the Nene. 7 Nene Locks already had electrified gates, 4 did not have vertical gates, and after consultation with the regional electricity companies, a further 10 appeared to be within cost-effective reach of grid electrification. The remaining 16 sites favoured a stand-alone supply, of which 3 had good hydropower possibilities.

Detailed investigation of the new electrically-powered lock drive at Upper Barnwell concluded that the mean power requirement would be around 370 Watts over a 6 minute cycle, leading to an indicative energy consumption of 37 Watt-hours (Wh) per locking.

The demand for pump-out facilities in the Anglian region is currently very low - not more than 5 times per week - due to the small percentage of boats with enclosed tanks. The proposed pump-out system for use with a stand-alone power supply would involve two FI ITT Jabsco pumps, one for sucking out the sewage and the other to pump rinse water. Their energy consumption per 7 minute pump-out will be a maximum of 88 Wh.

There are currently no dedicated electric boat charging points within Environment Agency jurisdiction in the Anglian region, and no immediate demand was foreseen. Boat-charging demands an order of magnitude more energy than the other facilities considered.

There is an identified need for emergency telephones. It is now legally possible to have a fixed cellular phone if it uses the GSM cellular system. Power consumption is very low and depends on usage, but a maximum of 50Wh per day.

Lighting units might be desirable for illuminating a public toilet, lock, tow-path, emergency telephone, etc. Energy-efficient compact fluorescent lamps are essential for using with a remote power supply: a single lighting unit would typically be an 18W lamp.

The energy requirements of the facilities considered are summarised below in Table 1, looked at for one cycle of usage, and as a peak daily requirement in the month of August.

Table 1 Summary of indicative maximum power requirements for navigation facilities

Facility	Peak Power W	Mean Power W	Cycle Time Mins	Energy per Cycle Wh	Peak No. of Cycles per day	Peak Daily Energy (August) Wh/day
VERTICAL GATE LOCK DRIVE	750	370	6.0	37	15	555
POINTING GATE LOCK DRIVE	4000	4000	2.0	133	15	1995
PUMP-OUT	1500	750	7.0	88	5	440
ELECTRIC BOAT CHARGING	1500	840	600.0	8400	1	8400
1 HOUR OF LIGHTING	18	18	60.0	18	14	252
EMERGENCY TELEPHONE						50 (if always on)

To convert daily energy demands into monthly and yearly figures, data from 1995 lock counts on the Nene were used to estimate the monthly variation in energy consumption for the range of navigation facilities.

In examining the types of power supply which could address these energy demands, the most important natural energy resources to be considered were hydro, solar and wind.

The solar resource is not site-specific and will be roughly constant across the region, at an average of 2.6 sunshine-hours per day over the year. In the summer months (navigation season) the average is 4 sunshine-hours per day, which is strong enough for solar powered devices to be considered an attractive option.

Hydropower is site-specific, requiring a lock or weir to provide a fall of at least 1 metre. The higher the head the better, preferably more than 2m. Flow data indicated that, even in summer months, there will be sufficient flow in the Nene (over 1 cumec) to operate a small hydropower device.

East Anglia experiences annual mean wind speeds of around 5m/s (at a height of 10m), and the wind exceeds 5m/s for about 40% of the time, which is a usable level for exploitation with a wind generator, though not very attractive. Local wind speeds depend on topography and local conditions (trees, buildings, etc.) and ideally need to be measured to have any confidence in the energy capture available.

The two priority end-uses - lock gate drives and pump-out facilities - have energy requirements that are too small for ‘on/off’ type power supplies to be considered cost-effective if supplying only these loads. A battery-based system is the main alternative, charged either by solar photovoltaics (PV), a small hydropower unit, or a wind turbine. Diesel generating sets are not available in sizes small enough to be cost-effective for such small loads, and petrol generating sets are too unreliable and the fuel potentially dangerous to be used in unattended enclosures.

From the technical viewpoint, the two systems that are favoured for implementation in the near term are a PV-battery unit operating a single, small load, or a larger hydro-electric scheme for a range of loads. Both these technologies are commercially available and have been utilised successfully. A smaller hydropower unit charging a battery also appears attractive economically (as an alternative to a PV unit), but is not commercially available.

It is believed that the near-term pump-out requirements for the Nene can be met at two grid-connected sites with sewage main and water supply available, and therefore that there is no immediate need for a stand-alone power supply for these systems. The remote likelihood of finding a riverside sewage main without an electricity supply nearby implies that this application for stand-alone power is unlikely to have a significant market - at least until all grid-connected options have been exhausted first. There is no immediate requirement for pump-outs on the Ouse.

However there does appear to be a significant role for lock-gate drives (and probably drives for many other sluice gates) to be operated by a small stand-alone supply. The study concludes that this can be achieved most reliably by a PV-battery supply. Such a PV unit is not site-specific and would have widespread application in off-grid areas to carry out similar functions. Furthermore it involves negligible environmental impact.

A larger hydro-electric system is attractive for off-grid sites where there are a range of loads to be supplied, and preferably also a ‘dump’ load which can make use of the energy that is not required by the principle loads. Such a system is necessarily site-specific, requiring a reasonable head and flow. However, there are known to be 10s of thousands of disused mills on UK rivers, so there will be wider applicability of this technology for Environment Agency and other applications. To be worthwhile economically, such a scheme needs to go hand-in-hand with an initiative to develop a full range of facilities to utilise the power, and hence a significant investment beyond the power supply system. The main alternative to hydro would be a diesel-electric system, possibly used in a CHP mode (combined heat & power) in which the exhaust gases are used for water-heating.

A detailed design study was undertaken to specify, size and cost a PV power supply for a lock gate drive. A system coupled with the existing type of Rotork actuator is proposed as a technically viable solution which uses proven, commercially available technology, illustrated schematically below.

The cost for procurement and installation of the PV system will be in the range £7000-£10,000. The equipment can be supplied and installed by UK suppliers. The total system cost (including Rotork actuator) will be in the region of £10-12k.

PV systems exhibit outstanding reliability due to the absence of moving parts. Operation and maintenance charges will be minimal relative to the installed cost, and on a 20 year life-cycle costing, the PV system can be considered cost-competitive relative to a grid-connection costing £10,000 or more.

It is recommended that a demonstration project be undertaken to establish the details, function and costs of the technology at a site where grid-connection costs are known to be prohibitive. This would be the first such system in the UK. A PV-powered lock and several sluices have been operating successfully in Holland for over 2 years.

KEY WORDS

Renewable energy
Alternative energy
Navigation services
Remote power supplies
Solar power
Wind power
Hydro power.

1. INTRODUCTION AND OBJECTIVES

1.1 Introduction

As part of planned improvements to navigation facilities, the Anglian Region of the Environment Agency has been installing the powered operation of vertical 'sluice-type' lock gates and boat pump-out facilities. In a number of remote locations the cost of connecting to the public electricity supply has been too high for these projects to be justified.

This study was commissioned in March 1996 to examine the feasibility of using alternative energy sources to provide power for such navigation services, with the objectives detailed below.

1.2 Objectives

- to undertake an overview of the problem of supplying power to off-grid locations, including a review of present knowledge and operating experience.
- to assess the power required by a range of navigation facilities.
- to identify sites that could benefit from on-site power generation from alternative energy sources.
- to asses the technical, financial, and environmental viability of different types of site and different energy technologies.
- to undertake a full assessment of a short-list of options in order to select a trial project.
- to complete a design study for a specific project to allow future implementation.
- to produce decision-making guidelines for Environment Agency staff to assess navigation sites, energy requirements, and options for instalment.

1.3 Structure of the report

The main body of the report summarises the research completed in carrying out the objectives of the project and presents the key results and conclusions. Extra technical information is enclosed in Annexes at the end of the document. The decision-making guidelines are prepared as a stand-alone document, with accompanying Lotus/Excel spreadsheet, and included as Annex **Error! Reference source not found.** to the main report.

2. SITE IDENTIFICATION

The aim of the Site Identification activity was to identify the most promising sites for benefiting from new navigation services and with the potential to exploit alternative sources of energy.

The study covered the navigable waterways within Environment Agency jurisdiction in the Anglian and Southern regions. In practise, it focused upon the rivers Ouse, Nene and Medway, where the majority of locks are found and which experience the highest levels of river traffic.

The main criteria for prioritising sites were assumed as follows:

- unelectrified locks with vertical-type lock gates
- furthest from the grid, or with high cost implications if connected to the grid
- highest levels of traffic
- furthest from other facilities, in particular sewage pump-outs

Information was collected from Environment Agency records, navigation publications, and discussions with regional electricity companies. Databases covering the Nene, Ouse and Medway are included as Annex **Error! Reference source not found.** which record data for each lock on these rivers. The data also includes:

- Head and flow data to indicate which sites offered the greatest hydropower potential.
- The presence of existing moorings, since, if close to a lock, these might prove to be an advantage as a location to situate new facilities such as pump-outs or charging points.

The main points noted for each river are summarised below.

2.1 Nene

- The Nene has 37 locks between Northampton and Peterborough and approximately 1200 boats are registered to use the river.
- 7 of the 37 locks are currently electrified and 4 do not have the vertical type of gate (3 pointing and one radial); 26 vertical gate locks are still manual.
- Of these, 4 sites have maximum falls of 2m or above, and a further 3 are over 1.9m. All these are likely to have realisable heads of over 1.7m. 3 sites have heads less than 1m, effectively ruling out a hydropower option.
- E.Midlands and Eastern Electricity companies indicated that 16 of the unelectrified vertical gates would require grid connections costing over £10k (categories B or C in the database).
- There are 3 existing pump-outs on the Nene (Northampton, Stibbington, Peterborough) and the Environment Agency have identified a short-term need for 2 further facilities. Tom Youdan, Catchment Engineer for the Nene, indicated that 2 sites had been provisionally identified as being suitable for pump-outs, namely Wellingborough Embankment and Thrapston. Both sites have supplies of electricity, water and a sewage main. These facilities would reduce the maximum river distance from a pump-out from 38km to 19km. Further facilities may be needed in the popular stretch between the pump-outs at Thrapston and

Stibbington, and a site at Oundle has also been identified which has water and electricity supplies.

- The busiest stretch of the river is the lower section between Titchmarsh and Orton.

2.2 Ouse

- The Ouse has 15 locks between Bedford and Earith, with approximately 3500 registered boats.
- 10 out of the 11 vertical lock gates on the Ouse have been electrified. The exception is Godmanchester, due to safety and vandalism concerns associated with proximity to a recreation ground.
- The four unelectrified sites with pointing lock gates (Castle Mill, Willington, Gt. Barford, Roxton) are on the quieter part of the river and are regarded by Eastern Electricity as being in the lower range of grid-connection costs (Category A in the database, implying a cost of <£10k).
- The Ouse has 5 existing pump-outs, spaced such that no part of the river is more than 10km from a pump-out facility, and although more pump-outs may be required in the longer term to reduce this distance, Mike Evans, Area FRCN Manager for the Ouse, indicated that there is no immediate pressure for these facilities. The pump-out in the busiest stretch of the river (at Hartford Marina) was said to be used less than 5 times per week even in peak season.
- The busiest stretch of the river is the lower section between Eaton Socon and St Ives.

2.3 Medway

- The Medway has approximately 1300 registered boats
- There are 10 locks, all of the manually-operated pointing-gate type.
- Three pump-out units have been newly installed by the Environment Agency and can be used for free by key-holders.

2.4 Other Rivers

Within the Anglian region, the rivers Ancholme, Glen and Welland are also under consideration for possible navigation services. Other than the tidal locks at South Ferriby (Ancholme) and Fulney (Welland) - manned by lock-keepers - only one other lock has been identified on these rivers, at Harlem Mill on the Ancholme. Since the initial thrust of the project has been to service lock locations, further data for these rivers was not pursued.

2.5 Site Selection Conclusions

The agreed top priority was to focus on the powering of vertical lock gates. All but one vertical lock gate on the Ouse were found to be electrified already, while all the Medway sites had locks of the pointing gate type. Therefore the focus of site studies was on the Nene.

A scoring system was used to rank the unelectrified sites in order of general attractiveness for both utilising a stand-alone power supply, and benefiting from navigation facilities. The 6 criteria used, and the scores available for each one, are summarised in Table 2.1.

Table 2.1 Scoring criteria and weighting

	A	B	C	D	E	F
POINTS	**Maximum Head**	**Mean Flow**	**Type of lock**	**Traffic (1995 lockings)**	**Cost for Grid-con.**	**km to nearest pumpout**
0	<1m	<5 cumecs	Pointing gates	<800	<£10k	<10km
1	1-1.7m	5-10 cumecs	Vertical (or radial) gate	800-1200	£10k-£20k	10-20km
2	1.7-2m	>10 cumecs	-	>1200	>£20k	20-30km
3	>2m	-	-	-	-	>30km
WEIGHT:	**3**	**1**	**5**	**3**	**4**	**4**

The ranked list and total scores are shown in Table 2.2. ‘Weighting’ factors based on the importance of each category are used to multiply the scores under each heading. Total scores and rankings are compiled in the right-hand columns in two sets: firstly using all scoring criteria, and secondly omitting the points attributed to the hydropower resource (head and flow). This ensured that sites with a strong need for a stand-alone power supply but poor hydro potential also stood out.

Twelve sites (underlined) were visited on 5/6 June 1996 to gain an impression of the variation in site layouts and to evaluate their realistic potential for utilising alternative energy sources. As a result, initial best estimates were made as to which sites were most likely to be of interest for a stand-alone alternative energy supply, and which would be better suited for a future grid-connection. Of those suited to a stand-alone supply, these have been divided in Table 2.3 into those which exhibit potential as a hydropower site, and the others where the hydropower potential is less compelling.

Those for which a grid-connection seemed the most cost-effective option are marked with an asterisk if they also had some potential for a future grid-connected hydro-scheme.

In summary, 7 sites already had electrified lock gates, and a further 14 appeared to be within easy reach of grid electrification (of which 6 had significant hydro potential). 16 sites appeared to favour a stand-alone supply, of which 3 had good hydropower possibilities.

An interesting observation during the site visits was that relatively close proximity to the grid did not necessarily mean that a simple and low-cost grid-connection would be possible. For example, according to the electricity companies, sites where the route of a new cable would have to cross a navigable stretch of river are required to have especially tall pylons, leading to high costs, especially if it is not possible to locate these conveniently. Nevertheless, a few sites seemed to present anomalies where a grid cable could be seen on site to power an isolated building or equipment, yet a relatively high price was quoted for grid connection, and it is recommended that any specific future plans be checked again with the Electricity Companies.

Table 2.2 Unelectrified River Nene Locks: site selection by 'point scoring'

		A	B	C	D	E	F	Hydro		non-Hydro	
Lock No.	Lock Name	Head	Flow	Type of lock	Traffic volume	Cost for Grid-con.	Nearest pump-out	Total A to F	Order A to F	Total C to F	Order Cto F
	WEIGHTING:	3	1	5	3	4	4				
23	Titchmarsh	2	1	1	2	2	3	38	1	31	1
19	Lower Ringstead	1	1	1	1	2	3	32	2	28	2
22	Islip	2	1	1	1	1	3	31	3	24	6
24	Wadenhoe	1	1	1	2	1	3	31	4	27	3
21	Denford	1	1	1	1	1	3	28	5	24	7
15	Ditchford	3	0	1	0	1	2	26	6	17	17
28	Ashton	1	1	1	2	1	2	27	7	23	4
17	Irthlingborough	3	1	1	1	0	2	26	8	16	22
16	Higham	1	0	1	0	2	2	24	9	21	5
29	Cotterstock	2	1	1	2	1	1	26	10	19	10
20	Woodford	0	1	1	1	1	3	25	11	24	8
13	Upper Wellingboro'	2	0	1	0	2	1	23	12	17	12
36	Alwalton	3	1	1	2	1	0	25	13	15	13
30	Perio	1	1	1	2	1	1	23	14	19	9
25	Lilford	1	1	1	2	0	2	23	15	19	16
18	Upper Ringstead	0	1	1	1	0	3	21	16	20	19
12	Wollaston	2	0	1	0	1	1	19	17	13	21
32	Elton	3	1	1	2	0	0	21	18	11	25
9	White Mills	1	0	1	1	1	1	19	19	16	15
10	Earls Barton	1	0	1	1	1	1	19	20	16	14
14	Lower Wellingboro'	0	0	1	0	2	1	17	21	17	11
31	Warmington	1	1	1	2	0	1	19	22	15	20
33	Yarwell	2	1	1	2	0	0	18	23	11	24
35	Water Newton	2	1	1	2	0	0	18	24	11	23
7	Cogenhoe	1	0	1	1	1	0	15	25	12	18
11	Doddington	1	0	1	0	0	1	12	26	9	27
8	Whiston	1	0	1	1	0	0	11	27	8	26
1	Northampton	1	0	0	0	1	0	7	28	4	28
2	Rush Mills	1	0	0	1	0	0	6	29	3	30
3	Abington	0	0	0	1	0	0	3	30	3	29

Table 2.3 Categorisation of Nene sites

Already electrified	Potential for Grid Connection	Good potential for stand-alone hydro	Potential for stand-alone supply eg. PV
Weston Favell	Wollaston	Alwalton	Ashton
Clifford Hill	Ditchford *	Titchmarsh	Cotterstock
Billing	Islip *	Upper Wellingboro'	Perio
Upper Barnwell	Elton *		
Lower Barnwell	Rush Mills		Probably:
Wansford	Abington		Northampton
Orton	Whiston		Cogenhoe
	Doddington		White Mills
	Irthlingborough *		Earls Barton
	Yarwell *		Lower Wellingboro'
	Water Newton *		Higham
			Lower Ringstead
	Probably:		Woodford
	Upper Ringstead		Denford
	Lilford		Wadenhoe
	Warmington		
7	14	3	13

* potential for grid-connected hydropower plant

3. ENERGY REQUIREMENTS OF NAVIGATION FACILITIES

This section summarises the types and power requirements of the navigation facilities considered. The two facilities of greatest interest were specified as lock drives and pump-outs, which are covered in greater detail. Energy requirements are described for:

- electrical drives for vertical lock gates
- electrical/hydraulic drives for pointing lock gates
- sewage pump-out units
- electric-boat battery charging systems
- emergency telephone units
- lighting units

3.1 Vertical lock gate drives

3.1.1 Overview

Manual opening of a vertical lock gate is normally via a hand-operated crank, as shown in Figure 3.1. Sufficient power is needed only to ‘tip the balance’ in enabling a counter-balance to raise the gate. Once the gate has been ‘cracked’ open, the power requirement is low, probably less than 50W of manual power.

7 locks on the Nene and 10 on the Ouse have had electrically-powered drive mechanisms fitted. The newest installations at Upper and Lower Barnwell on the Nene are fitted with units supplied by Rotork Controls Ltd of Bath, shown in Figure 3.2. The unit is adapted from a valve actuator and consists of a 415V, 3-phase induction motor operating a worm/wheel drive with an 18rpm output. This is connected to the main vertical shaft of the existing mechanism through a 6:1 reduction gearbox. System operation is governed by an electronic control system.

Problems have been reported with certain electrical drives, including:

- constant operation in hot summer weather causing the thermal trip to be activated
- breakdown or vandalism of the manual override lever
- general vandalism of the control unit

3.1.2 Energy requirement

The Rotork motor has a nominal rating of 750 Watts. Detailed investigation at Upper Barnwell (described more fully in Section 7) concluded that the mean power requirement would be around 370 Watts over a 6 minute cycle, leading to an indicative energy consumption of 37 Watt-hours (Wh) per locking.

Peak usage
Lock counter readings from summer 1995 (see Section 3.8) indicated that the peak usage of the most popular locks on the Nene averaged 12 lockings per day in the peak month, August.

In order to be pessimistic, this has been rounded up to 15 lockings per day in the energy calculations at the end of this section, leading to a peak requirement of 555 Wh/day.

Figure 3.1 Lock gate with manually operated crank

Figure 3.2 Electrical lock gate drive and control box, using a Rotork actuator and 1:6 gearbox

3.2 Electrical/hydraulic drives for pointing lock gates

There are believed to be no such drives currently installed in the Anglian region, nor any immediate plans to power the pointing gates in the region. However this may become a future demand upon an energy supply installed at a lock and summary data has therefore been collected for future reference.

The ‘Oxford’ design of lock gate drive, installed on the majority of Thames locks, utilises a 4kW motor and hydraulic pump which operate a ram on each gate. The operating cycle of 2 minutes for opening and shutting the upstream gates and sluices implies a maximum energy consumption of 130Wh per locking, significantly more than for the vertical gate.

3.3 Pump-out units

3.3.1 Overview

The recommended procedure for pumping out a typical river vessel is as follows:

1. pump out sewage from vessel's tank into shore-based holding tank
2. pump flushing water into vessel's tank
3. pump flushing water from vessel's tank into shore-based holding tank

Hence two pumping systems are needed, one to draw sewage from the vessel's tank and the other to supply river water for rinsing. If mains sewage is not accessible, there will need to be either a large holding tank on shore or a septic tank or some other hygienic facility. Hence most pump-out stations need to be accessible either to mains sewage or a road capable of carrying a slurry tanker. The other option may be a dedicated barge capable of removing sewage.

Typical family boats will deliver 200 to 600 litres of sewage 7.5 to 15 litres per person per day (depending on the toilet system). A few vessels (mainly yachts) have their own pump-out capability so there may be a requirement to provide access for direct pumping by the vessel into the shore-based tank.

Various standardised pump-out facilities exist; many marinas offer coin-operated systems which typically give 7 minutes pump-out time, including flushing. Lee Sanitation, the leading supplier of sanitary equipment for small boats, offer three pumping systems that are suitable for river-side pump-outs. They can package these in weather/vandal proof enclosures and offer key, coin or token operated systems. The three pumping options are summarised in Table 3.1.

Table 3.1 Pump-out equipment supplied by Lee Sanitation Ltd

	Power supply	Power Rating (kW)	Cost (£)
FI ITT Jabsco	240V Single phase	0.75	442
MVD Spate Simplite	240V Single phase	1.1	1886
Vacuum tank system	240V Single phase	1.5	discontinued

The preferred system seems to be the FI ITT Jabsco which involves a direct driven rotary flexible impeller (vane) pump, depicted in Figure 3.3. Although the Simplite pump is a heavier duty pump more suited to longer term operation, it is also considerably more costly, uses more power and is more complicated to maintain. It should be considered if the demand for pump-out services reaches a level where several hours usage per day is required (but this in turn would probably only be readily provided at sites with mains power and mains sewage).

Therefore the proposed system for use with a stand-alone power supply would involve two FI ITT Jabsco pumps, one for sucking out the sewage and the other to pump rinse water.

Figure 3.3 FI ITT Jabsco direct driven rotary flexible impeller pump

3.3.2 Energy Demand

If the FI pumps are used, their energy consumption per 7 minute pump-out will be a maximum of 88 Wh, on the basis that the two pumps will never run simultaneously. (In reality the pumps will probably usually run at less than rated power, but not in all cases).

Peak usage
It was noted in discussions with operators of existing pump-outs on the Ouse that the demand for their facilities is currently very low - not more than 5 times per week - due to the small percentage of boats with enclosed tanks. On the Thames, demand can be up to 200 pump-outs per week. 5 pump-outs per day was estimated as an initial pessimistic ‘ceiling’ on the average demand on a new facility on the Nene during the peak season, and hence a peak daily energy demand of 440 Wh/day.

3.4 Electric-Boat Charging

There are currently no dedicated electric boat charging points within Environment Agency jurisdiction in the Anglian region. Electric boats can be charged from 13 Amp sockets and users are able to come to informal arrangements with marinas or the owners of short-stay moorings. 6 dedicated charging points have been installed on the Norfolk Broads; one exists on the Thames, with a further 14 planned. A standard specification for charging points has now been agreed between the Environment Agency and the British Waterways Board.

With regard to energy requirements, discussions with the Electric Boat Association have indicated the following:

Typical battery capacities are: 175 to 350Ah at 48V for smaller boats, up to 700Ah at 72V for the largest boats.

Taking a 350Ah, 48V system as an example, and assuming 50% maximum battery discharge, one re-charge will require 8400 Wh (8.4 kWh). Maximum charging current is usually 30 Amps, which implies a maximum power requirement of 1.5kW.

Since charging can take 10-12 hours, it appears that one full (night-time) charge per day is likely to be the maximum usage per charging point, though 2 per day is possible and therefore may need to be catered for.

3.5 Emergency telephone

Until recently, it was illegal to have a fixed cellular phone, so that any fixed telephone in the UK was supplied with power from the same cable which connected it to the telephone network. Investigations via a telecommunications consultant indicated that it is now possible to have a fixed cellular phone if it uses the new GSM cellular system. Fixed cellular phones are already in use as emergency phones at unattended level crossings.

Power consumption is very low and naturally depends on usage. To receive incoming calls, there has to be a constant energy supply to operate the receiver, of the order of 50Wh per day. However if only outgoing calls are required, then power need only be consumed at the time of the call.

3.6 Lighting

Lighting units might be desirable for illuminating a pump-out facility, public toilet, lock, bridge, tow-path, emergency telephone, etc. Energy-efficient compact fluorescent lamps are essential for using with a remote power supply. A single lighting unit would typically be an 18W lamp, with either a single 18W bulb (100W equivalent) or 2 bulbs, 11W plus 7W. The number of units required will of course depend on the application.

The ‘worst case’ usage will be for a light required to be switched on for all night-time hours. In the peak season (May-September) this would vary from 8 to 12 hours per day at most, average 10 hours, or 180Wh per day. In winter, the peak usage would rise to 14 hours per day (250 Wh/day).

3.7 Summary

Table 3.2 summarises the energy demand estimates made in the above paragraphs. The last column estimates the average daily demand in the ‘peak’ month. This requires estimates of the maximum number of cycles per day for each facility, as discussed above, and the figures entered below are generally pessimistic estimates.

Table 3.2 Summary of indicative maximum power requirements for navigation facilities

Facility	Peak Power W	Mean Power W	Cycle Time Mins	Energy per Cycle Wh	Peak No. of Cycles per day	Peak Daily Energy Wh/day
VERTICAL GATE LOCK DRIVE	750	370	6.0	37	15	555
POINTING GATE LOCK DRIVE	4000	4000	2.0	133	15	1995
PUMP-OUT	1500	750	7.0	88	5	440
ELECTRIC BOAT CHARGING	1500	840	600.0	8400	1	8400
1 HOUR OF LIGHTING	18	18	60.0	18	14	252
EMERGENCY TELEPHONE						50 (if always on)

3.8 Seasonal pattern of river usage

3.8.1 Lock counters

The seasonal demand for navigation facilities is clearly dependent on the number of boats using the river over any particular period. Lock-counters have been installed on all 37 locks on the Nene. The data recorded for the summer of 1995 are presented Figure 3.4 in the form of the total number of lockings for each lock between April and September, clearly illustrating the busier and quieter stretches of the river.

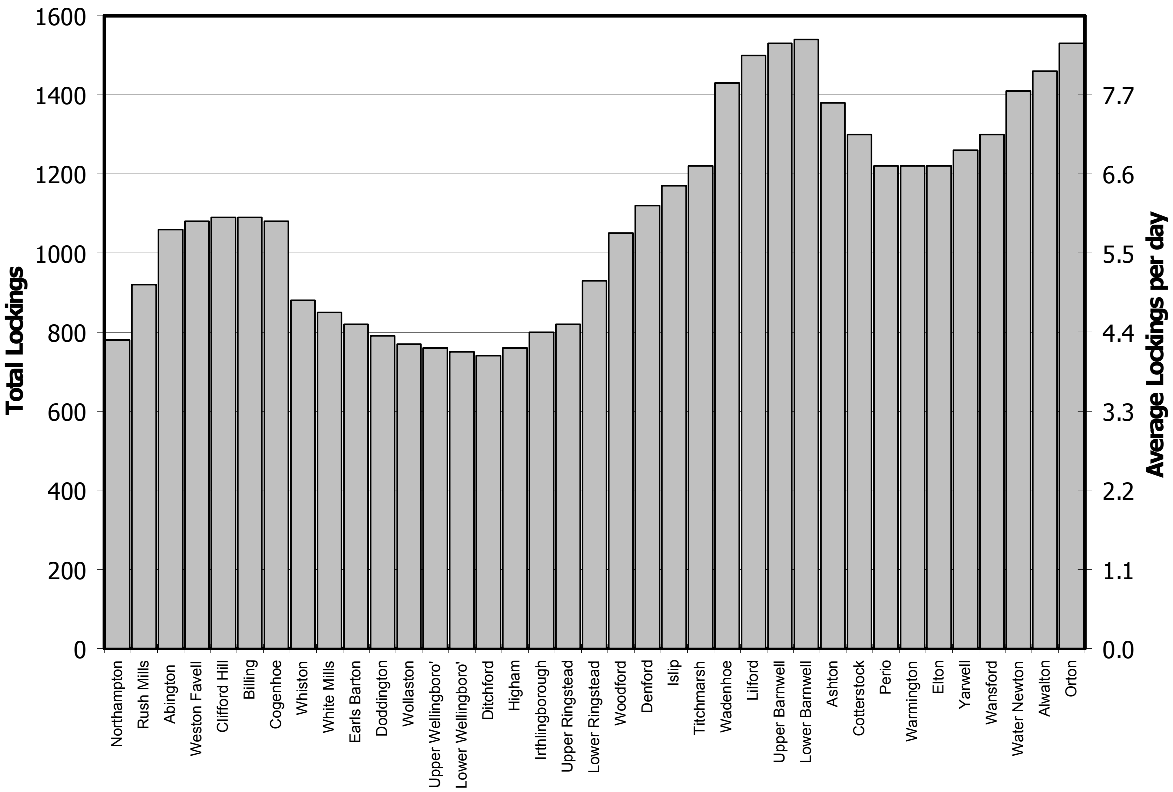

Figure 3.4 River Nene Lock Counts Apr-Sep 1995

3.8.2 Monthly scaling factors

Data was also provided in monthly totals for each lock, included as Annex **Error! Reference source not found.**. This data has been used to approximate a set of generalised 'monthly scaling factors' for the 6 months from April to September. These are intended describe the usage of the river in a particular month relative to the peak usage, which occurs in August. Factors for October and March were arbitrarily estimated at 20% of peak usage, and November to February at 10%. The factors are shown in Table 3.3.

Table 3.3 Monthly scaling factors

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Scale Factor	0.10	0.10	0.20	0.40	0.70	0.55	0.90	1.00	0.40	0.20	0.10	0.10

These figures have been used as a first estimate of the monthly variation in energy consumption for the range of navigation facilities, relative to an assumed peak consumption in August. The only exception will be the use of a lighting facility, for which the pattern is more likely to follow the number of hours of darkness per day, rather than river usage.

The energy consumption patterns will be used to size the various alternative energy technologies considered below. Figure 3.5 illustrates this variation in monthly energy consumption for a lock drive, based on the peak daily estimate of 555Wh/day.

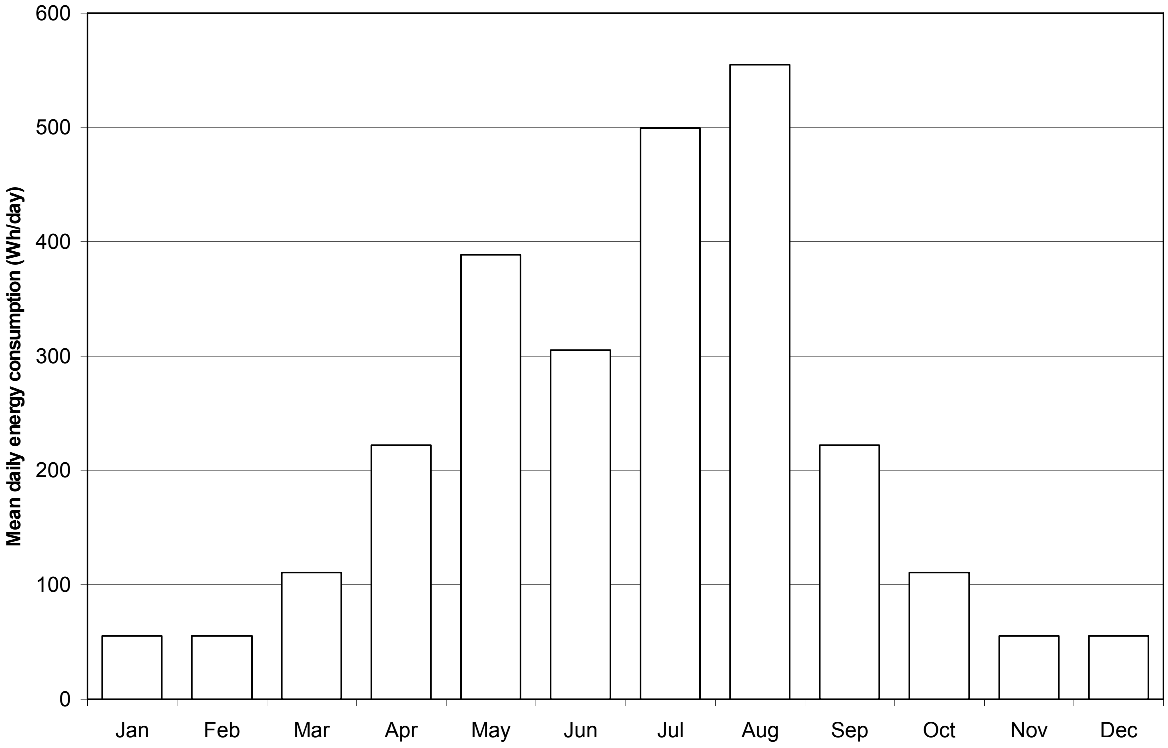

Figure 3.5 Estimated mean daily energy requirements for a lock drive

4. NATURAL ENERGY RESOURCES

4.1 Introduction

There are a variety of energy resources available for delivering electricity into remote areas, ranging from extending the grid or using petroleum-fuelled engine generating sets, to the use of the four main land-based renewable energy resources, namely hydro, solar, wind and biomass. The most important resources in this context are hydro, solar and wind, whose energy potential is quantified in this section.

4.2 Solar power

The maximum power available at the earth's surface due to the sun's radiation rarely exceeds 1000 Watts per square metre (or 1kW/m^2). This value is taken throughout the solar industry as the strength of 'peak sunshine', and can be thought of as the intensity of the sun at noon in mid-summer. Rather conveniently, this means that one hour of peak sunshine is equivalent to 1 kilowatt-hour per square metre (1 kWh/m^2) of incident energy.

The amount of sunshine at a particular location is usually expressed as the average number of peak sunshine-hours per day, or the *mean daily insolation*, in units of kWh/m^2/day. Figure 4.1 shows that in the Anglian Region, the mean daily insolation measured at Cambridge varies from about 0.6 kWh/m^2/day in December, to over 5 kWh/m^2/day in June, with an annual average of around 2.6 kWh/m^2/day. The 'seasonal' average for the middle 6 months of the year is about 4.0 kWh/m^2/day, and is the more relevant figure when considering the power supply to navigation facilities used primarily over the summer months. Figure 4.1 also shows the 'best and worst' recorded monthly sunshine readings, which indicate the statistical reliability of the resource.

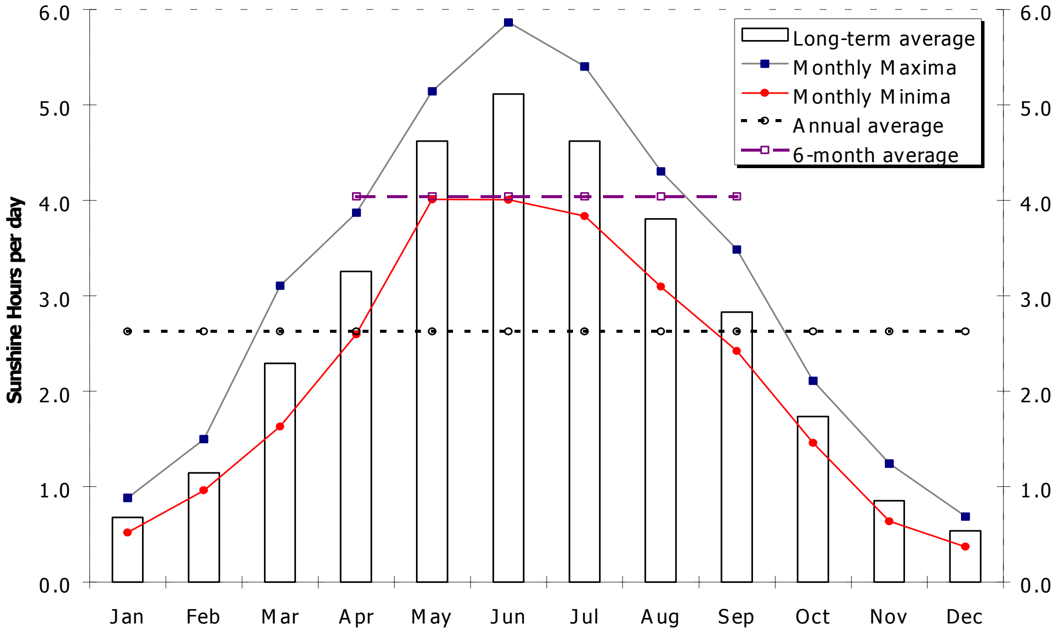

Figure 4.1 Monthly insolation at Cambridge

4.3 Hydropower

The two quantities which define the hydropower resource are the head and the flow. These do not remain constant, and their variation is related. River flow varies over the year with rainfall, and the head drop across a lock or weir varies with the flow rate. However during the summer season, when high flows are rare, the variation in head can be expected to be relatively minor. During winter months, there could be a reduction in peak power due to the head reducing as the flow increases.

Every lock has a nominal upstream water level which is meant to be adhered to, so the maximum possible head at a lock (as recorded for the sites in Annex **Error! Reference source not found.**) is the difference between the nominal upstream level and the nominal level of the next lock downstream. As a first estimate, this maximum head reduced by 0.2m will be close to the summer head.

Flow is more variable than head, but for the small amounts of power under consideration the key parameter of relevance is the minimum flow. If the flow required by a hydropower installation is less than the annual minimum flow, then there will always be sufficient flow for the unit to operate and provide power. In practice, the average minimum flow is rarely recorded, and the closest useful parameter is Q95, or the flow exceeded 95% of the time. If the flow required for a proposed hydropower unit is well below Q95, then it would normally be safe to assume that power will be available from the unit all year round. Q95 decreases as one moves upstream along the river, so for a specific site, Q95 has to be estimated by modifying the Q95 from the nearest gauging point.

In Figure 4.2, the monthly mean flows are plotted for Orton and Northampton on the river Nene, at opposite ends of the navigable stretch. The chart illustrates the seasonal variation of flow, which will be typical for all rivers in the region, with minimum flows from May to October, coinciding with the navigation season.

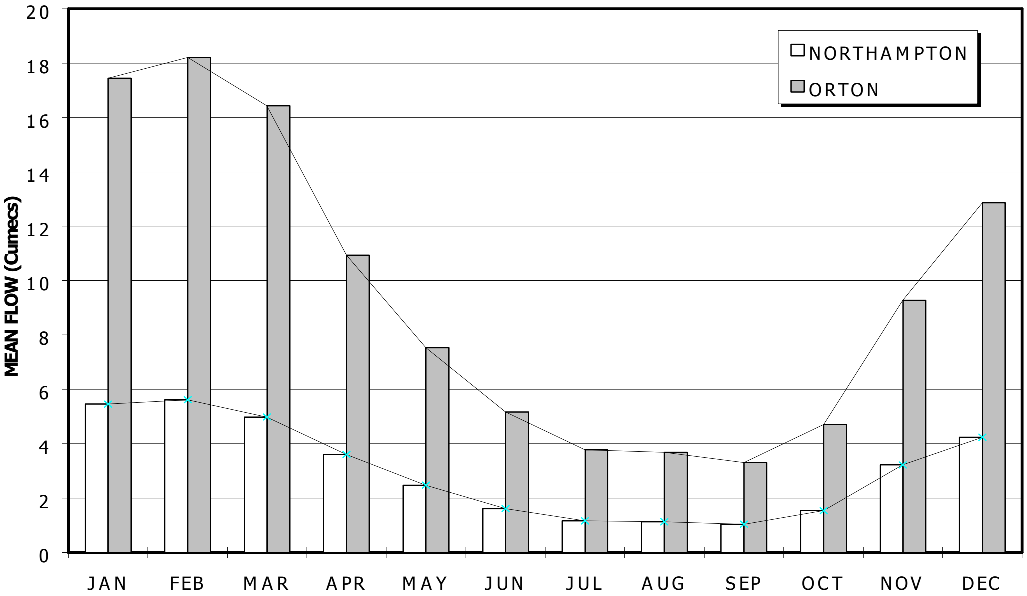

Figure 4.2 Mean monthly flows on the River Nene at Northampton and Orton

Figure 4.3 illustrates the flow and head duration curves for the Nene at Orton. They illustrate that the head hardly varies for the driest 50% of the year, and in a dry year (1991) it remained constant for 80% of the year. The minimum flow at Orton does not fall below 1 cumec; on the upper Nene at Northampton, the flow can fall to below 0.5 cumecs.

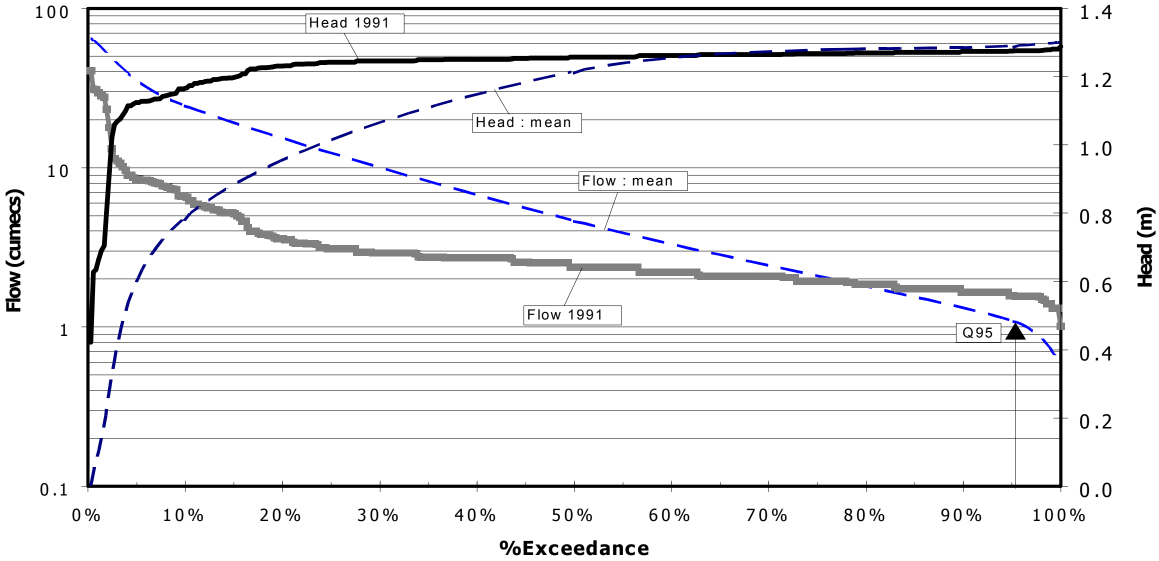

Figure 4.3 River Nene at Orton: Flow and Head Duration Curves, 1991 and long-term mean

4.4 Wind resource

Wind is a site-specific resource which can depend as much on the local topography as it does on the prevailing wind pattern. The wind resource is easy to summarise in general terms as the mean annual wind speed (in knots or m/s), which can be found for a region by consulting the local Met. Office. Alternatively ETSU can provide mean wind speeds for the square kilometre enclosing the site at heights of 10, 25 and 40m. East Anglia as a whole experiences annual mean wind speeds of around 5m/s, and the wind exceeds 5m/s for about 40% of the time.

Commercial wind 'farms' are not commonly situated where the mean wind speed is below 7m/s. These are usually on raised areas such as hill-tops ie. not riverside locations. However there may be locations where the local topography favours wind power, but these can only be determined from knowledge of the site in question.

The problem with the wind is that it is highly site-specific, and can be enhanced or reduced by local topography or the proximity of trees and buildings - especially if these introduce turbulence to the flow. For larger wind installations, decisions are taken only on the basis of data measured over a year or more at the site in question. For small systems, measuring the wind can be done with a cup anemometer, but rather than invest in collecting and analysing this data, it may prove more worthwhile investing in a bigger wind turbine.
In general, the seasonal variation in wind speeds is not extreme (monthly means within perhaps ±20% of the average wind-speed). However, one should bear in mind that the power in the wind is proportional to the cube of the windspeed, so a 20% increase in wind means a 70% increase in available power. Wind speeds are invariably higher during winter months than in summer. These features are illustrated in the wind-speed data for Capel Cynon in

Dyfed, Wales, in Figure 4[1]. (NB. to calculate the energy capture possible for each month requires details of the statistical distribution of the wind-speeds and the performance curve of a specific wind turbine.)

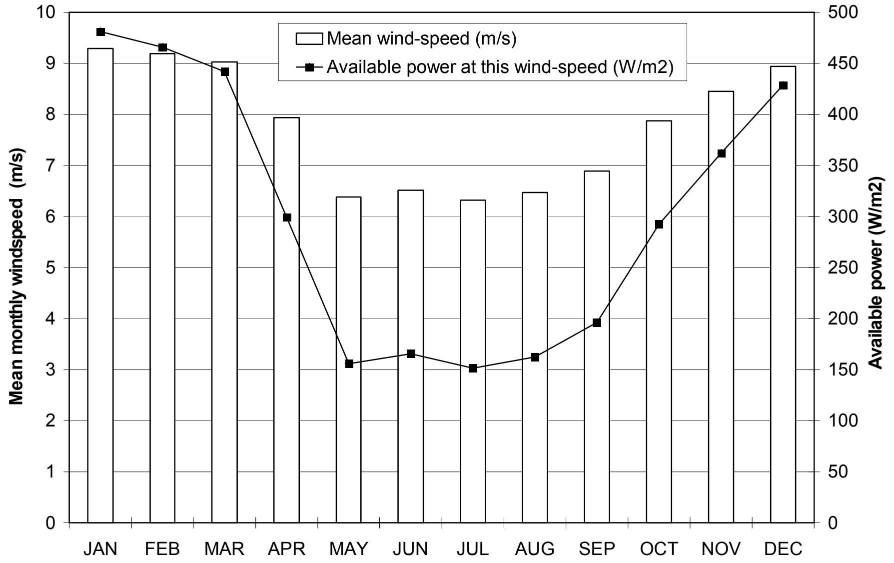

Figure 4.4 Mean monthly wind-speeds at Capel Cynon (6-year average)

4.5 Summary

- The solar resource is not site-specific and will be roughly constant across the region. In the summer months (navigation season) it is strong enough for solar powered devices to be considered an attractive option.
- Hydropower is site-specific, requiring a lock or weir to provide a fall of at least 1 metre. The higher the head the better, preferably more than 2m. Even in summer months, there will be sufficient flow in the Nene to operate a small hydropower device.
- The average wind speed in the Anglian region is at a usable level for exploitation with a wind generator, though not very attractive. Local wind speeds depend on topography and ideally need to be measured to have any confidence in the energy capture available.

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[1] Capel Cynon Wind Data: full summary of recorded data, Rutherford Appleton Laboratory, ETSU W/13/00484/17/REP/B, 1997

5. POWER SUPPLY OPTIONS

5.1 Overview

This section reviews the main power supply technologies that can be realistically considered for supplying navigation facilities in remote locations. The supplies covered in this section are:

- PV-battery supply
- Hydropower-battery supply
- Hydropower 'mains' supply
- Diesel gen-set
- Windpower and other solutions

5.1.1 On/off supplies or energy storage

With a stand-alone power supply, there is a fundamental choice between using a supply connected directly to the load, which is switched on and off each time power is required, or using an energy storage medium (eg. batteries) to act as a buffer between the power supply and the load. The key difference is that an on/off power supply has to be large enough to meet the peak load required, whereas a system with energy storage only needs to be sized to meet the average load, so allowing a much smaller power supply to be deployed.

Energy storage can be achieved in a number of ways, for example through pneumatic or hydraulic pressure, flywheels, or through electrical storage batteries. The storage medium can be more expensive than the power supply itself and, in the case of batteries, it can also be the component with the shortest lifetime.

In general, the smaller the peak load and the more intermittent the power requirement, the more likely it is that energy storage of some sort will be the more cost-effective option. Furthermore, if an intermittent energy resource is being utilised eg. the wind or the sun, then these must be used with a battery to ensure that power is available when the natural resource is not available.

5.1.2 A note on batteries

Storage batteries are relatively expensive, of variable quality, and need to be treated well to achieve a reasonable life-time. In particular, their lifetime is highly sensitive to the depth of discharge that is allowed on each charge-discharge cycle. However, if depth of discharge is controlled so as not to exceed the maximum recommended by the manufacturer, then 10-year guarantees can be obtained. Over a 10-year lifetime, the use of batteries can prove to be highly cost-effective.

Figure 5.1 illustrates how battery life can vary depending on depth of discharge, and shows that a solar battery discharged by no more than 40% can last up to 4000 cycles ie. more than 10 years of daily charging and discharging.

Batteries also constitute a potential safety and environmental hazard. A secure watertight enclosure be needed to prevent public access, vandalism, and ingress of water.

5.1.3 AC or DC

Batteries will supply DC power, probably at 12V, 24V, or 48V. If the need is for AC, than an inverter will need to be incorporated into the system to convert DC input into 240V AC output. Although an inverter adds to the system cost, it may be more than compensated by the convenience and cost-savings in using AC appliances rather than DC equivalents. Furthermore, a DC system requires thicker cabling to take the higher currents at lower voltage without excessive transmission losses.

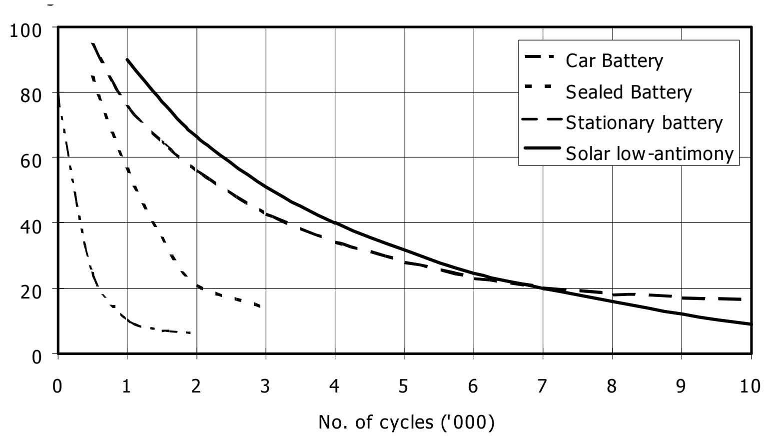

Figure 5.1 Lifetime (in cycles) vs depth of discharge for different types of battery[2]

5.1.4 Electrical vs non-electrical

A further fundamental choice is whether to use electricity as the means of transmitting power, or a range of alternatives such as mechanical drives, or hydraulic or pneumatic systems. Electricity is the most flexible medium, it is easily transmitted, and standard appliances exist for almost any application. So if one type of electrical supply becomes unusable, then another power source can replace it without having to modify all the end-use equipment. Or if a further application needs to be powered at the same site, it may be possible simply to run an extra cable from the same electrical power supply. However, electricity usually involves greater efficiency losses and may constitute a greater safety hazard.

Since the power supplies considered in this study are being judged in relation to a connection to the main electricity grid, and furthermore one of the main identified alternatives, solar photovoltaics, is inherently an electrical supply, the main options considered in this section assume the use of electricity for all the navigation facilities included in this study. This assumption also assists in being able to compare the various options on a like-for-like basis. Further non-electrical options are raised in Section 5.6, but are not pursued further.

5.2 PV-Battery supply

Photovoltaic (PV) modules convert sunlight directly into DC electricity. They have to be used in conjunction with a storage battery because the need for power will never be matched by the availability of sunshine. Figure 5.2 illustrates the main components of a PV-battery supply.

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[2] *Rural Lighting: a guide for development workers*, J-P Louineau, IT Publications, London 1993

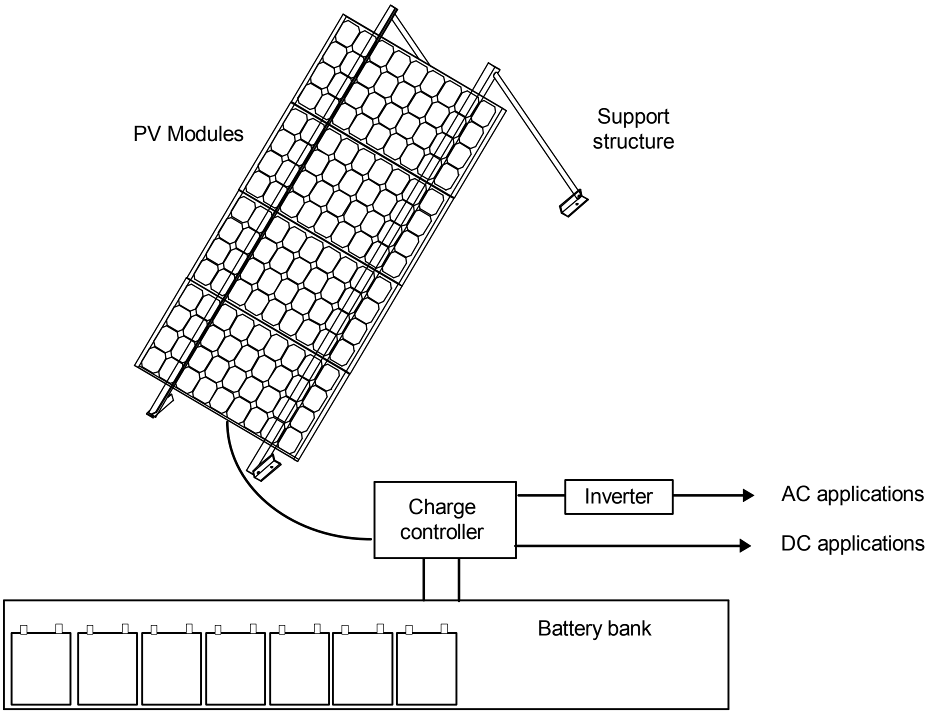

Figure 5.2 Elements of a PV-battery system

PV modules are mounted onto a support structure and angled so that they are south-facing at an appropriate angle to the sun. A steeper angle increases the amount of electricity generated in winter, when the sun is lower in the sky.

Electricity from the modules is fed into the battery bank through a charge controller. As a minimum, the charge controller must ensure that the batteries are not damaged by over-charging. More sophisticated controllers also prevent over-discharging by intelligently monitoring the energy flows into and out of the battery. This means that the controller would disconnect the load, or part of the load, in preference to discharging the battery beyond its recommended level. It is recommended that this more advanced type of controller be used in order to guarantee a long battery-life (see section 5.1.2).

PV systems are modular ie. the number of PV modules, or the battery capacity, can easily be increased to meet higher loads. The cost of a PV system is therefore closely proportional to the size of load being supplied. Since modules and batteries are expensive, it usually makes economic sense to minimise the load by using low-energy appliances. (This priority is less strong with diesel generators or hydropower plants where larger systems are not proportionately more expensive than smaller systems.)

Despite its high capital costs, PV has become an attractive option in recent years because it involves no moving parts, can achieve outstanding levels of reliability, and has negligible running costs.

PV has further advantages in the context off this project because the use of navigation facilities is heavily concentrated in the sunniest 6 months of the year. This enables much smaller PV systems to be used than if the load was sustained throughout the dull winter months. The one application for which this does not apply is lighting, which if required during all hours of darkness, would normally consume twice as much energy in mid-winter as in mid-summer.

The technical viability of using PV-battery units is well-proven and there are a number of UK and European suppliers. Detailed discussions were undertaken with a Dutch manufacturer and supplier of PV systems Marine Solair who specialise in marine applications for PV, for example warning lights, signal operation, lighthouses, buoys, etc. Figure 5.3 shows one of their PV streetlight systems. In particular they have supplied one PV system for operating pointing lock gates in Holland, described in Annex E.

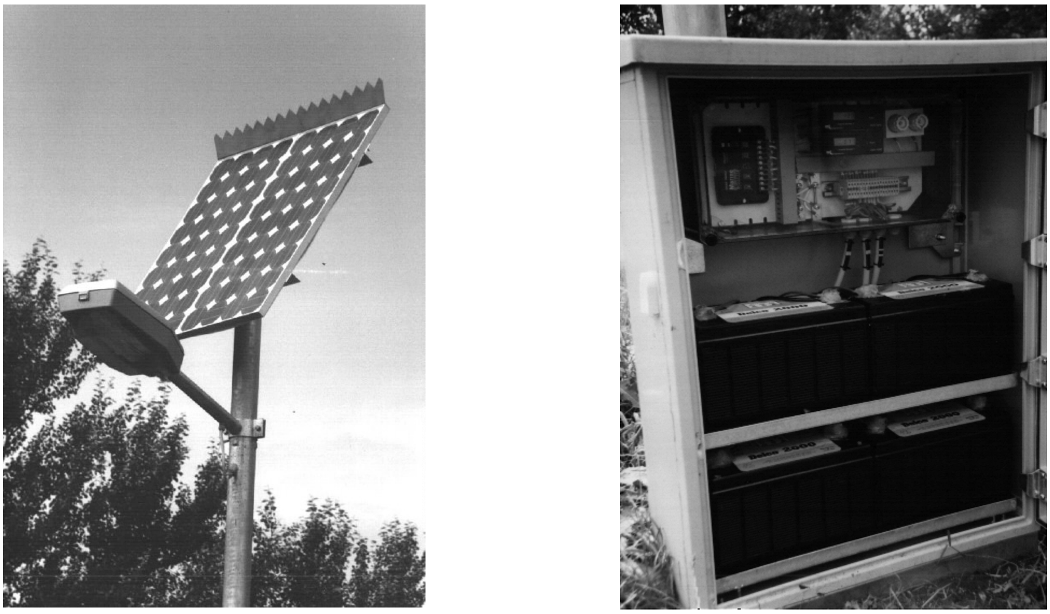

Figure 5.3 PV powered streetlight in Holland with battery bank and charge regulator

5.3 Hydropower-Battery supply

The head of water available at each lock - typically 1-2m in the Anglian region - can in principle be used to run a water turbine. A possible mode of operation would be use an extremely small hydropower unit to charge a battery bank, as a direct alternative to a PV supply.

One advantage of using hydropower is that the energy resource is more predictable than either wind or solar, and never completely disappears. In fact, given the small quantity of flow required, it would be possible for such a small water turbine to run constantly, charging the batteries 24 hours a day. In comparison, a PV supply will only charge the batteries at full power for the equivalent of 4-5 hours per day, even in summer. Therefore, for the same energy capture, a PV supply of 600W peak capacity could be replaced by a hydro unit of only 100W capacity. To give an idea of the scale involved, the rotor of a 100W propeller turbine would be no more than 10cm (4") in diameter.

Furthermore, since the waterpower resource is essentially constant (unlike wind and solar resources) the size of the battery can be smaller to achieve the same level of reliability of supply. This can amount to significant cost-savings on the energy storage element.

The lifetime and maintenance requirements of a hydropower unit are closely related to the hours of running, so it would also be possible to consider a non-continuous mode of operation in order to extend its lifetime. For example, the hydro unit could be automatically controlled to start up only when the battery is in need of charging, similar to the function of an auto-start diesel generating set. This would require adding a more sophisticated control unit with actuators into the system. It is then a question of balancing this added cost and complexity against the extended lifetime achieved.

The only type of water turbine that can realistically be considered for 2m head or less is a propeller turbine.

Enquiries among European hydro manufacturers confirmed that there are currently no commercially-available systems of this type in Europe for such low heads. The only countries which are known to sell battery-charging propeller turbine units are China and Vietnam (see Figure 5.4). These are used for charging one or two car batteries for providing domestic electricity in remote areas, in the 50W-1000W power range. However there are commercial battery-charging hydropower kits available for higher head sites of 10m or over using a different type of turbine, usually a Pelton wheel. These have become popular for remote holiday homes in the USA, for example, plus for developing country applications. One such unit is being used to power lights and a parking meter at a National Trust car park in Wales. Components such as the generator and control system from these units would be directly applicable to this application.

Figure 5.4 Battery-charging propeller turbine, manufactured in Vietnam

There is certainly no technical barrier to the exploitation of as little as 0.5m head with a propeller turbine. The problems revolve around the way the package is put together so that it is easy to install, maintenance-free, and robust in terms of resisting damage from floating debris or any attempt at vandalism.

Manufacturers are unlikely to be interested in 1-off machines of this size; a key aim would be to develop a layout which is not site-specific and could therefore be widely repeatable on, say, hundreds of similar but not identical sites as a standardised package.

Evans Engineering Ltd of Cornwall (a specialist manufacturer of small-scale waterpower equipment) was invited to visit several sites on the Nene and consulted on the design and approach that would best suit existing technology. A simple battery-based system layout was evolved from these discussions which is illustrated in Figure 5.5.

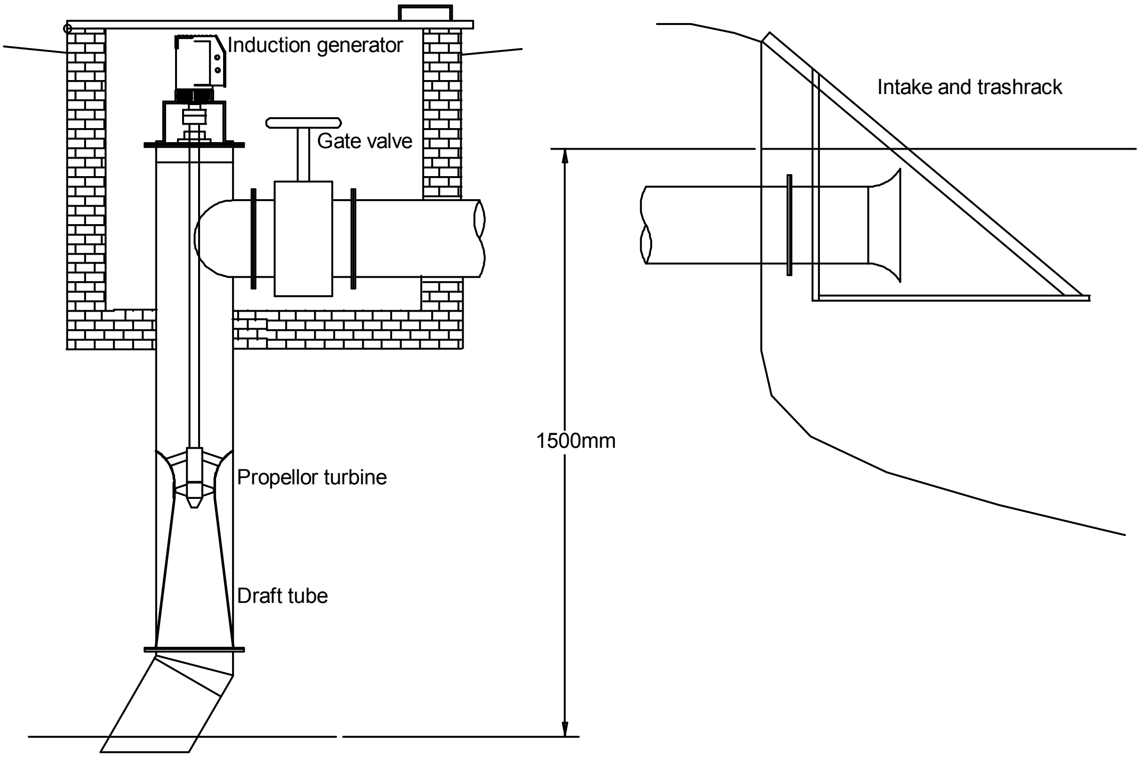

Figure 5.5 Hydropower battery-charging unit: schematic

In the schematic arrangement shown, a buried PVC pipe brings the water from upstream of the lock or weir structure and transfers it to a point downstream of the fall, where it falls vertically through the propeller turbine and back into the river. The turbine unit (propeller, draft tube, shaft, generator) would be a single, standardised assembly which is simply dropped into the vertical pipe and bolted onto the top pipe flange. The system as shown would run continuously and can be shutdown by manual closing of the valve (gate valve or butterfly valve). The unit is shown in a sunken concrete enclosure with secure access door. This could also contain the control unit and battery box. The only evidence of the system would therefore be the access door and a light hum from the turbine and generator.

One key problem area that would need to be resolved is the issue of trash and river debris passing into the turbine. Some type of trashrack, as shown in Figure 5.5, will be essential, but this may become blocked over time, and some potentially destructive items (eg. polythene bags) may still pass through, or might be intentionally pushed through. Automatic rack-cleaners would be prohibitively expensive for such a machine.

5.3.1 Costs

The hardware costs for such a unit (excluding battery costs) could in principle be relatively low, especially if the package was standardised to enable a manufacturer to build batches of several machines, achieving an installed price of below £5000 per unit for a reasonable quantity. However a 1-off project would inevitably involve a significant start-up cost to cover design, tooling and testing. On a 1-off basis, there would probably be little difference in hardware cost between a 100W or 500W unit.

5.4 Hydropower ‘mains’ supply

The more conventional mode for exploiting a hydropower resource is to supply mains-quality AC electricity. Such a unit would be sized to meet the peak load, and generate at this level of power for 24 hours per day. Any electricity not consumed by the loads would be ‘dumped’ automatically (by a standard ‘electronic load controller’) into a resistive heating load which could be used, for example, to heat water for on-site washing facilities. Any attempt to switch in more loads than can be met by the power rating of the machine would lead to a voltage drop and the rejection of one or more of the loads by the load controller until the voltage is restored.

It would probably not be worth installing a hydro-electric unit smaller than 1-2kW, and the flow rates recorded for the River Nene indicate that a scheme up to about 5kW would be able to operate year-round, even during low-flow periods in summer. Since energy is being generated all the time, such a scheme will prove most cost-effective if end-uses can be found to exploit as much of the power as possible for useful purposes, both day and night, winter and summer. An installation of this type will therefore not prove cost-effective for powering a single occasional application such as lock-opening, but may be worthwhile for supplying the full range of navigation facilities under consideration. Figure 5.6 illustrates a 7kW propeller turbine installed on an old mill site in Cornwall.

The costs of micro-hydro schemes of this type can be highly site-specific; the best sites will have the highest available head (preferably >2m) good access, and a convenient location for installing the plant eg. an old mill channel, so as to minimise civil engineering costs (which can otherwise absorb over 50% of the project costs). For example the site at Tichmarsh Lock has a head of 1.75m, good access, a convenient mill-race, plus a boat club on the site currently using a diesel generating set to meet its power requirements and to whom excess power might be sold.

The comments in Section 5.3 relating to trash will still apply in this context, although a larger turbine will be more damage resistant.

Figure 5.6 7kW propeller turbine and generator, on 3m head, Evans Engineering Ltd

5.5 Internal combustion engine generators

Until recent developments in renewable energy technologies, the conventional solution for a stand-alone electricity supply was (and still is) an internal combustion engine coupled to an electrical generator. It was therefore essential to include this option in the study as a 'baseline' comparison with alternative energy supplies.

5.5.1 Basic considerations

Internal combustion engines divide into two main categories:

- diesel or compression ignition (c.i.) engines
- petrol/gasoline/kerosene or spark ignition (s.i.) engines.

Manufacturers usually quote the maximum power an engine can achieve, so a 5kW engine will generally fit a need for continuous power in the range 1.5kW to 3kW (max. continuous) and 5kW (occasional peak). Diesel generating sets are available in power ratings from about 1.5kW to 2kW upwards, while spark-ignition (gasoline, kerosene or LPG fuelled) sets can be obtained with outputs as low as 500W.

It is unusual to use gasoline or kerosene fuelled engines in stationery generating sets for outputs much higher than 5kW since they are less efficient and less robust than their diesel equivalents, but their simplicity and low cost make them the only choice for loads of about 1kW or less, and they are attractive for higher power ratings when portability or low first cost are important. However small spark ignition engines tend to lack the durability of a diesel and since their operational life can be as low as 1500 to 2500 hours they are not well suited for long duty cycles.

Another problem with spark ignition engines, especially if applied in unattended situations, is relative unreliability at starting (compared with diesels) combined with a serious fire/explosion hazard. Remote operation demands enclosure, and a confined space can imply a hazard if there is any form of fuel leak when using such volatile fuels such as gasoline (petrol) or LPG.

Therefore, for the circumstances considered in this project, the need for reliability in operation and starting, relatively long duty cycles and minimum fire or explosion hazard when the engine is installed in a secure enclosure really dictate the use of a diesel engine as the only practical option.

5.5.2 The use of engines for navigation services

Internal combustion engines tend to be badly matched to the needs of small, continuous power applications of under 1kW. They are better suited to continuous loads in excess of 5kW. Therefore, it is normal to supply small electrical loads (which are important enough to justify the cost e.g. telecommunications) by using a diesel generating set to charge a battery bank.

A major supplier of small diesel sets (Haverhill) was contacted for recommendations on systems to suit 3 types of sample loads relevant to this study as follows:

- 200 Wh/day mean (525 Wh/day peak) for lock gate servo power
- 436 Wh/day mean (1150Wh/day peak) for lock gate plus a pump out
- 840 Watts mean on demand (peaking at 1500 Watts) for electric boat charging

Of these three duty requirements, the first two were considered too small to be met conveniently and economically by the smallest size of diesel engine, even if applied via charging a battery.

The electric boat charging duty could be met from a small diesel battery-charger fitted with automatic starting and control system. This would require provision of a 50V 30A battery charging unit, probably powered by a 2.5kW air cooled diesel with electric start. The control system would need to recognise the state of charge of the batteries by virtue of their voltage and cause the engine to run so as to deliver the appropriate charging current. Voltage sensing should allow the engine to maintain a decreasing charging rate as the voltage builds up and then to automatically shut down once the batteries achieve their fully charged condition.

The engine would need to be installed in a secure, vandal proof enclosure with an adequate fuel supply and preferably with automatic lubrication feed for topping up the sump from an extra lubricating oil tank. It will need various sensors to ensure automatic shut-down so as to protect the system from damage in the event of overheating, high vibration, loss of lubricant or fuel, or electrical fault.

The engine will need its own battery to maintain the electronic management system and for starting. The controller would be programmed to "exercise" the engine if it had not been used for some predetermined interval (say 7 days) or if the state of charge of its own battery fell below some predetermined level. An exercise run would usually be timed to take, say, 30 minutes or until the battery was recharged.

Ideally it should have a telephone modem connection to allow its condition to be monitored and to transmit a warning if some form of malfunction occurs. The warning signal can include diagnostic data to give an indication of the likely fault and the modem could also be interrogated to gain an indication of the system status (eg. quantities of fuel and lubricant remaining, hours of operation since last service, etc.).

Various special features would need to be considered. A soundproof enclosure can be provided to reduce noise to a low level. The battery should have jellied electrolyte so that there is no possibility of leakage of battery acid into the local environment. Similarly the fuel tank should be double-skinned and possibly installed in a pit so that the risk of leakage of diesel fuel is minimised and any leak could not enter the river. All these features can be provided by equipment suppliers, but add significantly to the cost.

5.5.3 Costs

Haverhill provided the cost estimate shown in Table 5.1.

Table 5.1 Cost estimate for a Haverhill diesel battery charger

Diesel battery charger (30A x 50V)
Automatic start facility
Electrical management and diagnostic system
Large fuel tank
Enclosure
Total cost: approx. £6000 to £7000

The basic engine and generator are only about half the total price as indicated. If the level of automation and safety monitoring could be reduced, the costs could also be significantly reduced.

Fuel consumption would be approximately 1 litre/hour of running. The running hours between services would be 250 hours but the first service from new would be after only 50 hours. Servicing costs might be around £100 including site visit. The overall useful life would be 5000 hours, but a major overhaul would be needed after 2500hrs costing around £600.

These are "typical" parameters for a small diesel battery charger and should give a reasonable indication of the requirements.

5.5.4 CHP

It should be noted that in addition to its potential use for electric boat charging, a small diesel engine set could be used to power leisure facilities such as a public toilet and washing facility. In this kind of application the exhaust heat could be extracted from a heat exchanger to heat the water supply. A 3.5kW rated diesel will typically deliver around 2 to 3kW of exhaust heat while the engine is running. Supplementary heat could be provided from thermostatically controlled oil-fired boiler running from the same diesel fuel supply.

5.6 Other relevant concepts

5.6.1 Windpower

Windpower may be able to play an important contributory role in battery-based power supplies, but it is unlikely to be used as the sole supply technology except where there is a particularly good wind resource. The wind resource is least favourable in the summer months, and small wind turbines are probably the least reliable of the renewable energy technologies since they can be subject to rare but extremely adverse wind and weather conditions. They are also the most visible of the available systems, and are difficult to isolate completely from the public in terms of damage that either might do to the other. However, they are also the cheapest of the technologies in capital cost terms and therefore should not be ruled out in the right circumstances. In particular, if there is significant power demand outside the peak season, they can be a good match for a PV-Battery supply by providing power to top up the battery in winter months when there is limited sunshine.

The most established UK suppliers of small wind generators for battery-charging are:

- Marlec Engineering of Corby, Northants (20W, 100W and 250W models)
- Proven Engineering of Kilmarnock, Ayrshire (500W, 2.2kW, 5kW models)

Typical wind turbine costs (wind turbine plus control system only) are shown in Table 5.2.

Table 5.2 Prices of commercial wind generators

Machine	Energy capture in 4 to 6m/s wind Wh/day	Cost £
Marlec FM910 - 50W	150 - 500	400
Marlec FM1800 - 250W	500 - 2000	1380

5.6.2 Hydropower: non-electrical options

Whereas photovoltaic and, in practice, wind generators need to generate and store electricity in order to provide energy in a useful form, this is not necessarily the case for hydropower systems (nor diesel engines) whose primary output is shaft power.

It would certainly be feasible to devise a layout in which the fast-rotating shaft of a hydro-turbine was geared down to suit the slow-speed requirements for lowering a vertical lock gate. In this arrangement, the propeller turbine, located adjacent to the lock gate, would be set in motion by opening a gate valve, and the lowering mechanism of the gate then activated by engaging a clutch. The gearing would need to allow for reversing the direction of operation in order to lift the gate again. The details of such a system would need to be worked out and verified, and are beyond the scope of this study, but the fact that it would bypass the need for a battery bank, charge controller, and Rotork actuator, (which otherwise account for a major part of the system cost) plus avoid the need for on-site electricity, indicate that it may be worth pursuing.

A hydropower unit could also be used in conjunction with a storage and transmission medium alternative to batteries and electricity, for example a **pneumatic** (compressed-air) system, or **hydraulic** (probably pressurised water) system. Pneumatics in particular may be an attractive option because both compressors and pneumatic devices tend to be less complicated, lighter and easier to maintain than electric or hydraulic equivalents. Such devices are also robust and can take a lot of mis-use before failing, hence the popular use of pneumatics with engineering tools. Air is also an inherently safe medium to work with.

A hydro-turbine could in theory be connected directly to an air-compressor, probably via a belt drive, which would supply pressurised air to a pressure chamber. The pressure chamber maintains a controlled air pressure to supply to the end-use equipment eg. air motors connected to mechanical equipment such as lock gate drives or sewage pumps.

As with the battery-charger, there would be a choice between operating the turbine and compressor in a stop/start mode, re-pressuring the cylinder only when the pressure falls to a certain level, or running continuously, and discharging the excess air into the river for the purposes of aeration.

5.7 Summary of power supply options

1. The two end-uses of greatest interest - lock gate drives and pump-out facilities - have energy requirements that are too small for ‘on/off’ type power supplies to be considered cost-effective if supplying only these loads
2. A battery-based system is the main alternative, charged either by solar photovoltaics, a small hydropower unit, or a wind turbine. Diesel generating sets are not available in sizes small enough to be cost-effective for such small loads, and petrol generating sets are too unreliable and potentially dangerous to be used in unattended enclosures.
3. A hydro-battery unit of a few 100 Watts would be able to run 100% of the time, so a smaller and cheaper battery would be possible than for PV and wind systems, which rely on intermittent energy resources. A hydro unit would realistically need 1m or more of available head. A standardised propeller turbine unit does not exist commercially and would need to be developed for this application, but the other system components are available from other battery-charging kits. Dealing with trash in the river and guaranteeing low-maintenance operation are key issues that would need to be resolved.
4. PV is not restricted to lock locations, so a PV-powered pump-out unit, for example, could be deployed anywhere. There is a good match between the resource and river-usage, and in Holland a successful PV-operated lock and several PV-powered sluice gates are now in operation. Photovoltaics is also an extremely reliable technology, having no moving parts, but both PV modules and batteries are relatively expensive.
5. Wind-generators are available at lower costs than either PV or hydro, but they need a good wind resource and have lower reliability. Their best role is likely to be in support of a PV-battery system.
6. A larger hydro-electric unit (perhaps 2-5kW) will be a more cost-effective option for larger combinations of end-use devices (eg. electric boat charging and power hook-ups, and including water-heating to absorb all excess power). The main alternative to this would be a diesel-electric system, possibly used in a CHP mode (combined heat & power) in which the exhaust gases are used for water-heating.
7. A hydropower unit could be used non-electrically, either with a direct mechanical drive, or to run a pneumatic or hydraulic system, but would require significant development work to establish a reliable system.

6. APPLYING RENEWABLE ENERGY TECHNOLOGIES TO NAVIGATION FACILITIES

6.1 Introduction

This section attempts to match the energy requirements of the navigation facilities, identified in Section 3, with appropriate power supplies discussed in Section 5, with the aim of confirming appropriate system sizes and costs, and selecting the most promising type of installation for detailed analysis in the Design Study of Section 7.

Two types of energy system were recommended in Section 5 as being most applicable in supplying navigation services, namely PV and hydropower units. PV units are not restricted by location, and are therefore discussed without reference to a specific site. The hydropower unit (option 4) is discussed in the context of a specific site at Titchmarsh Lock.

The systems considered are as follows:

1. a lock gate drive, powered by a PV-battery unit.
2. a pump-out unit, powered by a PV-battery unit.
3. a lock gate drive and pump-out unit combination, powered by a PV-battery unit, but with consideration also for a hydropower-battery unit.
4. a full range of facilities, powered by a hydropower system, using Titchmarsh Lock as a site-specific example.

6.1.1 Target costs

Discussions with the regional electricity companies had ascertained that over half the Nene locks would require an investment of over £10,000 in order to provide a connection to the local grid network. The economics of both a grid connection and an alternative energy supply are similar in that they both have high start-up costs and relatively insignificant running costs. A key aim was therefore to establish whether alternative energy supplies could meet the necessary power requirements at installed costs of less than around £10,000.

6.2 Lock Gate Drive with PV Power Supply

6.2.1 Battery operation : AC or DC

The possibilities for battery operation are either to use a DC actuator powered direct from the batteries or to provide a mains-quality AC supply by passing power from the batteries through a DC/AC inverter.

Both options were considered in consultation with Rotork and the preference is to use an inverter to permit the use of standard AC equipment. The cost of the inverter will be similar to the extra cost that would be paid for a special DC actuator, and the inverter losses will be compensated for by lower cable losses. Hence the cost and efficiency of either option will be similar.

6.2.2 Energy Demand

Section 3 quantified the energy demand of the Rotork actuator as around 370W (mean) over a 6 minute cycle, or 37Wh per locking.

The total energy required from the PV system also has to take into account the losses in the battery and inverter, assuming 90% efficiency in each case, leading to a gross energy requirement of 46Wh per locking.

Table 6.1 summarises the mean daily energy requirements for the month of August, which represents the worst case in terms of river usage. The PV system needs to provide an average of 690 Wh/day, assuming 15 lockings per day.

Table 6.1 Mean daily energy requirements of a PV-powered lock drive in August

Mean Power W	Cycle Time mins	Net Energy per cycle Wh	Battery Efficy	Inverter Efficy	Gross Energy per cycle Wh	No of cycles per day	Energy per day Wh/day
370	6	37	0.90	0.90	46	15	690

Using the monthly scale factors estimated from the 1995 lock counts, the expected daily energy requirement for each calendar month are shown in

Table 6.2 Scale factors and daily energy requirement of a PV-powered lock, shown monthly

Month	Scale Factor	Average Daily Energy Consumption [Wh/day]
Jan	0.1	69
Feb	0.1	69
Mar	0.2	138
Apr	0.4	276
May	0.7	483
Jun	0.55	380
Jul	0.9	621
Aug	1.0	690
Sep	0.4	276
Oct	0.2	138
Nov	0.1	69
Dec	0.1	69

6.2.3 PV System Sizing

A PV power supply is normally sized so that the energy supplied by the PV system will exceed the monthly energy requirement of the load for each month of the year. The battery is designed to ensure that there is sufficient reserve to power the load during periods of poor sunshine.

Penmaritime Solar, a UK supplier of PV systems, was requested to provide a computer simulation for a correctly sized PV system to meet this load, using weather data for Cambridge. The results in Figure 6.1 show that a system consisting of 6 modules was required (3 parallel strings of two modules in series). The right-hand column gives the average daily output in watt-hours for each month of the year, showing that in each month the PV system will supply more energy than the expected demand from the lock drive. Figure 6.2 illustrates the monthly variation in energy demanded by the lock drive versus energy available from the PV system.

```
PV SYSTEM PERFORMANCE ANALYSIS PROGRAM

INSOLATION DATA LOCATION:  CAMBRIDGE
LATITUDE:  52.22 DEG N     LONGITUDE:    0.10 DEG E

ARRAY SIZE:  2 (S)  X  3 (P)   SIEMENS M55 MODULES

ARRAY TILT:  45.0 DEGREES, FACING DUE SOUTH

SYSTEM LOAD TYPE:  CONSTANT VOLTAGE TRACKING @ 24 VOLTS
WIRING INFORMATION:  1 VOLT OF FIXED VOLTAGE LOSSES

         (BASED ON 90% OF RATED OUTPUT

                       RADIATION     RADIATION
              MONTH    HORIZONTAL     PV ARRAY    MAX CELL      DAILY DC
                       kWh/m²/day    kWh/m²/day   TEMP (C)      WATT-HRS
               JAN        0.63          1.38        11.2         283.88
               FEB        1.24          2.29        14.7         470.91
               MAR        2.31          3.41        20.8         703.22
               APR        3.28          3.92        24.1         805.37
               MAY        4.52          4.70        29.0         964.81
               JUN        5.22          5.10        32.8        1044.75
               JUL        4.65          4.67        33.3         956.64
               AUG        3.79          4.29        32.7          878.8
               SEP        2.92          4.01        30.6         826.99
               OCT        1.69          2.91        15.3         602.44
               NOV        0.89          1.89        16.8         391.35
               DEC        0.52          1.25        12.0          257.2

YEARLY TOTAL OF DC ENERGY DELIVERED BY THE ARRAY:  249,414 WATT-HRS
```

Figure 6.1 PV system sizing programme: PV lock drive

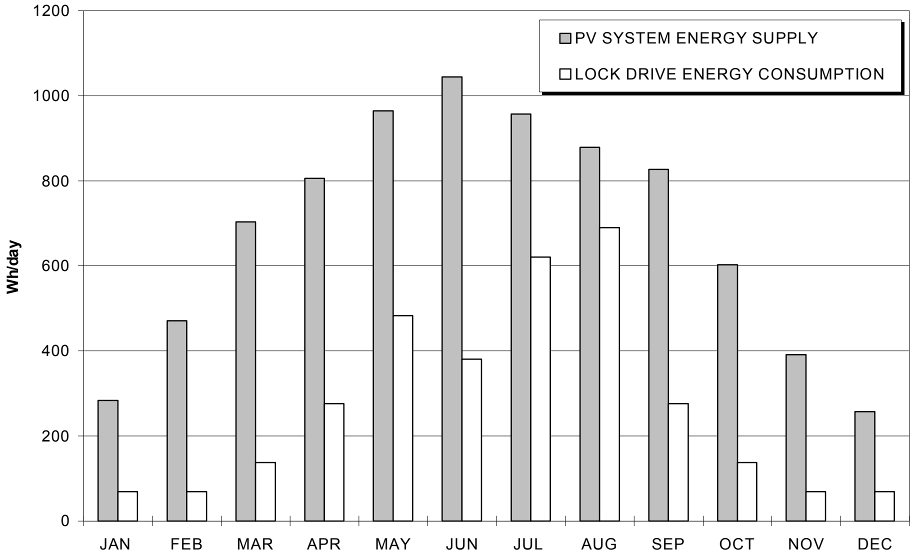

Figure 6.2 Monthly energy supply vs consumption for a PV lock drive

6.2.4 Cost Estimates

Table 6.3 provides rounded cost estimates for the PV power supply based on known 'typical' costs from similar installations, and on the basis of a one-off system. A detailed economic analysis is undertaken in Section 7.

Table 6.3 Budget PV system costs

Item	Cost estimate (£)
Modules M55 x 6	1,750
Module Support Structure	750
Batteries	1000
Charge Controller	100
Inverter	1500
Cabling and accessories	250
Installation (electrical/mech.)	800
Vandal-proofing measures	150
Housing	1000
Foundations	500
Total:	**7,800**

6.3 Pump-out Facility with PV Power Supply

6.3.1 Energy Demand

The energy consumption per 7 minute pump-out is estimated to be a maximum of 88 watt-hrs, assuming the use of two FI pumps.

Table 6.4 summarises the energy requirements for the month of August. As no reliable figures for the usage of pump-out facilities are available, three scenarios are shown which relate to three levels of usage: base case, low and high usage. The low usage scenario is probably closest to present reality, while the base case and high usage assume compulsory pump-out legislation to be in force.

Table 6.4 Mean daily energy requirements of a PV-powered pump-out in August

Parameters used						Low usage		Base case		High usage	
Mean Power W	Cycle Time mins	Net Energy per cycle Wh	Battery Efficy	Inverter Efficy	Gross Energy per cycle Wh	No of cycles per day	Energy per day Wh/day	No of cycles per day	Energy per day Wh/day	No of cycles per day	Energy per day Wh/day
750	7	88	0.9	0.90	108	1	108	5	540	10	1080

The average daily energy requirement for each month is shown in Table 6.5

Table 6.5 Scale factors and daily energy requirement of a PV-powered lock, shown monthly

Month	Scale Factor	Average Daily Energy Consumption (Wh/day)		
		Low usage	Base case	High usage
Jan	0.1	11	54	108
Feb	0.1	11	54	108
Mar	0.2	22	108	216
Apr	0.4	43	216	432
May	0.7	76	378	756
Jun	0.55	59	297	594
Jul	0.9	97	486	972
Aug	1	108	540	1080
Sep	0.4	43	216	432
Oct	0.2	22	108	216
Nov	0.1	11	54	108
Dec	0.1	11	54	108

6.3.2 PV Power Supply

A PV power supply for a pump-out station was sized on the same basis as the lock gate drive. The computer analysis in Figure 6.3 shows the expected energy production of a PV system sized for the base case defined above. In this case a 4-module PV array is sufficient. The system components and installation details are otherwise the same as for the lock-drive.

```
PV SYSTEM PERFORMANCE ANALYSIS PROGRAM

INSOLATION DATA LOCATION:  CAMBRIDGE
LATITUDE:  52.22 DEG N     LONGITUDE:    0.10 DEG E

ARRAY SIZE:  1 (S)  X  4 (P)   SIEMENS M55 MODULES

ARRAY TILT:  45.0 DEGREES, FACING DUE SOUTH

SYSTEM LOAD TYPE:  CONSTANT VOLTAGE TRACKING @ 24 VOLTS
WIRING INFORMATION:  1 VOLT OF FIXED VOLTAGE LOSSES

         (BASED ON 90% OF RATED OUTPUT

                         RADIATION      RADIATION
              MONTH     HORIZONTAL      PV ARRAY     MAX CELL       DAILY DC
                        kWh/m²/day     kWh/m²/day    TEMP (C)       WATT-HRS
               JAN         0.63           1.38         11.2          189.26
               FEB         1.24           2.29         14.7          313.94
               MAR         2.31           3.41         20.8          468.81
               APR         3.28           3.92         24.1          536.91
               MAY         4.52           4.70         29.0          643.21
               JUN         5.22           5.10         32.8          696.51
               JUL         4.65           4.67         33.3          637.77
               AUG         3.79           4.29         32.7          585.87
               SEP         2.92           4.01         30.6          551.33
               OCT         1.69           2.91         15.3          401.63
               NOV         0.89           1.89         16.8          260.91
               DEC         0.52           1.25         12.0          171.47

YEARLY TOTAL OF DC ENERGY DELIVERED BY THE ARRAY: 166,276 WATT-HRS
```

Figure 6.3 PV system sizing programme: PV pump-out

6.3.3 Costs

The expected inventory and budget costs for the total system installation (not including site preparation and any sewage holding tank) is as summarised in Table 6.6.

Table 6.6 Budget PV pump-out system costs

Item	Cost (£)
PV SYSTEM	
Modules M55 x 6	1200
Module Support Structure	750
Batteries	700
Charge Controller	100
Inverter	750
Cabling and accessories	200
Installation (electrical/mech.)	600
Vandal-proofing measures	150
Housing	1000
Foundations	500
Sub-Total	**5950**
PUMP-OUT UNIT	
2 x FI pumps	884
Hoses and fittings	100
Stainless Steel lockable housing	1000
Control pedestal housing	475
Hose hanger stand	700
Coin / token control system	1400
Misc. items	100
Sub-Total	**4659**
TOTAL:	**10609**

6.4 Lock-Drive and Pump-Out Combination

6.4.1 Energy Demand

The energy requirement (and power rating) for a combined lock gate and pump-out will be simply the sum of the requirements for the two systems considered in isolation.

6.4.2 PV-Battery Supply

Even at sites where both functions are needed, it is unlikely to make sense to combine the two systems into a single integrated unit, but to install two independent PV systems with two independent power supplies. There is no significant economy in combining 2 PV systems (it leads to a non-standard installation which may even cost more) and the location of the pump-out may be compromised by the need to minimise cable runs between it and the lock gate. There would naturally be some small savings on installation costs if two systems were installed instead of one.

However, it also needs to be borne in mind that, depending on the site, the investment required for two PV systems may exceed that for a grid connection.

6.4.3 Hydropower-Battery Supply

The greater load produced by the combination of lock-drive and pump-out enhances the case for considering a hydropower unit. As presented in Section 5, an extremely small hydropower unit could be used to charge a battery bank, as an alternative to a PV supply. Such a system is technically viable, but has a few unresolved questions. After consideration of the available information, it is the consultants' view that in the near term, this technology is not as attractive as the PV-battery option, for the following reasons:

- There are no commercial units available in the UK or Europe
- The commercially available systems from SE Asia are not designed for non-stop unattended use, and are reported to have a life-time of only 1-2 years.
- Some investment in development work would therefore be required for a manufacturer to produce a commercial product of the appropriate quality.
- Projects would be unlikely to be viable on a one or two-off basis. Reasonable batches would be required to achieve a competitive price for the product and it is not evident that there would be a market for these numbers.
- In some respects this technology is too small - more in the realm of model-making, giving rise to small, fiddly mechanical components that are harder to manufacture and assemble to the required precision than those for a larger and more powerful system.
- There are a number of question marks relating to long-term reliability which would be difficult to solve cheaply or with sufficient certainty, mainly related to the likely blocking of the water channels with leaves and river debris, or the potential for damage to the turbine from fishing twine, squashed drinks cans, etc. which might accidentally or intentionally pass through the trash-rack and into the water intake.

If a sizeable market could be identified for this product, the above points could be addressed through a development and demonstration project which might lead to a more economically attractive product in the longer term than the PV option which is currently favoured. 14 of the 16 identified sites on the Nene would have sufficient head to be able to utilise such a system.

6.5 Full Navigation Facility : Titchmarsh lock

6.5.1 Overview of Possible Load Applications

A more ambitious future development for navigation facilities might involve not only lock-gate drives and pump-out facilities but also:

- electric boat charging points
- power hook-ups
- heated water for washing and showers
- local lighting, telephones, etc.

Such a development would normally only be considered if grid electricity were available. However several of the locks, and associated weirs, on the Nene have the potential for generating 10s of kW of hydro-electric power. If there is sufficient demand for this power (i.e. applications which will make it pay) then this can be a cost-effective method for providing significant amounts of power in remote areas. If sized and operated correctly the scheme could supply mains-quality AC electricity all year round to power the range of facilities listed above.

An attractive site for such an installation has been identified at Titchmarsh Lock. The cruising club[3] on the site currently use a diesel generating set to meet its power requirements and have expressed interest in benefiting from a hydro-electric scheme.

6.5.2 System Sizing

For such a system, the unit would be sized to meet the peak power demand (rather than the mean energy demand - as with a battery-based system) i.e. it needs to be large enough to supply the power drawn when all appliances are switched on. The maximum power that can be supplied is dictated by the available head and the varying flow in the river.

The head at Titchmarsh is 1.75m (measured on 3 separate visits) and the flow characteristic is shown in Figure 6.4, both the long-term flow-duration curve and the curve for 1991, a dry year. These curves are inferred from the mean flow measured upstream of Titchmarsh and the shape of the duration curves for Orton. The chart shows that 1 cumec or more is normally available for all but a few days per year. 1 cumec would enable a hydro generating capacity of about 10kW to be considered. However, this flow would normally be divided between the lock channel and the main river. A minimum ‘environmental flow’ would need to be left in the river, probably in the range 0.25-0.5 cumecs but to be agreed with the Environment Agency, leaving a reduced figure for the hydroplant.

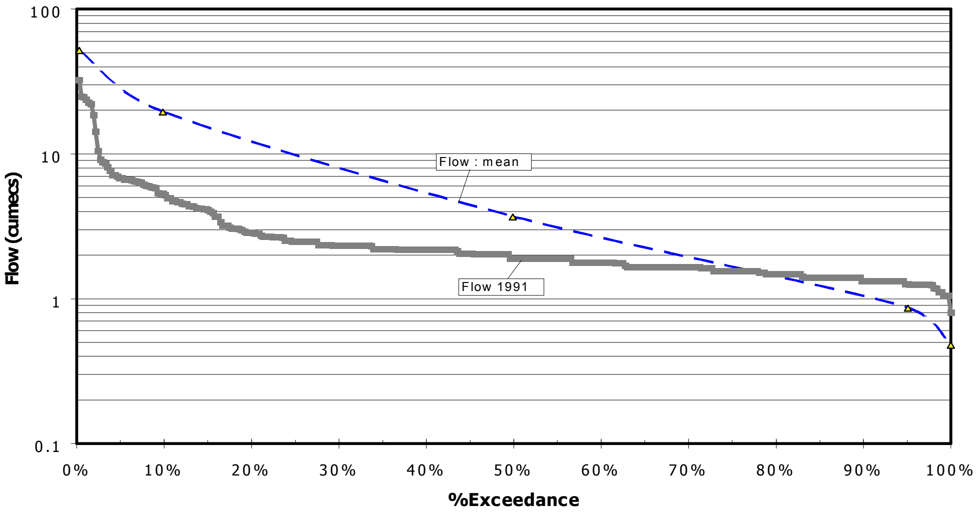

Figure 6.4 Flow Duration Curves for the River Nene at Titchmarsh: 1991 and long-term mean

The size of unit depends on the number and type of facilities to be powered on site: the hydroplant would preferably be able to cope with all appliances switched on at the same time, although some limited power management (cutting off lower priority loads for short periods) could reduce the peak load. The minimum power requirement would be around 1.5kW, but in fact it would not be worth installing a hydro-electric unit smaller than about 2kW, and since demand for power usually grows once it becomes available and there is little price difference between such small units, it is generally cost-effective in the long-run to install the largest scheme which can operate all year round. Hence for Titchmarsh, a scheme in the range 5.0 to 7.5kW is proposed as the most sensible option.

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[3] Contact: Joyce Mains, 12 Charles St., Thrapston, Northants, NN14 4NU

6.5.3 Scheme Layout

Figure 6.5 illustrates the layout at Titchmarsh lock. The proposed scheme would utilise the existing civil structures of the mill building on the site.

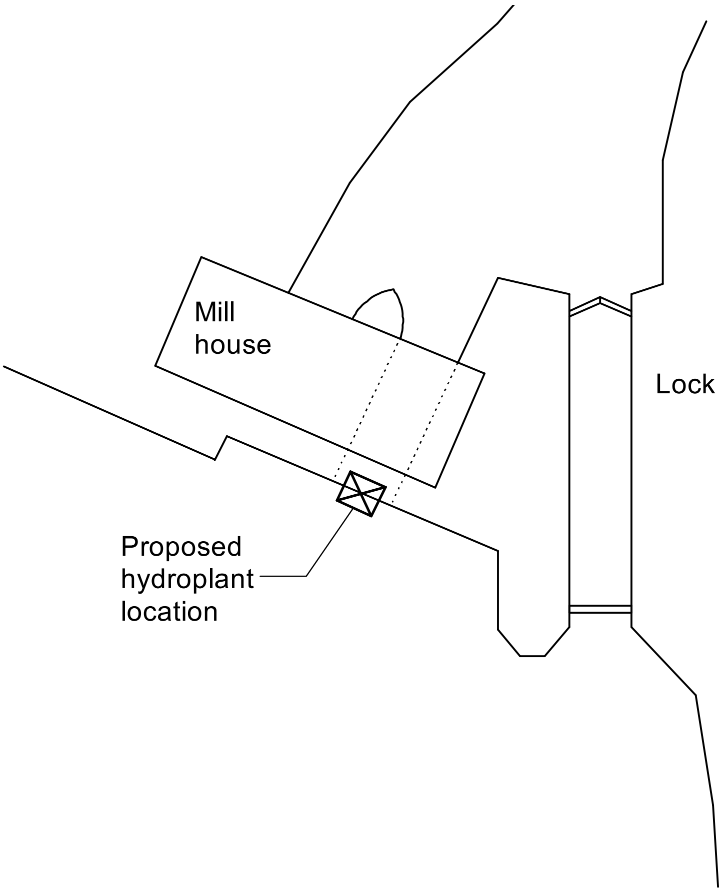

Figure 6.5 Schematic layout of Titchmarsh lock and proposed hydropower plant

The mill-house is used by Middle Nene Cruising Club, who lease it from Merchant Ventures, agents for the land-owner. The Mill Rights are owned by the Environment Agency (agreement dated 1942) which confirm the upstream level (86.4m) that has to be maintained by the mill for navigation purposes.

The mill has two mill-races. One runs under the mill-house and has been blocked upstream by a concrete wall. The second has a sluice gate at the upstream end which is normally closed but is used to allow high river flows to pass down the mill-race, bypassing the lock.

Relatively small modification of the end of the open mill-race would allow a scheme of the type shown in Figure 6.6 to be installed. The mill-race would run full of water, with a propeller turbine mounted at the downstream end angled at 45°. A small power-house would be mounted above, situated adjacent to the track which runs past the mill-house towards the lock. There is excellent access for installing the machinery and no need to disturb the existing mill buildings. The existing sluice gate would be used to shut-down the turbine.

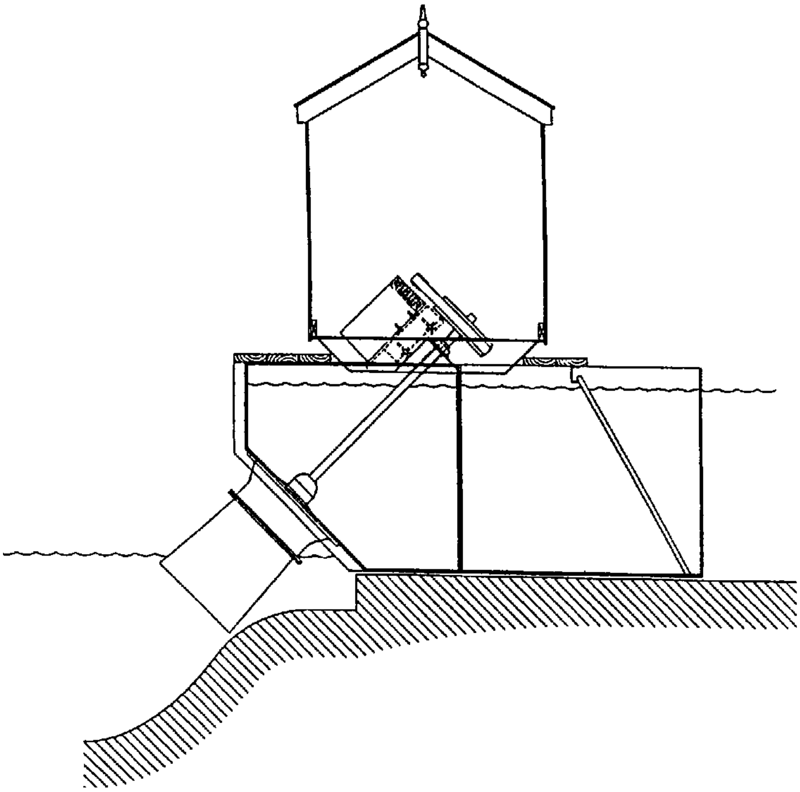

Figure 6.6 Low-head propeller turbine system, Evans Engineering Ltd

6.5.4 Scheme Components

Electro-mechanical system

The hydraulic system would consist simply of a bell-mouth intake, a propeller-type rotor, and a short draft tube. The propeller shaft runs in two bearings: a water-lubricated bearing mounted in the centre of the bell-mouth and a dry, thrust bearing inside the powerhouse. The shaft speed is geared up with a belt drive in order to run a generator at 1000rpm or 1500rpm.

Civil works

The installation of the proposed system would require some modification to the end of the mill-race to allow the turbine unit to be dropped in vertically and secured to the foundations. A trash screen of angled bars would need to be installed upstream of the intake sluice to keep out river debris. Some modification may also be required to the weir several 100m upstream of the lock to ensure that sufficient flow is able to reach the mill, and this may require an automated sluice to be fitted. Also the lock gates would be modified so as to raise their upper level thus preventing excessive flow being lost into the lock.

Automatic control system

There is no facility for reducing the flow through the turbine, so the unit would normally generate at full power for 24 hours per day.

Any electricity not consumed by the loads would be diverted automatically by an electronic load controller into a dump load. The dump load is usually a resistive heating load which could be used, for example, to heat water for on-site washing facilities. If water-heating is not a particular requirement, there may be a case for trying an alternative dump load more suited to the location, for example operating a pump to aerate the river.

Any attempt to switch in more loads than can be met by the power rating of the machine would lead to a voltage drop and the rejection of one or more of the loads by the load controller until the voltage is restored.

The control system would also incorporate an automatic (and fail-safe) shut-down facility if either the electrical system fails (eg. a generator failure) or the turbine becomes damaged, or if the water level falls below the minimum level specified, as measured by a level sensor. The system would shut the entry sluice-gate, or close a butterfly valve, thereby preventing water from passing through the turbine.

6.5.5 Operation and Maintenance

The scheme would normally run unattended, with occasional inspections of the meter readings in the powerhouse to check for any abnormalities, vibrations, etc. The one regular maintenance activity would be to clean the trash-screen from floating debris. This would need to be done daily in winter months to prevent a reduction in power. An annual inspection is recommended to check for any damage to the rotor, wear of the shaft, and play in the water-lubricated bearing.

6.5.6 Cost Estimates

Evans Engineering Ltd, who have supplied several similar systems to mill-owners, provided the budget quotation in Table 6.7. In the case of Titchmarsh, East Midlands Electricity had quoted a connection charge in excess of £40,000, so at half the investment this system appears an attractive option.

Table 6.7 Budget quotation for a hydro-electric installation at Titchmarsh Lock

ITEM	£
Turbine and generator	7500
Trash-screen and sundry steelwork	2000
Electrical control system and panel	1500
Control actuators	2000
Powerhouse and foundation	1500
Installation and civil work	2500
Drawings, administration	1000
Sundries and contingency	2000
TOTAL	**20000**

6.5.7 Environmental Factors

The main environmental issues revolve around the change in the flow regime and the possible effect on fish passing through the turbine. These issues would need to be examined in detail for Titchmarsh as part of a full feasibility study prior to commissioning the work, but the following points are worth noting:

- A minimum ‘environmental flow’ to be left in the river is not specified in the Mill Rights and would need to be agreed with the Environment Agency.
- It has been found that at such low-heads, the speed of the turbine and the changes in water pressure involved can be low enough for small fish to be able to pass through the turbine unscathed. (The trashrack will deter any large fish.)
- Other impacts to be investigated would involve possible changes to water velocities, turbidity, bed or bank erosion, or river quality for angling.

6.6 Recommendation for the Design Study

It was concluded from the analyses completed that the most attractive immediate options for the provision of remote power supplies, from the technical, economic and environmental viewpoint, were:

1. a lock gate drive powered by a PV-battery unit
2. a full set of navigation facilities operated by a small hydro-electric scheme

As the final phase of the project, the consultants were instructed to undertake a detailed design study covering Option 1: a PV-powered lock gate drive, described in Section 7 below.

7. DESIGN STUDY OF A PV LOCK DRIVE

7.1 Introduction

The aim of the design study was to specify, size and cost an electrical supply powered by photovoltaic (PV) modules, which can be used to operate the lock-drive mechanism on the vertical sluice-type lock gates on the Rivers Nene and Ouse.

After consideration of various alternatives, the preferred option was to use the same Rotork actuators as installed on mains-connected locks, and to provide mains quality power from a solar PV power supply.

Extensive discussions were undertaken with Rotork, including on-site measurements of the actuator at Upper Barnwell Lock, in order to define the peak power and average energy requirements to raise and lower the gate.

The approach taken was to design a system for a defined base case which is intended to cover all the locks of this type. In the event that the base-line system proves not to be powerful enough to operate a specific lock, there would be a straightforward fallback option, consisting of replacing the actuator motor with a more powerful unit and adding additional PV modules and batteries to meet the increased energy requirement, but all within the same design envelope. In order to make this extension as easy as possible, the standard system would have some built-in reserve, i.e. a battery box larger than required to accommodate a larger battery, and space on the mounting pole to allow mounting of additional PV modules.

7.2 Description of the PV System

The proposed PV system consists of the following components, illustrated schematically in Figure 7.1 and described in more detail below:

- PV modules
- module support structure
- storage battery
- charge control unit
- DC/AC inverter
- enclosures for battery, charge controller and inverter
- conduit and cabling

7.2.1 PV modules

The use of standard *monocrystalline* PV modules is recommended. These are usually made with toughened front glass and a tedlar backing, and with a lightweight anodised aluminium frame for easy mounting. They have a nominal output voltage of 12V (DC) and are available at several peak power output levels. Modules with between 50 and 110 Watts-peak (Wp) output are best suited for this application, as they offer flexibility to adapt the array size to the requirements of the load without being too small and therefore requiring more wiring. Modules are available in the UK from various manufacturers; product literature from BP Solar and Siemens Solar is enclosed with Annex **Error! Reference source not found.**.

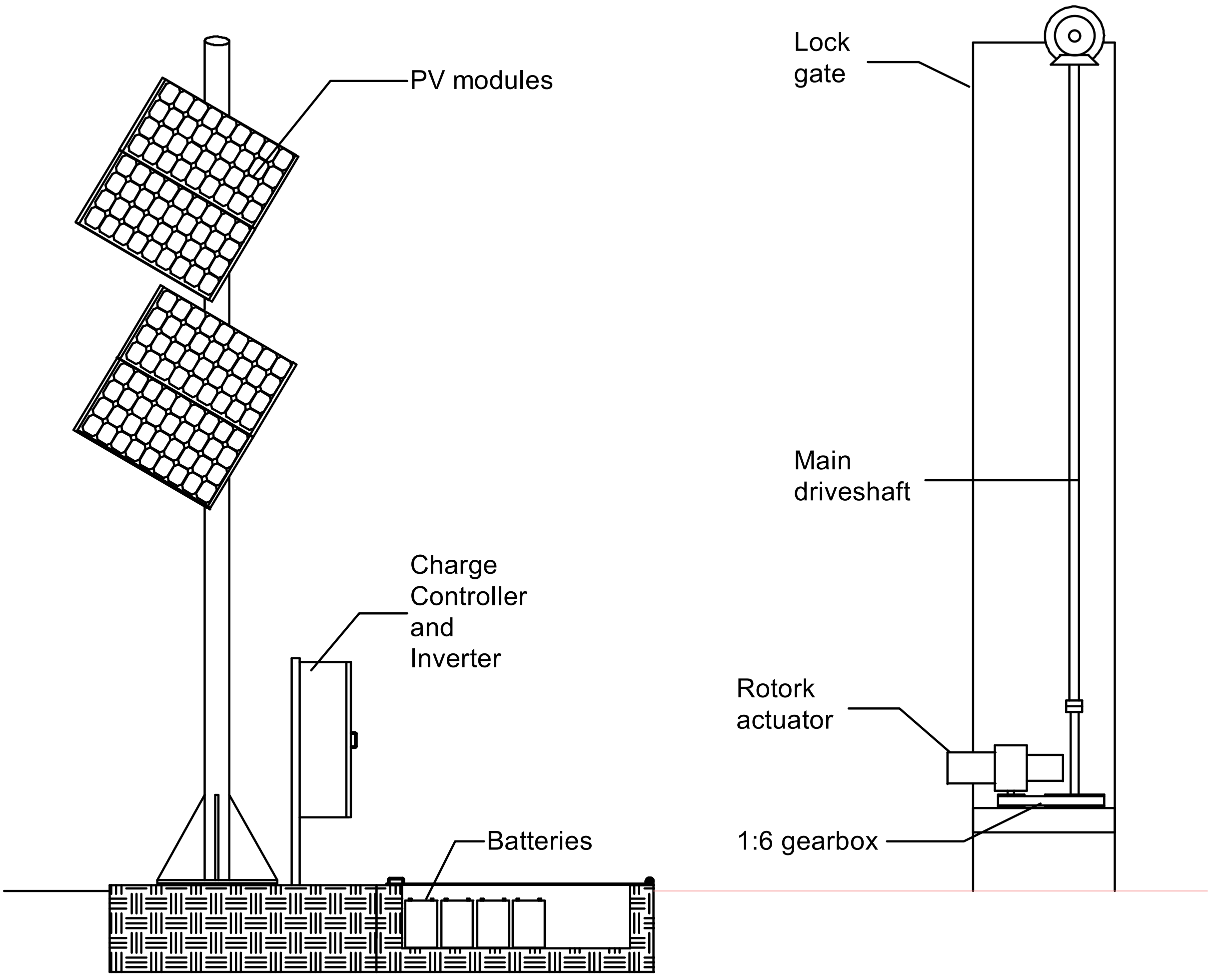

Figure 7.1 Elements of a PV lock drive system

7.2.2 Support structures

Standard module support structures are available for ground mounting or pole mounting of the PV modules. Often modules are mounted on structures designed for a specific application. Most mounting structures are made of aluminium, aluminium alloy, or painted or galvanised mild steel. For this application, the modules could be mounted on the ground, on top of the battery housing, on top of the lock gate, or on a tall mounting pole. At Almere in Holland (see Annex **Error! Reference source not found.**) a tall pylon has been used to mount the modules high off the ground out of human reach and has (to date) safely avoided damage. This approach is recommended in the UK context.

7.2.3 Batteries

The options for a storage battery are vented lead acid, sealed lead acid or nickel cadmium technology. Vented lead acid batteries are often used in stand-alone PV systems as they are the least expensive option. Their disadvantage is that some electrolyte is lost over time due to gassing of the battery during charging. Therefore the electrolyte needs to be checked at least annually, and topped up if required. For use in PV systems, batteries with large electrolyte reservoirs are available. Vented lead acid batteries are available with different plate constructions which are associated with different life expectancies and costs. Sealed lead acid batteries are maintenance free but are generally more expensive than vented batteries.

Lead acid batteries with a small capacity (e.g. 100Ah) are available as 12V blocks, while larger batteries consist of 2V blocks connected in series to form a battery bank with typical nominal voltages of 12, 24 or 48V. This corresponds with one, two or four PV modules connected in series.

Nickel cadmium batteries have a higher life expectancy than lead acid batteries, but are also considerably more expensive, so they are not used very often in PV systems. If nickel cadmium batteries are used, a specific charge controller must also be used.

Since the site will be visited at least once a year to check overall system function, it is proposed that vented lead acid batteries will be the most cost-effective choice. The quotations supplied in Annex **Error! Reference source not found.** therefore assume the use of good quality vented lead acid batteries.

7.2.4 Charge controllers

Charge controllers are required to ensure that the batteries are not damaged by over-charging or over-discharging. Charge controllers for small or medium-sized PV systems with lead acid batteries are available from PV manufacturers as off-the-shelf items. The lifetime of a battery is closely related to how deeply it is discharged. By setting the charge controller to cut off the load at around 40% of battery discharge, battery life can be extended for up to 10 years. However this means that, in extreme circumstances, saving the battery is given higher priority than allowing the system to operate. This may be an unacceptable constraint, and therefore may need a 'manual override' facility, or extra battery capacity to 'guarantee' a low level of discharge.

7.2.5 DC/AC inverter

If AC loads are to be supplied with power, an inverter is required to convert DC from the battery to mains quality AC. Inverters are available for different power levels and input voltages and with different output waveforms. Square wave or semi-square wave inverters can be used for most applications. However, problems can occur when they are used to power AC motors. Therefore the use of a sinewave inverter is recommended. Sinewave inverters have a sinusoidal output waveform which is similar to that of the public electricity supply network.

7.2.6 Enclosure

Battery, charge controller and inverter must be accommodated in a suitable enclosure to protect them from the elements and from unauthorised access. The battery should be in a separate enclosure or at least a separate compartment to prevent corrosion of the electronic equipment. The battery housing must have adequate ventilation to avoid build-up of explosive gases. The options range from a steel or stainless steel box to a brick or concrete building. A brick or concrete box with a steel lid is also possible. Safety screws which require special tools can be used to secure openings which are necessary for access. Risk of vandalism, visual impact and budget constraints will have to be considered when choosing a suitable enclosure; the system costings have assumed a steel enclosure.

7.3 Actuator Selection

7.3.1 Maximum Torque at Upper Barnwell Lock

The maximum torque required to lift the gate determines the peak instantaneous power requirement and hence the rating of the actuator, battery and inverter. Ideally, the maximum torque should be measured for each lock which is to be mechanised. It was beyond the scope of this design study to carry out torque measurements on a range of locks, so reasonable assumptions had to be made. The assumptions border on the pessimistic to ensure that the system will be capable of operating any lock of the same design as the Upper and Lower Barnwell Locks on the Nene (which were fitted with mains-powered electrical actuators in 1995).

The Rotork actuator drives a 1:6 reduction gearbox connected to the driveshaft of the existing lifting mechanism. The following torques were measured at Upper Barnwell Lock at the output of the actuator:

Table 7.1 Measured torque at the actuator output drive

Torque measurement	Torque (Nm)	Torque (ft lbf)
Breakaway torque to lift the gate with lock pen full - first opening	180	135
Breakaway torque to lift the gate with lock pen full - subsequent openings	40-55	30-40
Torque to lift the gate with lock pen empty	16-25	12-18
Torque to lower the gate with lock pen empty	0	0
Torque to lower the gate with lock pen nearly full	76	56

Note that the torque required for the first opening of the gate was about four times as high as that required for subsequent openings.

Assuming 90% efficiency for the 1:6 gearbox (giving a net ‘mechanical advantage’ of 0.9 x 6 = 5.4) the torque at the output of the gearbox (input to the lock-gate driveshaft) would be as follows:

Table 7.2 Calculated torque at the input to the lock-gate driveshaft

Torque measurement	Torque (Nm)	Torque (ft lbf)
Breakaway torque to lift the gate with lock pen full - first opening	1000	730
Breakaway torque to lift the gate with lock pen full - subsequent openings	210-290	160-215
Torque to lift the gate with lock pen empty	85-135	65-100
Torque to lower the gate with lock pen empty	0	0
Torque to lower the gate with lock pen nearly full	410	300

The maximum torques given in the Tender Documents / Specifications for the Upper Barnwell Locks are 60 ft lbf for lifting the gate and 120 ft lbf for lowering the gate with the lock pen nearly full. It is assumed that these figures relate to the lock-gate drive shaft (output of the gearbox). However these figures do not correspond with the figures obtained from measurements on site. It is assumed that these figures were used to design the system at Upper Barnwell Lock, which then had to be modified by adding the 1:6 gearbox in order to operate the lock gate.

7.3.2 Effect of Head on Maximum Torque Required

Theoretical considerations show that the head across the lock (varying between 0.5m and 2.5m for locks on the Nene) should have only a minimal effect on the maximum torque required to lift the gates, as the pressure forces of the water in the lock pen are perpendicular to the forces required for lifting or lowering the lock gate. Greater friction losses in the guide-wheel bearings would therefore be the only effect of a greater head.

7.3.3 Choice of Actuator

The readings taken at Upper Barnwell Lock have been taken as the basis for the sizing of the actuator. It is important that the actuator is not unduly oversized, since this affects the size of the PV array and battery bank as well, hence leading to a significant increase in system cost. The following actuator was selected (see product details in Annex **Error! Reference source not found.**):

Rotork IQ20.
Rated torque: 203Nm (150 ft lbf) at 18 rpm at the actuator output.
Gearbox used at the actuator output: 1:6 spur

The torque available at the actuator output represents 111% of the highest torque requirement measured at Upper Barnwell Lock. This worst case represents the break-away torque, which only occurs at startup and for a very short period of time. The stall torque of this actuator is twice the rated torque, giving an additional safety factor.

The actuator selected should be sufficient to operate a typical lock of the type considered. However should the actuator output be insufficient to operate a particular lock, a contingency plan would be to upgrade the IQ20 to an IQ25 actuator. This simply requires exchange of the actuator motor within the same overall assembly, and some additions to the PV power supply (modules and battery). Rotork, the actuator manufacturer, has agreed to do this on site for a small additional cost should this prove necessary. The IQ25 actuator has a rated torque of 400Nm (295 ft lbf) at 18 rpm, which is nearly twice the torque of the IQ20, and should cover every possible case.

The motor of the IQ25 actuator has a higher power requirement at the same torque than the motor of the IQ20. Therefore the energy required per cycle is higher, and a larger PV system would be required for use with the IQ25.

7.4 Energy Requirements.

The average energy required for each locking, and the number of lockings per day, dictate the size of the array of PV modules required to capture sufficient solar energy to power the lock all year round.

7.4.1 Average Power Requirement

Laboratory test results obtained from the actuator manufacturer (see Annex **Error! Reference source not found.**) give data on the motor current and the active and reactive power requirement for different torque levels at the actuator output. When the motor is operating at part load, the power factor is very low, which is an important consideration when selecting the inverter.

The full open/close cycle was timed at 5 mins for Upper Barnwell. To allow for some variation, each cycle was assumed to consist of 3 minutes at normal operation (raising the gate) plus three minutes at zero torque (lowering the gate). The startup surge is of very short duration and will have no significant effect on the energy requirement.

Two systems are considered: System A is the standard system using an IQ20 actuator. This system is expected to be sufficient for most situations. System B, using the IQ25 actuator, is a fallback option for locks where the output torque of the IQ20 is insufficient.

Table 7.3 Rotork motor characteristics for a 3-phase 400V/50Hz unit

System	Mode	Active Power (W)	Power Factor
System A (IQ20)	1. Zero Torque	295	0.21
	2. Normal Operation	450	0.33
	3. Start up*	5800	0.84
System B (IQ25)	1. Zero Torque	575	0.17
	2. Normal Operation	700	0.23
	3. Start up*	11000	0.83

* Duration is a few milli-seconds

7.4.2 Frequency of Usage and Resulting Daily Energy Requirement

In order to determine the daily number of locking cycles, the 1995 usage figures for Upper Barnwell (the lock with highest usage on the Nene) were used. A safety factor of 167% on the 1995 peak (12 per day) was applied, implying a design figure of 20 lockings per day, to ensure plenty of reserve for a 'first-off' demonstration unit.

Table 7.4 Daily Energy Requirement during August (worst month)

System	Mean Power W	Locking Cycle mins	Net Energy per locking Wh	Battery Efficy	Inverter Efficy	Gross Energy per locking Wh	Peak no. of lockings per day	Energy per day Wh/day
A: IQ20	372.5	6	37	0.90	0.90	46	20	920
B: IQ25	63.5	6	64	0.90	0.90	79	20	1574

Note: 1 locking covers raising and lowering the gate

The figures were based on lock counts made on all Nene locks during the summer of 1995, showing peak usage in August. River usage for all other months is expressed in Table 7.5 as a scale factor relative to August. For a PV-powered lock gate, August presents the worst case, with peak usage of the river at that time coinciding with reduced incoming solar radiation due to shorter daylight hours in late summer. The daily energy requirements are illustrated in Figure 7.2.

Table 7.5 Daily Energy Requirement using Scale Factors for each Calendar Month

Month	Scale Factor	Average Daily Energy Consumption [Wh/day]	Average Daily Energy Consumption [Wh/day]
		System A	System B
Jan	0.1	92	157
Feb	0.1	92	157
Mar	0.2	184	315
Apr	0.4	368	630
May	0.7	644	1102
Jun	0.55	506	866
Jul	0.9	828	1417
Aug	1.0	920	1574
Sep	0.4	368	630
Oct	0.2	184	315
Nov	0.1	92	157
Dec	0.1	92	157
AVERAGE		364	623
ANNUAL TOTAL		132921Wh	227410Wh

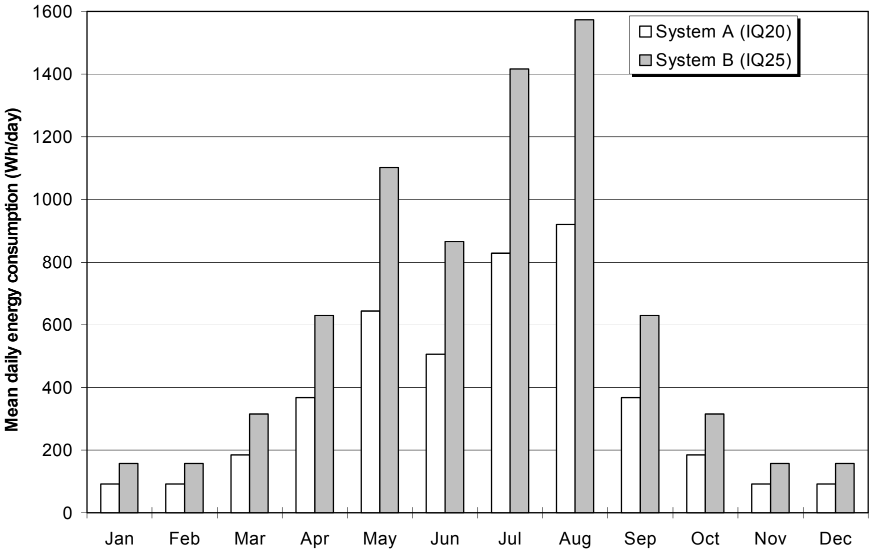

Figure 7.2 Average daily energy requirements from the PV array

7.5 PV System Sizing

Budget quotations and system sizings were obtained from two suppliers of PV systems. The more conservative of the two suggests an array of 350-400Wp for system A (using the IQ20 actuator) and 600Wp for system B (using the IQ25 actuator).

The system voltage could be 24 or 48V. If for instance BP Solar's BP250 modules are used (output power 50Wp, nominal voltage 12V), 4 parallel strings of 2 modules in series can be connected for a 24V system. Alternatively, 2 parallel strings of 4 modules in series are required for a 48V system. A copy of the module data sheet can be found in Annex **Error! Reference source not found.**.

7.6 Inverter

A three-phase inverter is required to convert 24 or 48V DC from the batteries to 400V three-phase AC for the actuator. Two quotes were obtained for the inverter. Douglas Electronics, a UK manufacturer, was confident that their inverter is capable of supplying the high starting current which the actuator motor requires. Their 1000VA inverter would be suitable for both systems A and B.

Techsearch, the UK agent for the US manufacturer Abacus, suggested to oversize the inverter and use a 3000VA unit in order to provide the starting current for the actuator motor. This obviously makes their unit more expensive.

7.7 Single-Phase Option

The IQ range of actuators use three-phase motors, however, Rotork also supply single-phase units. The use of a single-phase actuator would lead to reduced costs for the inverter (by about £500), but to increased costs for the actuator (by £1,000-1,200), leading to an increased total cost. The IQ actuator range is only available with three phase motors; for a single phase system, an ‘A range’ actuator would have to be used. The A range actuators do not offer all of the control, protection and communication features of the IQ actuators. Furthermore, only a limited range of output torques is available with the A range actuators. For these reasons, the option of using a single-phase system was not considered further.

7.8 Site Requirements and Installation Details

Ideally, a PV system requires a site which is free from any shading on its southern, eastern and western side. However, some shading can be tolerated. Whether a certain amount of shading is acceptable should be assessed individually for each site under consideration.

As the sites under consideration are in remote areas, the installation should be as **vandal-proof** as is feasible from an economic point of view. The PV modules obviously have to be exposed to the sun, and need to be south-facing at an appropriate angle. In order to make the modules less accessible it is recommended to mount them on a tall pole (or possibly on top of the lock gate). The battery bank and the electrical equipment will have to be in a housing which could be made from steel, brick or concrete.

7.9 Operation and Maintenance Issues

PV systems have no moving parts and require very little maintenance. A PV module should operate satisfactorily for at least 20 years without any attention. Wiring needs to be checked and may need replacing after 10 years or so. The electrolyte level of the battery should be checked once a year. If it is below the specified level, the battery has to be topped up with purified water. (Alternatively, sealed batteries do not require any maintenance, but are usually more expensive.)

A visual check of the whole system by an expert is recommended at least annually, so that any problems or potential problems can be detected. Occasional cleaning of the modules might be required, especially at sites where leaves and bird droppings are a problem. Bird droppings can be minimised by serrated 'anti-bird' edges along the top of the PV array which deter birds from landing on the modules or the support structures.

Experience with other stand-alone PV systems has shown that annual O&M costs typically equate to less than 2% of the installed cost, covering the labour cost of occasional visual inspections, cleaning of modules, and topping up the batteries. A figure of 2% is used in the costing below, but could be less if these labour costs are absorbed into existing maintenance responsibilities of the Agency, or more if a more stringent maintenance regime is specified.

7.10 Environmental Impact

PV systems are environmentally benign. The only potential hazard is related to leakage of chemicals from the battery, and the design of the enclosure needs to ensure that fluid cannot escape form the battery compartment.

7.11 Costs

A breakdown of the system costs is provided in the table below. Quotes can be found in the annexes. Note that costs have not been included for the control box to operate the lock-gate, nor for project management, supervision, or contingency.

Table 7.6 Breakdown of system costs:

Item	**System A IQ20 £**	**System B IQ25 £**	**Quotation from**
PV modules	1,550	2,480	On-Site Power
Module support structure	800	1,000	On-Site Power
Batteries	670	1,100	On-Site Power
Charge controller	90	100	On-Site Power
Steel enclosure	800	800	On-Site Power
Inverter	1,450	1,450	Douglas Electronics
Installation of PV power supply	1,400	1,650	On-Site Power
Vandal-proofing measures	150	150	Estimated
Foundations	500	500	Estimated
Subtotal PV power supply	**7,410**	**9,230**	
Actuator	1,782	1,981	Rotork Controls
Installation of actuator	500	500	Rotork Controls
Subtotal actuator	**2,282**	**2,481**	
Total system costs	**9,692**	**11,711**	

7.12 Life-Cycle Cost Comparison

A simple life-cycle costing calculation is given in Figure 7.3 to compare the PV option against the 'default' option of connecting to the grid, over a 20 year period. In practice, both a PV system and a grid connection require a high up-front cost followed by relatively insignificant operating costs. Grid connection depends on distance and terrain to be covered, and can be anything from £2000 to over £100,000. The PV system cost will be almost constant, wherever the site.

Figure 7.3 illustrates the break-even position. If a grid-connection can be obtained at less than £10,000, then this is the more attractive option; above £10,000 and a PV system may be the least-cost option over a 20 year period (equal to the guaranteed life of the PV modules). On the river Nene, the local electricity companies have estimated that 16 of the 30 unelectrified locks would cost more than £10,000 to connect to the grid.

If operating costs alone are examined, then the labour cost of annual maintenance of a one-off PV system will be more expensive than the annual electricity charge - roughly double on the assumptions used in this study. This included the assumption that the annual standing charge was at the normal rate for business consumers. It should be borne in mind that the maintenance per system of several PV systems would achieve a lower cost.

ECONOMIC PARAMETERS					
Period of analysis	20	years			
Discount Rate	10%				
Discount Factor	0.91				
Annualisation Factor	8.51				
LOAD					
Mean Daily load	0.36	kWh/day			
Total Annual load	133	kWh/year			
PV SYSTEM (System A)					
CAPITAL COSTS					
PV System (excl. battery)					£6700.00
Battery					£700.00
SUB-TOTAL					££7400.00.00
REPLACEMENT COSTS					
Item	Year		Pr	Present Value	
Battery	10		0.39	269.88	
SUB-TOTAL					£269.88
O&M Costs (2%/year)	148.00	£/year			
Life Cycle O&M costs					£1259.48
LIFE-CYCLE COST					**£ 8929.36**
GRID CONNECTION					
Capital Cost of grid connection					£10000.00
Price per kWh consumed	0.10	£/kWh			
Annual electricity cost	13.30	£/year			
Standing charge	50.00	£/year			
Annual Operating cost	63.30	£/year			
Life Cycle Operating cost					£538.68
LIFECYCLE COST					**£10538.68**

Figure 7.3 Life-cycle cost comparison for a lock-gate drive: PV vs Grid Connection

7.13 Applicable Sites on the Nene

Since there is very little limitation on the location for a PV power supply, all 16 of the locks identified as being under consideration for a stand-alone supply can also be considered for a PV-battery unit, as follows:

Table 7.7 Locks on the Nene which favour a stand-alone energy supply

Lock No.	Name	No. of Lockings (Apr-Sept 1995)	Estimated Grid Connection Cost
1	Northampton	780	£10-20K
7	Cogenhoe	1080	£10-20K
9	White Mills	850	£10-20K
10	Earls Barton	820	£10-20K
13	Upper Wellingboro'	760	> £20K
14	Lower Wellingboro'	750	> £20K
16	Higham	760	> £20K
19	Lower Ringstead	930	> £20K
20	Woodford	1050	£10-20K
21	Denford	1120	£10-20K
23	Titchmarsh	1220	> £20K
24	Wadenhoe	1430	£10-20K
28	Ashton	1380	£10-20K
29	Cotterstock	1300	£10-20K
30	Perio	1220	£10-20K
36	Alwalton	1460	> £20K

The key criteria in prioritising these sites will be:

- level of traffic using the lock
- comparative cost for installing a grid connection
- vulnerability to vandalism
- site details: ease of access to site, potential for modules to become shaded
- politics: local interest, gaining planning permission

7.14 Design Study Summary

- A PV power supply with Rotork actuator is proposed as a technically viable solution for powering lock gate drives which are remote from the grid. The system uses proven, commercially available technology.
- The cost for procurement and installation of the PV system will be in the range £7000-£10,000. The equipment can be supplied and installed by UK suppliers. The total system cost (including Rotork actuator) will be in the region of £10-12k.
- PV systems exhibit outstanding reliability due to the absence of moving parts. Operation and maintenance charges will be minimal relative to the installed cost, and on a 20 year life-cycle costing, the PV system can be considered cost-competitive relative to a grid-connection costing £10,000 or more.
- This would be the first such system in the UK and the first project will need to be undertaken on a demonstration basis i.e. with greater overhead allowed for supervision, commissioning , testing and troubleshooting. A PV-powered lock has been operating successfully in Holland for over 2 years.

8. CONCLUSIONS

- There appears to be a significant role for small stand-alone power supplies to automate lock-gate drives on the Nene (and drives for other sluice gates throughout the region). Although 7 Nene Locks already have electrified gates, 4 do not have vertical gates, and a further 10 appeared to be within easy reach of grid electrification, 16 sites appear to favour a stand-alone supply, summarised in Table 8.1.

Table 8.1 Nene Locks which could benefit from a stand-alone power supply

Lock No.	Name	No. of Lockings (Apr-Sept 1995)	Estimated Grid Connection Cost
1	Northampton	780	£10-20K
7	Cogenhoe	1080	£10-20K
9	White Mills	850	£10-20K
10	Earls Barton	820	£10-20K
13	Upper Wellingboro'	760	> £20K
14	Lower Wellingboro'	750	> £20K
16	Higham	760	> £20K
19	Lower Ringstead	930	> £20K
20	Woodford	1050	£10-20K
21	Denford	1120	£10-20K
23	Titchmarsh	1220	> £20K
24	Wadenhoe	1430	£10-20K
28	Ashton	1380	£10-20K
29	Cotterstock	1300	£10-20K
30	Perio	1220	£10-20K
36	Alwalton	1460	> £20K

- The demand for pump-out facilities in the Anglian region is currently very low due to the small percentage of boats with enclosed tanks. It is believed that the near-term pump-out requirements for the Nene can be met at two grid-connected sites with sewage main and water supply available, and therefore that there is no immediate need for stand-alone power supplies for these systems. The remote likelihood of finding a riverside sewage main without an electricity supply nearby implies that this application for stand-alone power is unlikely to have a significant market - at least until all grid-connected options have been exhausted. There is no immediate requirement for pump-outs on the Ouse.
- There are currently no dedicated electric boat charging points within Environment Agency jurisdiction in the Anglian region, and no immediate demand was foreseen. Boat-charging requires an order of magnitude more energy than the other facilities considered.
- There is an identified need for emergency telephones. It is now legally possible to have a fixed cellular phone if it uses the GSM cellular system. Power consumption is very low and depends on usage, but a maximum of 50Wh per day.
- Lighting units might be desirable for illuminating a lock, emergency telephone, public toilet, tow-path, etc. Energy-efficient compact fluorescent lamps are essential for using with a remote power supply: a single lighting unit would typically be an 18W lamp.
- Data from 1995 lock counts on the Nene indicated a monthly variation in energy consumption for navigation facilities, relative to peak consumption in August, as shown in Table 8.2

Table 8.2 Monthly scaling factors

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Scale Factor	0.10	0.10	0.20	0.40	0.70	0.55	0.90	1.00	0.40	0.20	0.10	0.10

- The solar resource in the region provides an average of 2.6 sunshine-hours per day over the year. In the summer months (navigation season) the daily average is 4 sunshine-hours, which is enough for solar powered devices to be considered an attractive option.
- Hydropower is site-specific, requiring a lock or weir to provide a fall of at least 1 metre. Three of the sixteen Nene sites were attractive for hydropower exploitation and a further eleven were ‘usable’. Flow data indicated that, even in summer months, there will be sufficient flow in the Nene (over 1 cumec) to operate a small hydropower device.
- East Anglia experiences annual mean wind speeds of around 5m/s, and the wind exceeds 5m/s for about 40% of the time, which is a usable level for exploitation with a wind generator, though not attractive.
- Apart from electric boat charging, all the facilities considered have energy requirements that are too low for ‘on/off’ type power supplies to be cost-effective. A battery-based system is the main alternative, charged either by solar photovoltaics (PV), a small hydropower unit, or a wind turbine. Diesel generating sets are not available in sizes small enough to be cost-effective for such small loads, and petrol generating sets are too unreliable and potentially dangerous to be used in unattended enclosures.
- For combinations of end-use devices (eg. electric boat charging and power hook-ups, and including water-heating to absorb all excess power), a larger hydro-electric unit (perhaps 2-5kW) will be a more cost-effective option. Such a system is necessarily site-specific, requiring a reasonable head and flow, and benefits from existing civil works being in place, such as an old mill-house. However, from a national perspective, there are known to be 10s of thousands of disused mills on UK rivers, so there will be wider applicability of this technology for Environment Agency and other applications. To be worthwhile economically, such a power-generation scheme needs to go hand-in-hand with an initiative to develop a full range of facilities to utilise the power, and hence a significant investment beyond the power supply system. The main alternative to this would be a diesel-electric system, possibly used in a CHP mode (combined heat & power) in which the exhaust gases are used for water-heating.
- The most technically and economically attractive power supply technology for an individual end-use facility is a photovoltaic (PV) unit with battery supply.
- The detailed design study focused on powering a lock gate drive. It concluded that a PV-battery unit coupled with the existing type of Rotork actuator will be a cost-effective solution which uses proven, commercially available technology. PV systems exhibit negligible environmental impact and outstanding reliability, so that operation and maintenance costs will be minimal relative to the installed cost.
- The cost for procurement and installation of the PV system will be in the range £7000-£10,000. The equipment can be supplied and installed by UK suppliers. Including the Rotork actuator, the system cost will be in the region of £10-12k. On a 20 year life-cycle costing, the PV system can be considered cost-competitive relative to a grid-connection costing £10,000 or more.
- This would be the first such system in the UK. A PV-powered lock and several sluices have been operating successfully in Holland for over 2 years.

9. RECOMMENDATIONS

- It is recommended that a demonstration project be undertaken to establish the details, function and costs of the PV lock gate drive system, at a site where grid-connection costs are known to be prohibitive (for example, one of the 6 sites which will cost over £20,000 to grid-connect).
- The power requirements of cellular telephones also lend themselves to battery-charging with a PV system, and any Environment Agency initiative to install riverside phones should examine the PV option.
- Before pursuing the powering of pump-out units any further, the issue of getting rid of the waste needs to be clarified. If the sewage can be removed cost-effectively from a remote location, than a PV system can provide a technically and economically viable stand-alone power supply.
- If there is a requirement for a more major site development at an off-grid location, with greater energy demands, then a hydropower unit should be evaluated as the first priority if the grid connection cost is likely to be more than £20,000.

A.