



# **Hydropower Turbine Types Comparison for Ebley Mill, Stroud**

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## Executive Summary

At the current 1.25 metres head, the Ebley Mill weir is not a good prospect for demonstrating viable small hydropower – although even at this head a Kaplan installation would probably provide a 500% increase in Return on Investment (ROI) to that of an Archimedes Screw. This situation can however be in part or fully remedied, with several engineered measures - installation of a ‘Tilt-Gate’ on the weir and varying options for ‘Regrading’ (lowering & clearing) the river bed downstream. A low cost investment into such exploratory work would fully determine the potential for the project and should pay for itself if the project were to proceed.

Small hydropower is largely a ‘Lost Art’ in the UK; with a few notable exceptions including a local installation at Coaley Mill; Continental European small hydro has however been continuously developed throughout the last century. Hydropower provides many additional functions (biodiversity, leisure etc) in addition to presently, some of the cheapest electricity in the UK – at those few sites that have followed proven continental designs.

This report compares the possible ROI for 3 different turbine types for Ebley Mill, using varying development scenarios and examines some of the uncertainties that exist here. The assumptions made apply to all 3 turbine types; therefore if any assumptions require change the ratio of net returns is likely to remain the same.

The following table represents possible ranges for ROI over the lifetime of the turbine for the options considered.

	Head	Kaplan	Crossflow	Archimedes’ Screw
<b>Possible ROI range over lifetime</b>  (Excluding costs for regrading of river and tilt gates)	<b>Lowest Highest</b>	<b>£1,236,775 £4,925,990</b>	<b>£4,938,585</b>	<b>£220,160 £1,289,440</b>

## Flow data

The flow data used in this report was obtained from the Goring/Hebe report of 1994. This data will need to be updated to reflect the changing rainfall and run-off patterns as a result of climate and other catchment changes.

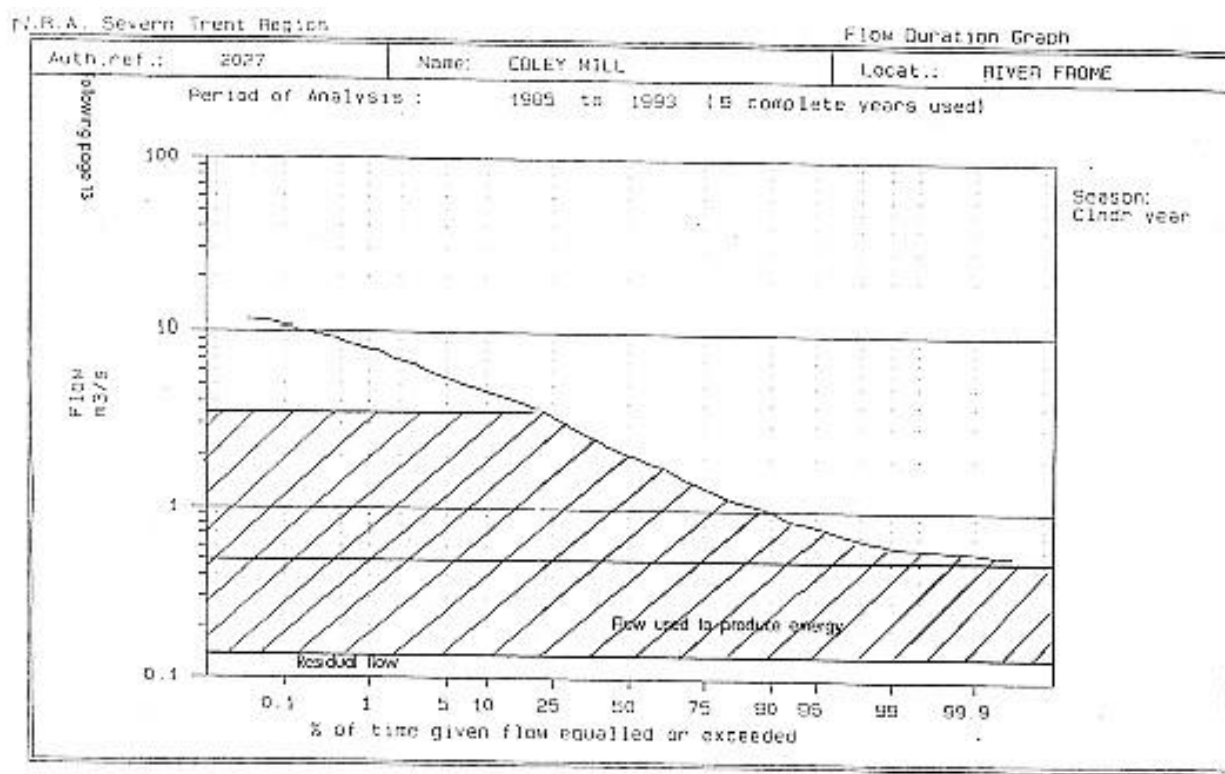


Figure 9 FLOW DURATION CURVE FOR EBLEY MILL

Flow Data, River Frome at Ebley Mill (Hebe, 1994)

## Flow Statistics

Units:  $\text{m}^3\text{s}^{-1}$  unless otherwise stated

Mean flow	2.38	
Mean flow ( $\text{ls}^{-1}/\text{km}^2$ )	12.03	
Mean flow ( $10^6\text{m}^3/\text{yr}$ )	75.1	
Peak flow & date	19.4	30 May 1979
Highest daily mean & date	11.8	15 Feb 1974
Lowest daily mean & date	0.256	25 Aug 1976
10 day minimum & end date	0.275	27 Aug 1976
60 day minimum & end date	0.340	20 Sep 1976
10% exceedance	4.695	
50% exceedance	1.922	
95% exceedance	0.707	
Mean annual flood		
Bankfull flow		

**Current Net Head 1.256m**

## Assumptions

In order to maximise the ROI, energy carbon reduction, community (flood), leisure and biodiversity benefits there are a number of opportunities here that could also increase the net head at the site and therefore increase ROI and these other benefits, in the downstream reach of river.

The list of scenarios below highlights options 2 and 3, as stated in the Segen report ( August 2009 ) which could be achieved by installing tilt gates on the existing weir – although structural integrity to support these gates needs be determined. Note that the head stated in the Segen report appears incorrect and corrected figures are used in this report – it is assumed that the possibility of increasing head by 700mm and 900mm has been previously agreed as being possible.

Note : The levels assumed in this report are derived from existing previous reports.

The recent development of new canal weir that will allow flood water into the River Frome just upstream of Ebley Mill, may further impinge on any hydropower development here.

Options 4 represent work regrading the river bed downstream without additional tilt gate installation.

Options 5 and 6 represent work regrading the river bed downstream combined with tilt gate installation and result in the greatest increase in head and therefore ROI.

The minimum achievable net head at site after river re-grading (without additional tilt gates) may be 2-2.5m, average 2.25m assumed.

The maximum achievable head at the site (without additional tilt gates) could be about 3.58m. These need further investigation to understand the parameters more definitively.

The typical reserve flow assumed to be acceptable to the Environment Agency is Q95 which represents 0.707 m<sup>3</sup>/s.

### ***Scenario Assumptions***

This report therefore concentrates on five head options:

1. Use existing head 1.256m
2. Increase weir sill height by 700mm using tilt gate giving head 1.956m
3. Increase weir sill height by 900mm using tilt gate giving head 2.156m
4. Minimum river regrading + no increased sill height to give net head 2.25m, Flow as per flow duration curve, reserve flow 0.707 m<sup>3</sup>/s
5. Minimum river regrading + Increase weir sill height by 900mm to give net head 3.15m, Flow as per flow duration curve, reserve flow 0.707 m<sup>3</sup>/s
6. Maximum river work and regrading + Increase weir sill height by 900mm to give net head 4.48m, Flow as per flow duration curve, reserve flow 0.707 m<sup>3</sup>/s. This would require removal of sluice gates at downstream Mill.

## **River Regrading**

It is difficult to estimate the costs necessary to re-grade a river because it is uncertain what will be discovered once regrading work starts – for example, whether any river structures need replacing.

However, for relatively low cost (circa £10,000 ) a mechanical excavator should be hired to explore this further – it may be that no extra work, apart from removal of accumulated downstream debris and channel clearance is required in order to increase the available head and therefore substantially increase the ROI on this project.

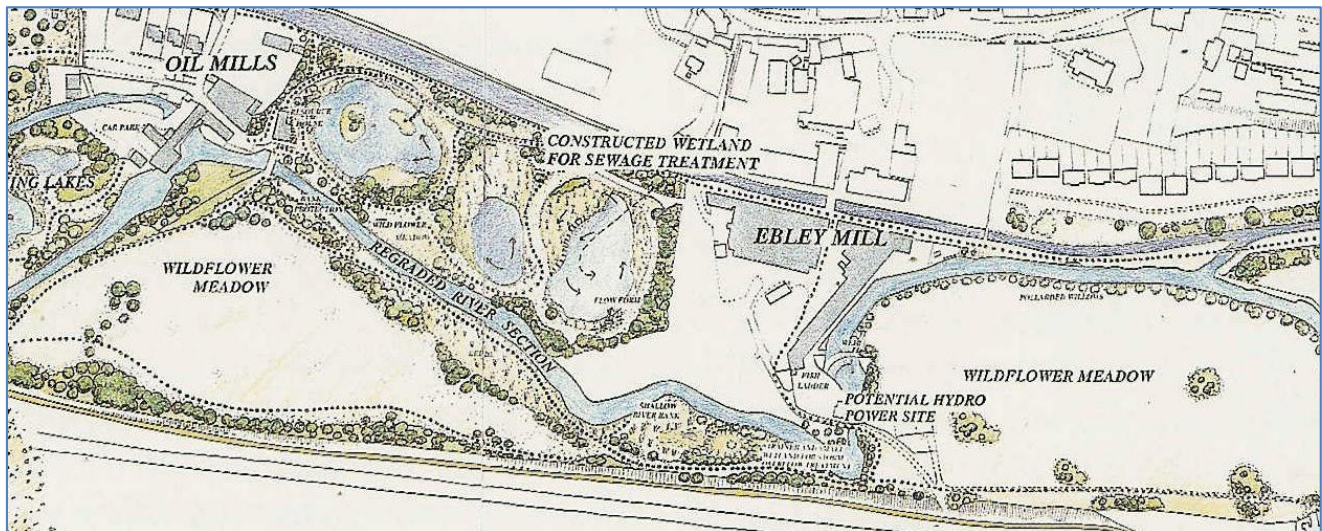
**The increase in revenues as a result of any increase in head made by river re-grading should vastly outweigh the exploratory cost of re-grading work.**

This is well demonstrated by comparing the revenues for a Kaplan turbine with option 2 and option 3, which differ by only 200mm head – the difference in projected lifetime revenue being approximately £294,875.

In order to maximise the ROI made by the Council it is therefore **highly recommended** to perform exploratory river channel clearance work in order to properly assess the hydropower potential of the site and to identify the most favourable option for maximising ROI.



## Flood, Community & Biodiversity benefits



**A 1993 Landscape feasibility analysis considered regrading the river at Ebley to improve flood alleviation, biodiversity and hydropower potential (L Williams/Water21).**

A range of additional community benefits can be provided as an adjunct to river regrading work at Ebley, these could include improved flood water storage here, as a result of the potential of widening the river channel section downstream of Ebley Mill.

Ebley Meadows is an important public amenity area; regrading the river offers other possibilities for leisure and biodiversity. A local Rugby Club is wishing to re-locate to the meadows here; their project could be enhanced. Historically, this stretch of river has been used by local children for bathing and fishing; pools to benefit this could be included here.

## Choice of location

An experienced opinion on the most favourable location for any turbine house would be on the opposite bank, below the weir at Ebley Mill. This would allow maximisation of available head and minimisation of disruption and additional costs incurred by the scheme. This would require detailed planning and is an important factor to the success of the scheme.

The location of an Archimedes' Screw immediately adjacent to the mill & weir may introduce operational noise and low frequency vibrations associated with such systems in the area of the offices here and the possibility of water ingress to Ebley Mill should any water proofing applied adjacent to the river be damaged.

## Unknowns

There are a number of unknowns in relation to the engineered design of this project. It is recommended that a full, detailed and costed engineering exercise is completed following



investigation of potential head in the river to understand the likely total capital costs and net returns of this project.

Some of the unknowns here are the structural state of the weir, waterproofing of the wall adjacent to Ebley Mill, the extent of foundations on the bridge downstream of the weir, the quantity of accumulated debris and rubble dumped in the river etc.

The extent of civils works and likely costs are therefore unknown until a full detailed evaluation is completed, preferably after an initial site investigation using an excavator.

## Cooperation with Snow Mills

In order to maximise the available head, and therefore return on investment, a cooperative arrangement would need to be established between SDC and Snow Mills (Snow Business) downstream for greatest benefit from the increased head.

Currently such an understanding currently does not exist; however, we understand that D Crownshaw of Snow Business has a detailed proposal that outlines terms for such works.

## Screening and Ongoing Maintenance

All options require acceptable screening to protect the turbine from entry of debris and to protect fish. It is now recommended that Archimedes' Screw turbines use the same level of screening of other more traditional turbines in order to protect fish. (The Environment Agency had previously recommended Archimedes' Screw turbines as 'fish friendly' and not requiring screening).

However there is now a change of policy within the EA, following a number of reports from Anglers and others about fish damage from Archimedes Screws, furthermore stating that it is not now EA role or intention to make recommendations for turbine types for use on UK rivers – and that the most important issue to address is effective screening of any technology used.

A further refinement of any fish friendly turbine installation is that water flow velocities on any turbine intakes are so low as to discourage fish entry, regardless of river flow conditions. Accompanying fish pass arrangements are made in a manner that encourages fish passage that avoids any screened turbine.

In order to minimise operational costs and maintain turbine efficiency it is recommended to install an automatic screen cleaning mechanism.

## Choice of Turbine

3 turbine types are considered for the 6 head options identified, the second option considers maximum available energy and limiting rated output to 100kW to maximise feed in tariff revenue.

Option 1 to 5 – OSSBERGER Double Regulated **Kaplan turbine** and **Archimedes' Screw**

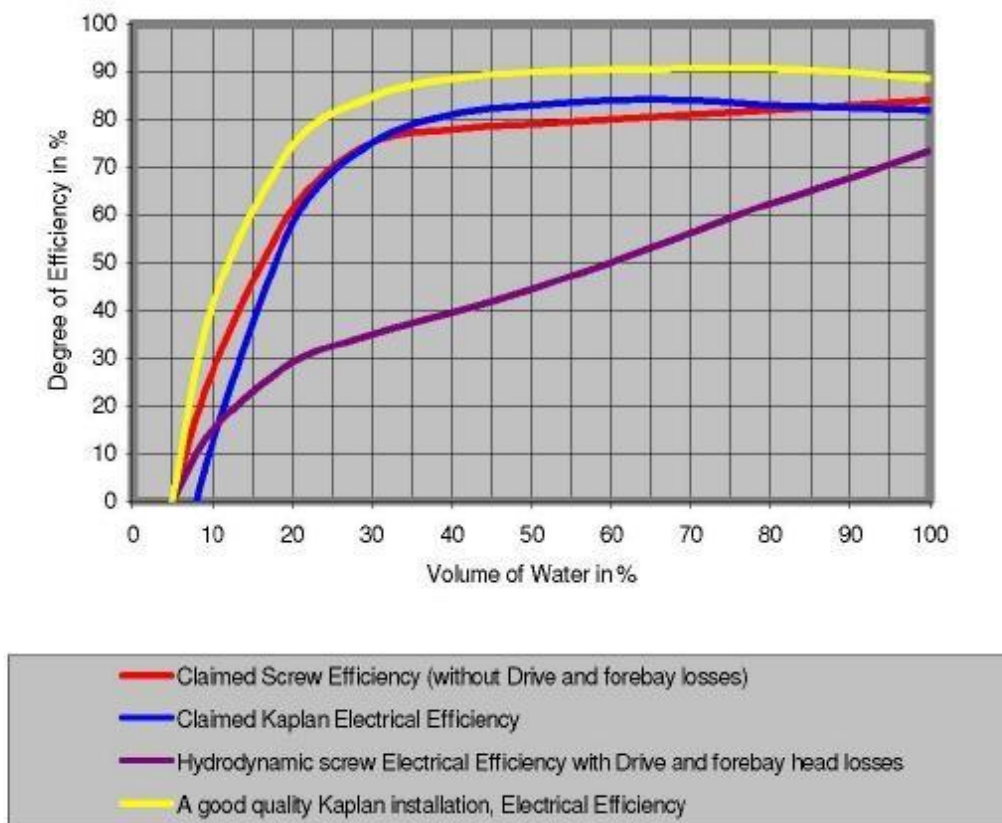
Option 6 – OSSBERGER **Crossflow turbine**, – OSSBERGER Double Regulated **Kaplan turbine** and **Archimedes' Screw**

## Archimedes Screw – Claimed vs Actual Efficiency

A recent independent report (Tarrant, 2012, available upon request), highlights a number of important operational issues arising in Archimedes' Screw turbine applications (a relatively new technology) versus mature turbine technologies such as Kaplan or Crossflow turbines.

The report suggests that the actual performance of hydrodynamic screw turbines in real conditions is significantly less than claimed by the manufacturer, as highlighted in the graph (Tarrant, 2012) below which infers that the actual output of an Archimedes' Screw turbine is approximately 50% less in real conditions than claimed.

Fixed speed Hydrodynamic Screw Efficiency Claimed V,s Actual @ 2.22 mtr net head  
for a 3.6 mtr Dia screw rated @ 6.8 Q (all data supplied by a manufacturer)



This claim has been further documented as a result of a comparison between the actual energy output of two hydropower sites on the same reach of river over the same time & flow period; a summary of which is below (see Appendix A for detail) – which demonstrates that an Archimedes' Screw turbine on the same river produces 41% less energy than a good quality Kaplan installation; though other factors are claimed by Tarrant to reduce energy by more typically 50% in other situations. The average figure of 45% less energy is thus assumed here.

This report therefore used the above efficiency curve +5% for an Archimedes' Screw turbine.

## Comparison of estimated annual energy output

	<b>Kaplan</b> (kWh)	<b>Crossflow</b> (kWh)	<b>Arch' Screw</b> (kWh)
<b>Option 1</b> Head 1.256m	151,000		108,000
<b>Option 2</b> Head 1.956m	237,000		168,000
<b>Option 3</b> Head 2.156m	262,000		185,000
<b>Option 4</b> Minimum re-grading Head 2.25m	271,000		193,000
<b>Option 5</b> Minimum re-grading + Increase weir sill height by 900mm Head 3.15m limited to 100kW installation	374,000		271000
<b>Option 6</b> Maximum re-grading + Increase weir sill height by 900mm Head 4.48m - limited to 100kW installation	472,000	463,000	372,000

**See appendix B for assumptions and detail that could be achieved.**

**Note** Ossberger Kaplan turbines may continue to generate down to approximate 5% of maximum flow, but Ossberger will only guarantee down to 15% of maximum flow. The output stated in this report is therefore likely to be higher in practice.

## Return on Investment (ROI)

The energy usage pattern assumed in this calculation is that all energy is consumed by Ebley Mill; ie out of hours energy is consumed in a dump load ( eg water heating/heating systems ) rather than exported. Further analysis of returns would be required in order to calculate export income when energy is not fully consumed – this can be achieved once energy usage patterns are established.

The cost of energy beyond the Feed in Tariff period is assumed constant at 10p/kWh and therefore doesn't take into account future energy price increases which would result in a further increase in the effective rate of return.

In order to estimate the ROI it was necessary to assume a design life for the equipment.

Mature technologies such as Ossberger Kaplan and Crossflow turbines have been in operation at tens of thousands of sites worldwide and many for well over 50 years. It is generally recognised that the design life of these mature technologies is between 50 and 100 years. A design life for these has therefore been assumed to be 75 years.

Archimedes' Screws, used as turbines, have only been in operation for 5 years (First Archimedes Screw commissioned April 2007, River Dart Country Park Ashburton ). There have been a number of mechanical issues as highlighted in the Tarrant report referred to. Due to their large size they are subject to high mechanical torques and it is expected that shafts, flights and bearings will have a significantly shorter design life than mature technologies. Predications of high annual maintenance costs of up to 5% of revenues demonstrate that they require significant continued investment to maintain operation – and therefore significant downtime maintaining the systems.

Due to their very short period in operation of 5 years there is no data to confirm their longevity however the issues highlighted in the report (Tarrant 2012) suggest that their lifespan is likely to be significantly less than tried and tested existing turbine technologies.

Comparison of Archimedes' Screws maintenance requirements as wastewater pumps indicates typical main bearing replacement is required every two years, and refurbishment of the main runner <10 years. Archimedes' Screws manufacturers are claiming operational duty of >60 years; there is no experience yet to validate this.

Furthermore, an annual expenditure of 5% of annual income on maintenance for Archimedes' Screws suggests that in approximately 20 years the initial capital cost would have been spent on maintenance. Such a depreciation rate therefore leads us to assume that the realistic lifespan of these devices is 20 years.

**It should be noted that all values are in current day prices – in reality the cost of energy is highly likely to rise which would result in a far greater ROI than that shown in this report over the lifetime of the equipment.**

## Comparison of Possible Return on Investment for each option

### *Feed In Tariff and savings Assumptions*

#### Between 15 - 100kW systems

**Up to 20 years – 30.1p/kWh**

Generation Tariff 19.6p + LEC 0.5p + Savings made by using energy 10p

**Over 20 years – 10.5p/kWh**

LEC 0.5p, Savings made by using energy 10p

**Current cost of energy 10p/kWh**

## Comparison of Possible Return on Investment for each option

	Kaplan	Crossflow	Archimedes' Screw
	<b>Estimated Income/Savings</b>		
Expected life (years)	75	75	20
Option 1	£1,781,045		£650,160
Option 2	£2,795,415		£1,011,360
Option 3	£3,090,290		£1,113,700
Option 4	£3,196,445		£1,161,860
Option 5	£4,411,330		£1,631,420
Option 6	£5,567,240	£5,461,085	£2,239,440
<b>Annual Maintenance Costs</b>	Low Typically £550 a year	Very low Typically £300 a year	Medium/High Typically <£5000 a year

Typical installation cost range (Excluding regrading of river and tilt gates)	£500,000 £600,000	£500,000	£330,000 £850,000
<b>Possible Net return range over lifetime</b> (Excluding costs for regrading of river and tilt gates)	<b>£1,236,775</b> <b>£4,925,990</b>	<b>£4,938,585</b>	<b>£220,160</b> <b>£1,289,440</b>

## Appendix A Comparison of performance of an Archimedes Screw and Kaplan turbine on the same river.

Renewable energy data is available in the public domain at the following site:

<https://www.renewablesandchp.ofgem.gov.uk>

The following data taken from this Ofgem REGO register is for a Kaplan and an Archimedes Screw on the same river for the same. The Archimedes Screw has a head of 2.55m the Kaplan 1.7m both at a design flow of 4.5 cumecs.

	Archimedes'	Kaplan
Max Rating	85kW	55kW
Mar-12	14	17
Feb-12	20	24
Jan-12	33	34
Dec-11	34	33
Nov-11	14	15
Oct-11	4	5
Sep-11	5	6
Aug-11	5	5
Jul-11	5	5
Jun-11	10	11
May-11	4	5



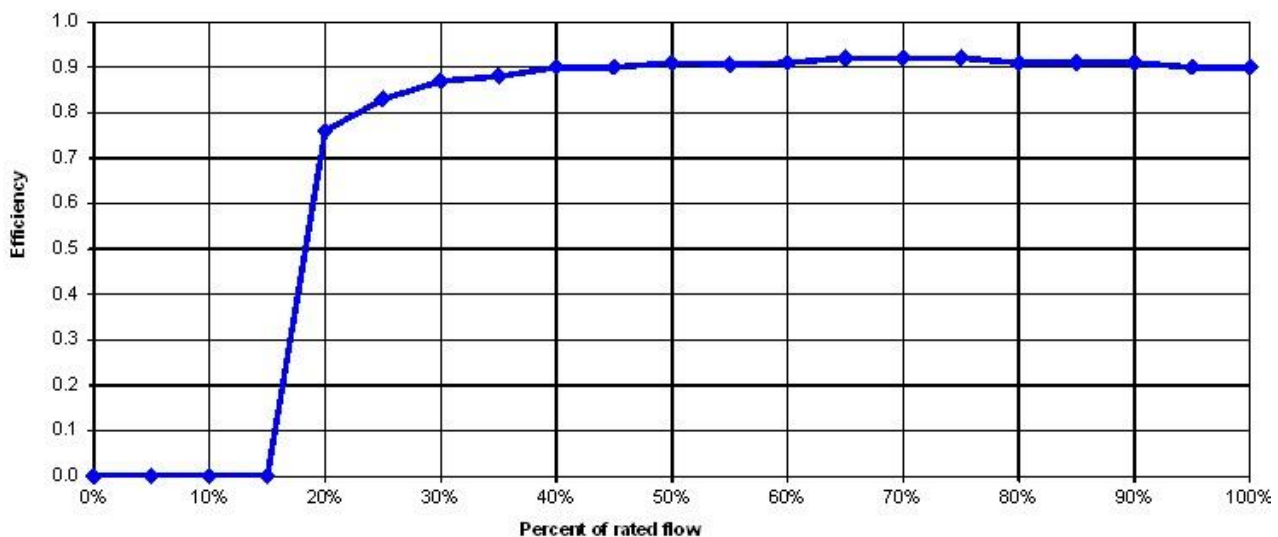
Apr-11	8	9
Mar-11	17	20
Total MWh	173	189
Maximum MWh based on DNC	809.88	524.04
Load Factor	21.40%	36.10%

The resulting load factors clearly demonstrate that that the Archimedes Screw turbine, on the same river produces 40.7 % less energy that a precision engineered Kaplan turbine.

## Appendix B Input / Output data from estimated energy evaluation analysis based on the assumptions in this report.

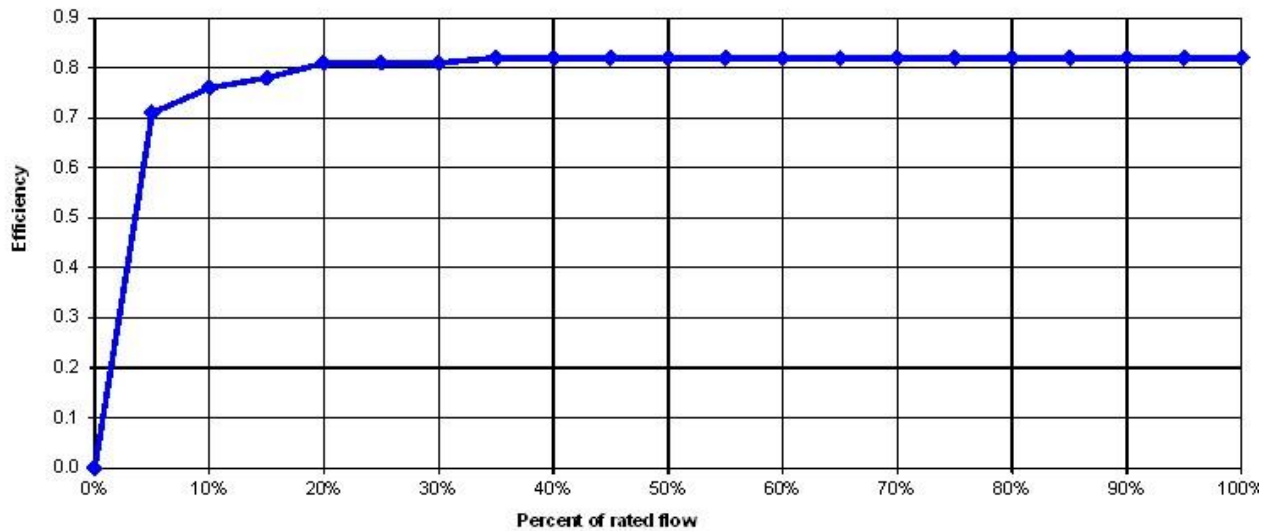
### Assumed Turbine Efficiency Curves

#### OSSBERGER Double Regulated Kaplan Turbine



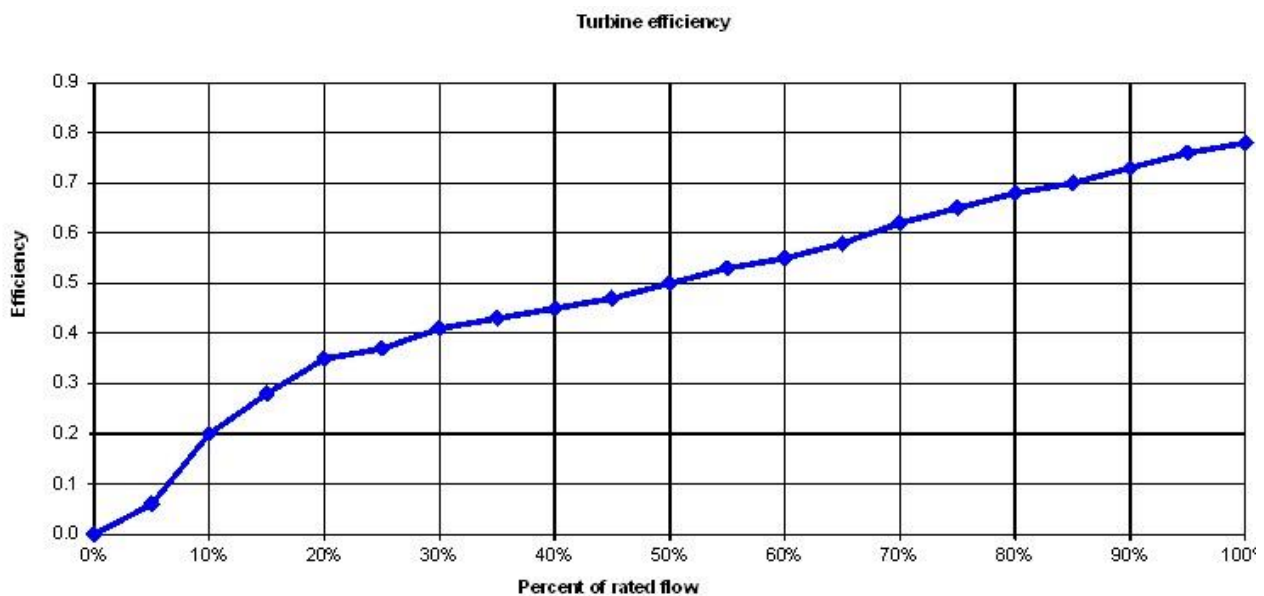
Ossberger Kaplan turbines may continue to generate down to approximate 5% of maximum flow, but Ossberger will only guarantee down to 15% of maximum flow. The output stated in this report is therefore likely to be higher in practice.

## OSSBERGER Crossflow Turbine



It should be noted that the Kaplan and Crossflow efficiency curves are typical curves for the turbines but dependent on the specific site configuration. Efficiency shown represents output at the turbine shaft.

## Archimedes, Screw – See earlier section “Claimed vs Actual Efficiency”



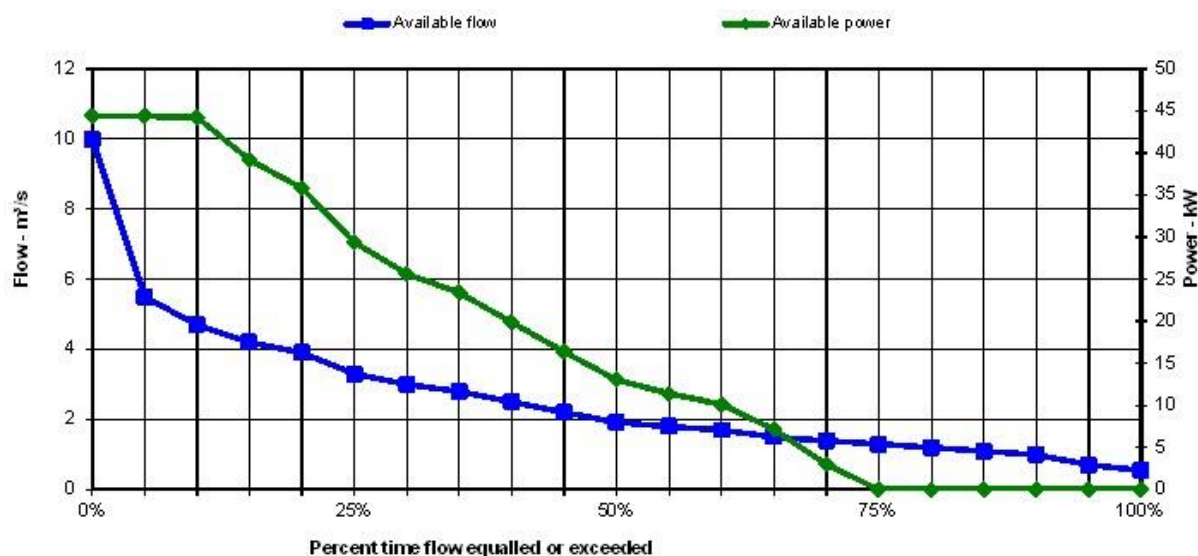
## Option 1 Net head 1.256m

### OSSBERGER Double Regulated Kaplan Turbine

Design flow 4.0 m<sup>3</sup>/s

Rated Capacity 44kW

Estimated annual energy production 151,000 kWh Energy production profile:

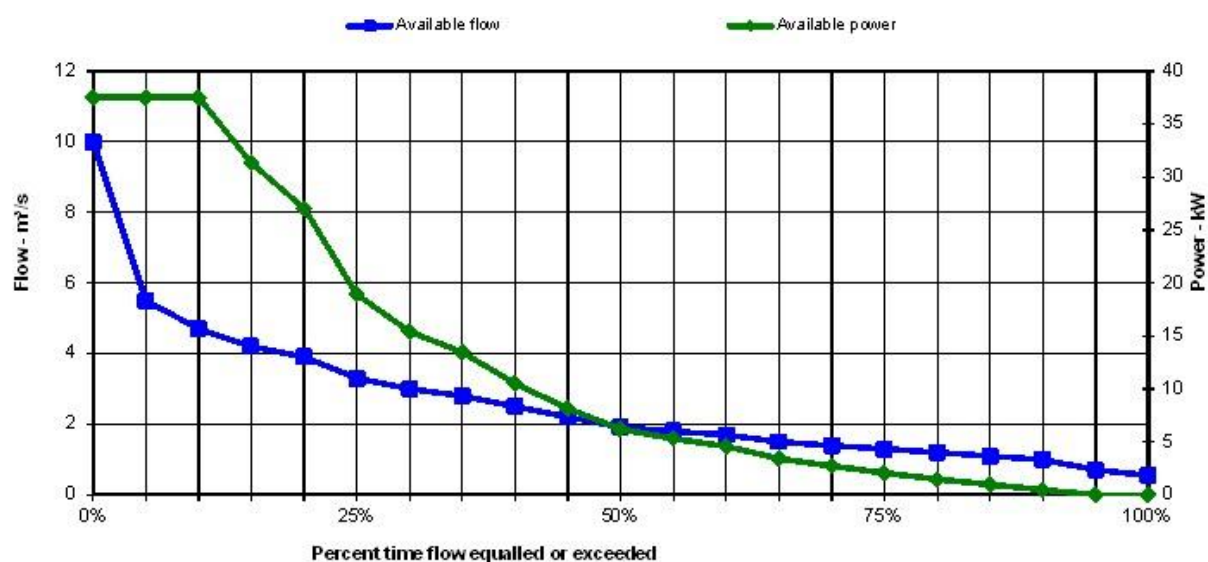


### Archimedes Screw

Design flow 3.9 m<sup>3</sup>/s

Rated Capacity 37kW

Estimated annual energy production 108,000 kWh Energy production profile:



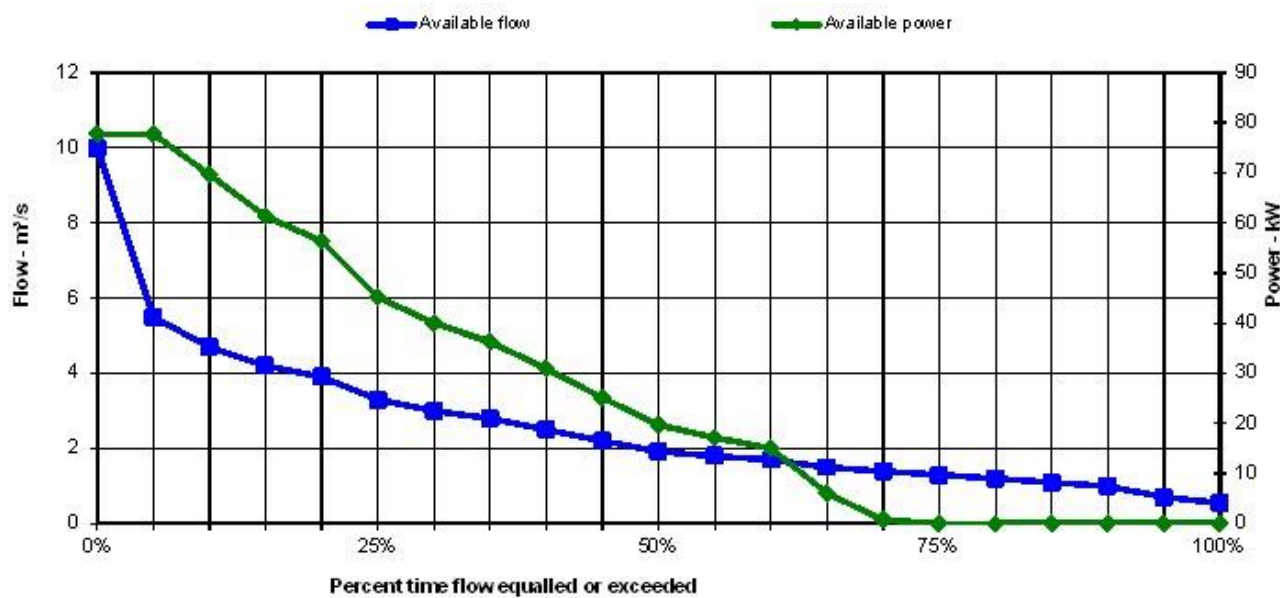
## Option 2 Net head 1.956m

### OSSBERGER Double Regulated Kaplan Turbine

Design flow 4.5 m<sup>3</sup>/s

Rated Capacity 78kW

Estimated annual energy production 237,000 kWh  
Energy production profile:



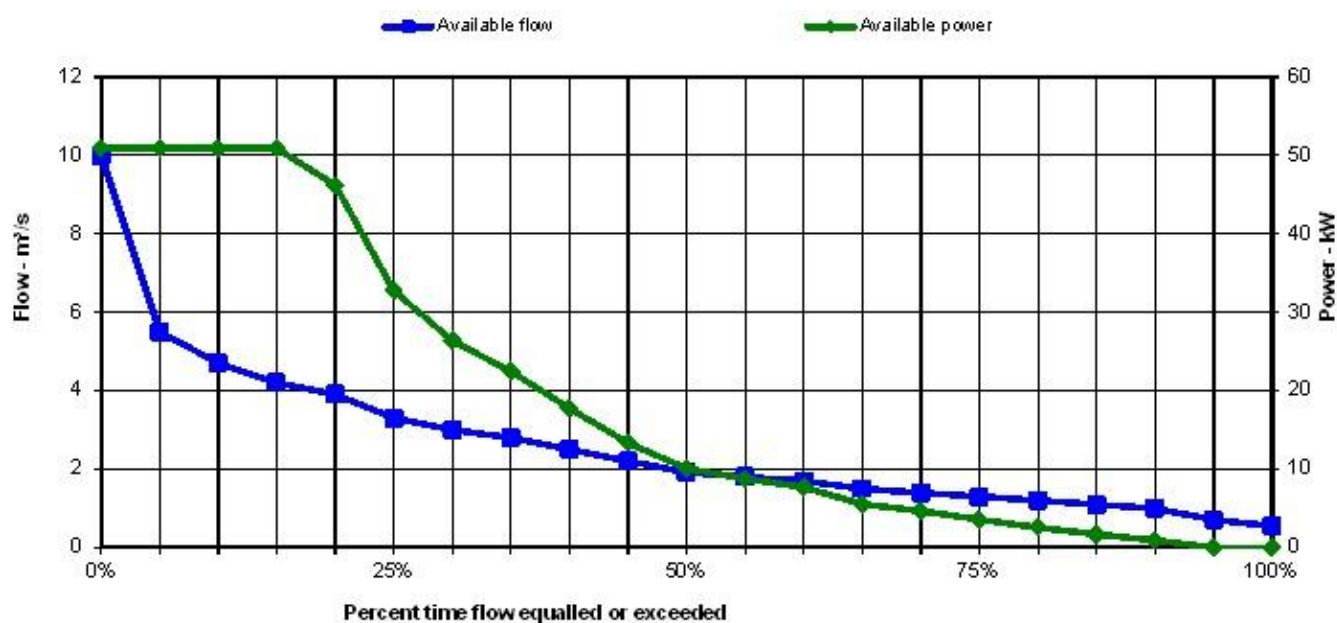
### Archimedes' Screw

Design flow 3.4 m<sup>3</sup>/s

Rated Capacity 51kW

Estimated annual energy production 168,000 kWh

Energy production profile



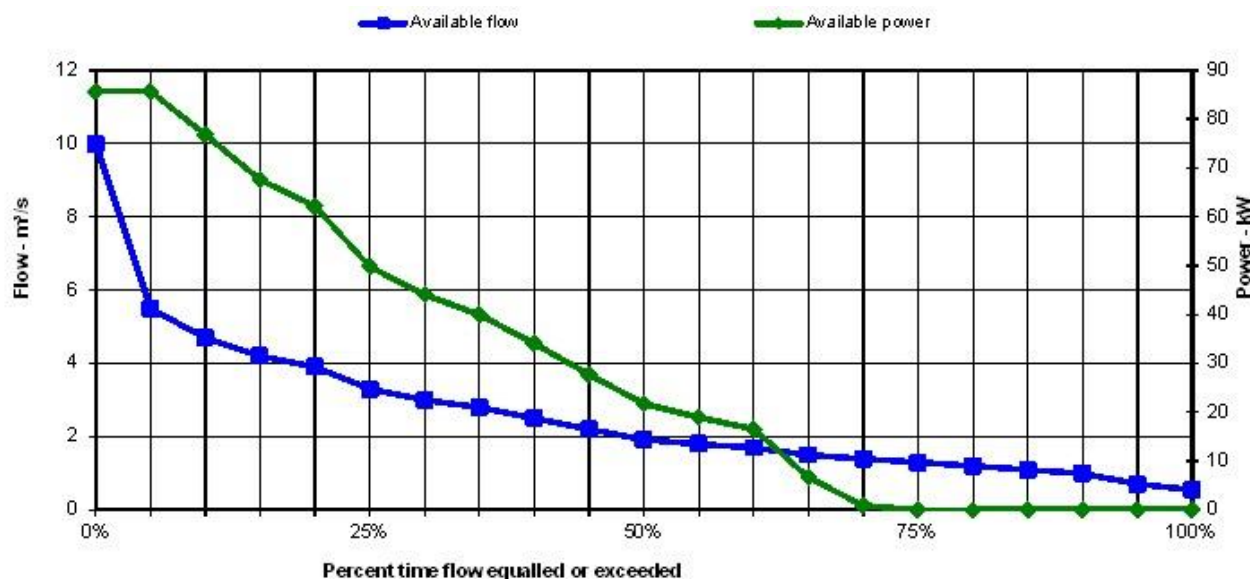
## Option 3 Net head 2.156m

### OSSBERGER Double Regulated Kaplan Turbine

Design flow 4.5 m<sup>3</sup>/s

Rated Capacity 86kW

Estimated annual energy production 262,000 kWh Energy production profile:

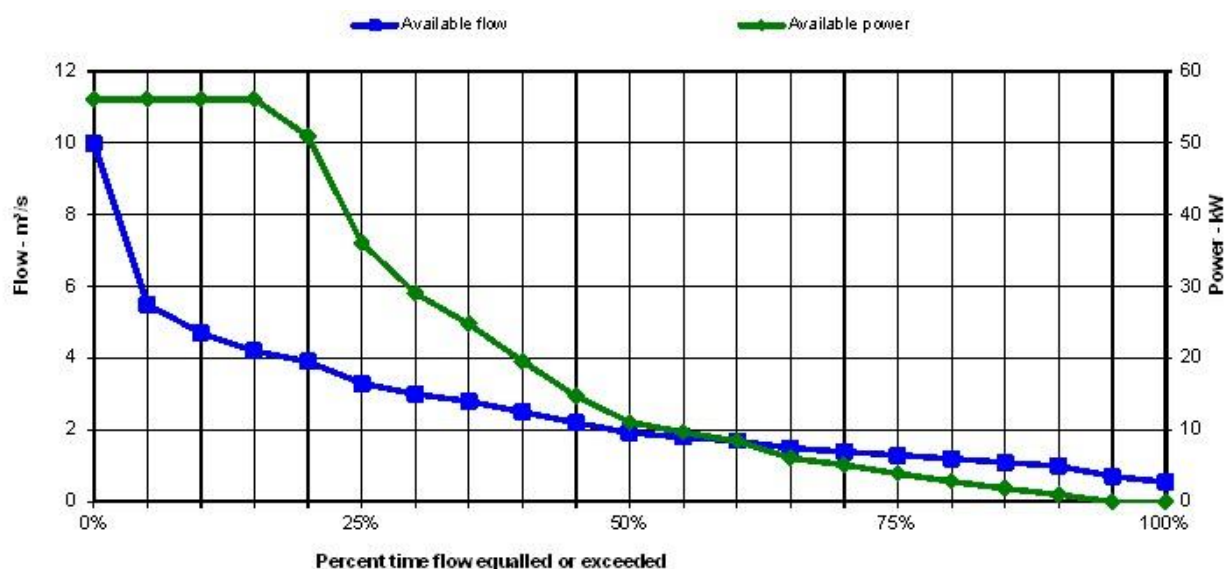


### Archimedes' Screw

Design flow 3.4 m<sup>3</sup>/s

Rated Capacity 56kW

Estimated annual energy production 185,000 kWh Energy production profile:



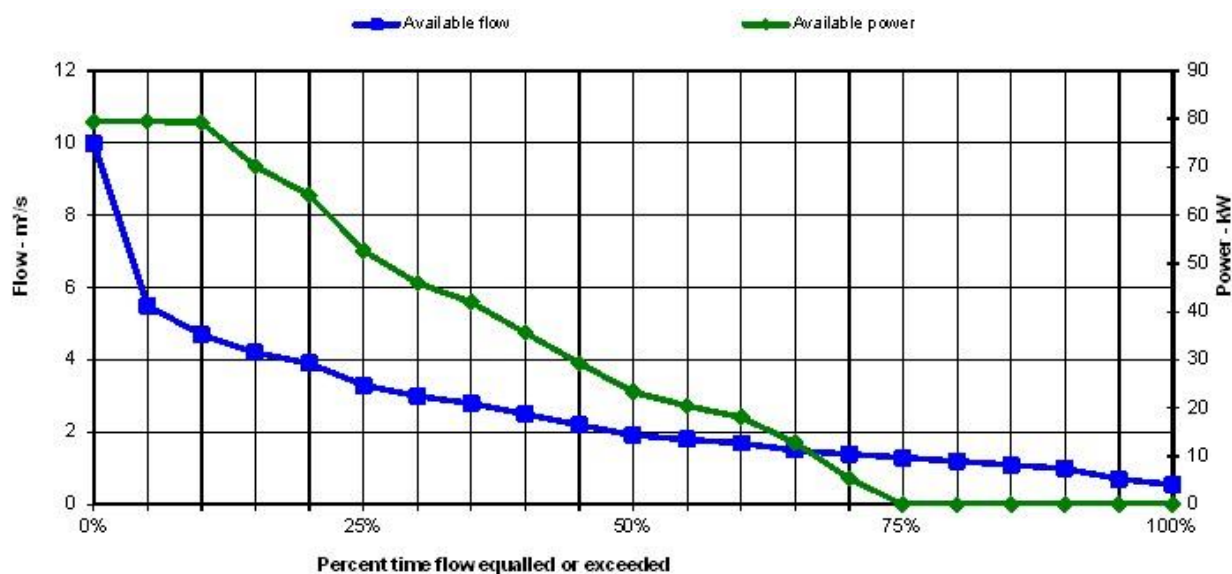
## Option 4 Net head 2.25m

### OSSBERGER Double Regulated Kaplan Turbine

Design flow 4.0 m<sup>3</sup>/s

Rated Capacity 79kW

Estimated annual energy production 271,000 kWh Energy production profile:

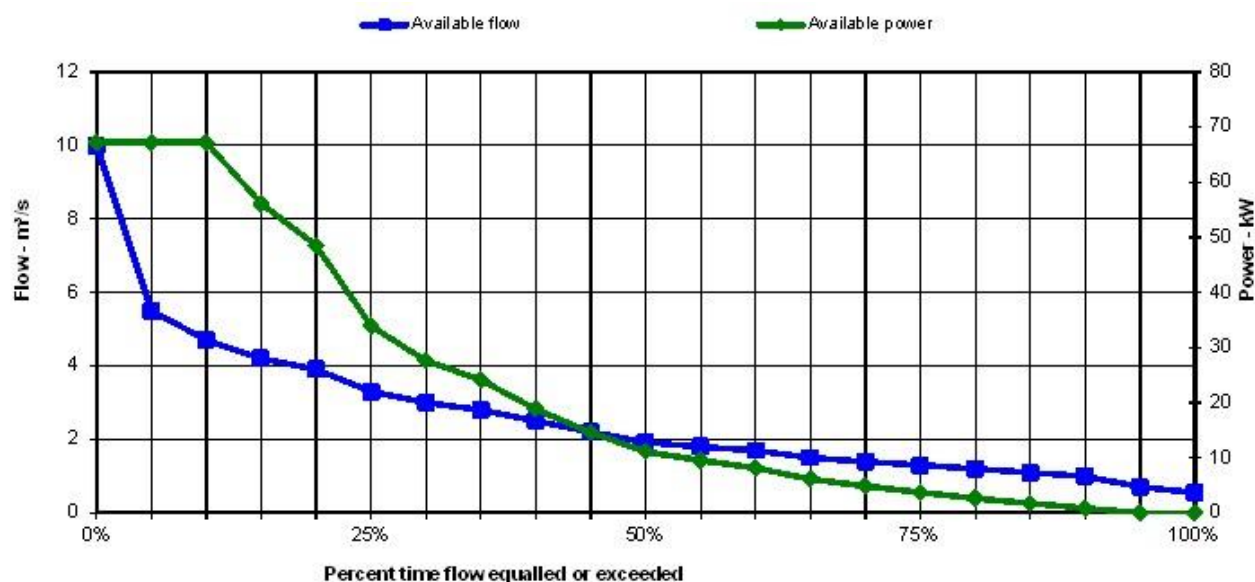


### Archimedes' Screw

Design flow 3.9 m<sup>3</sup>/s

Rated Capacity 67kW

Estimated annual energy production 193,000 kWh Energy production profile:





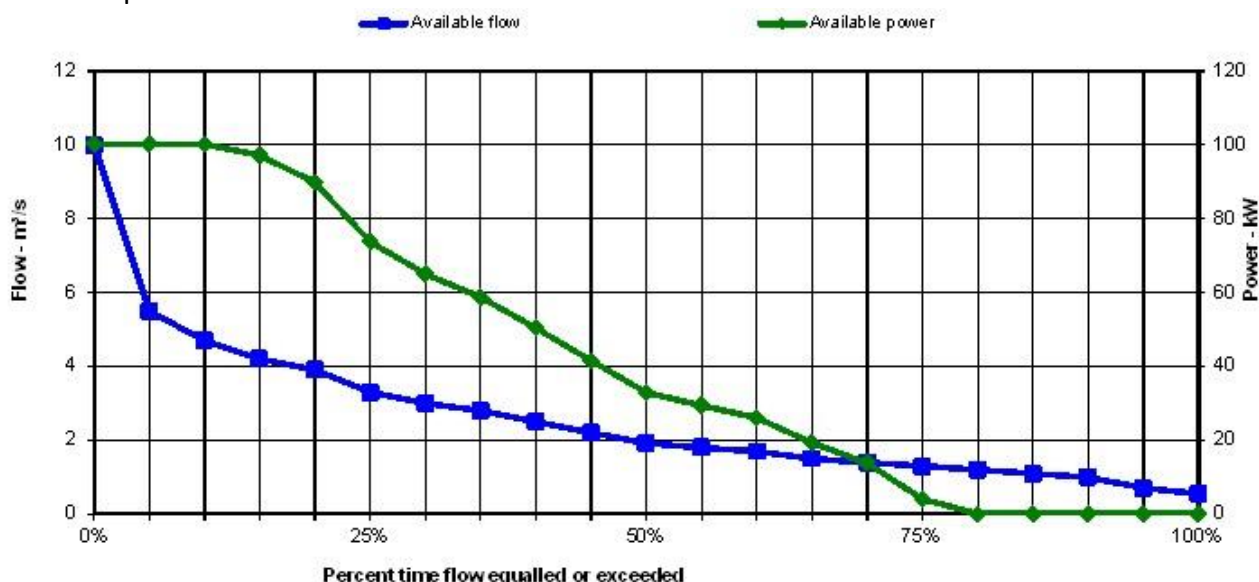
## Option 5 Net head 3.15m – Limited to 100kW

### OSSBERGER Double Regulated Kaplan Turbine

Design flow 3.6 m<sup>3</sup>/s

Rated Capacity 100kW

Estimated annual energy production 374,000 kWh Energy production profile:

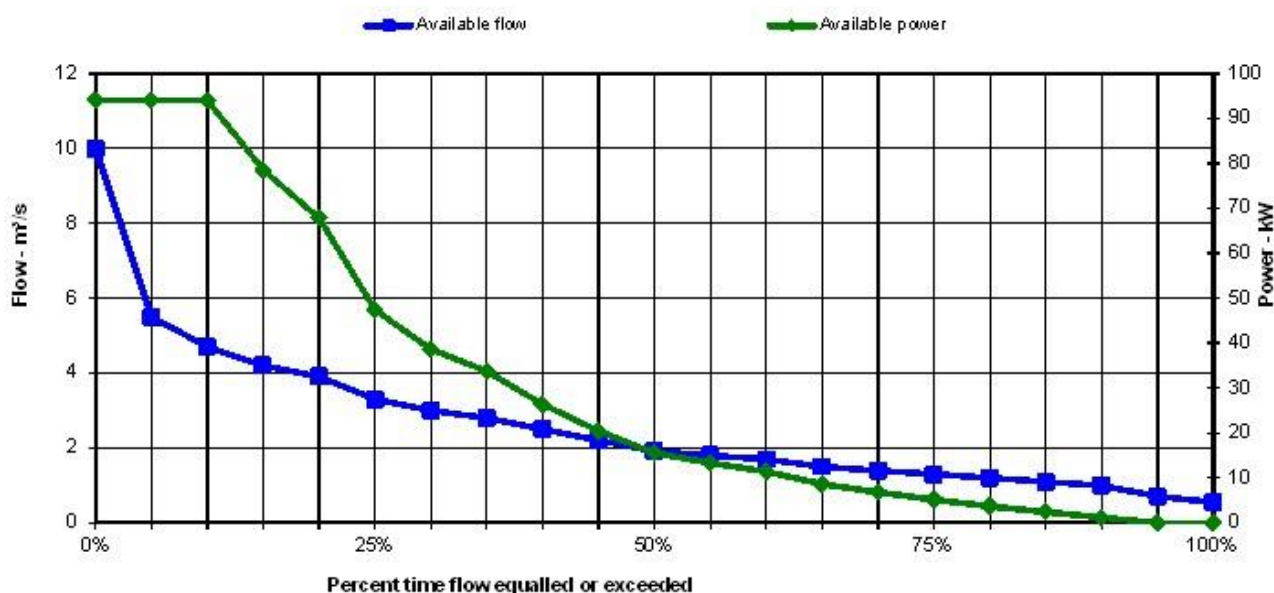


### Archimedes' Screw

Design flow 3.9 m<sup>3</sup>/s

Rated Capacity 94kW

Estimated annual energy production 271,000 kWh Energy production profile:





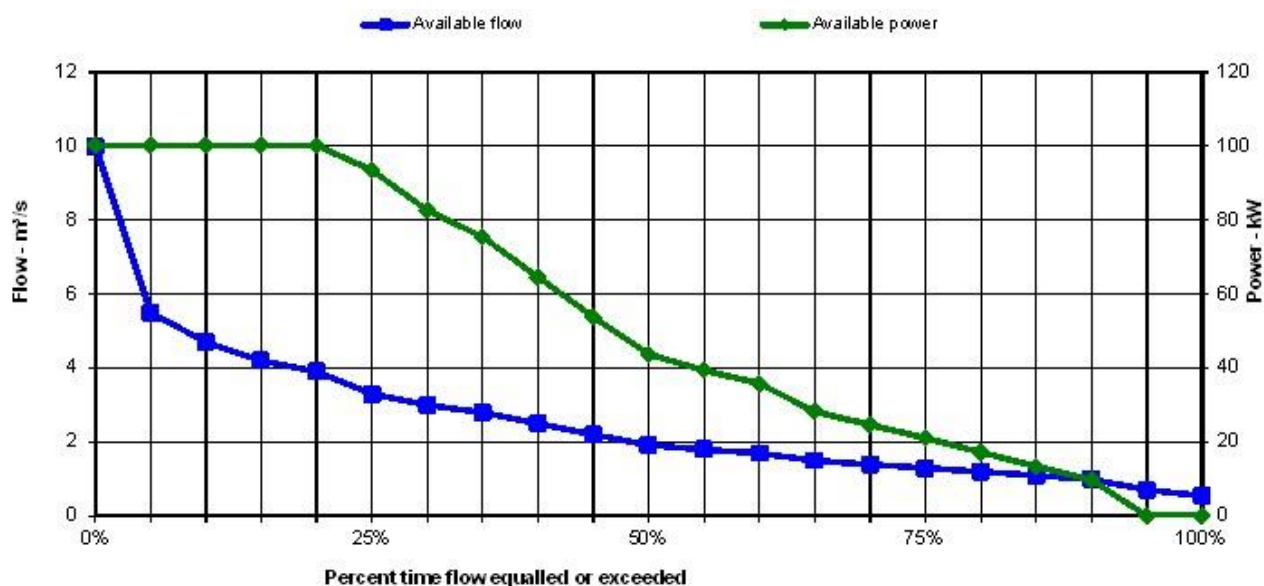
## Option 6 Net head 4.48 – Limited to 100kW

### OSSBERGER Crossflow Turbine

Design 2.8 m<sup>3</sup>/s

Rated Capacity 100kW

Estimated annual energy production 463,000 kWh Energy production profile:

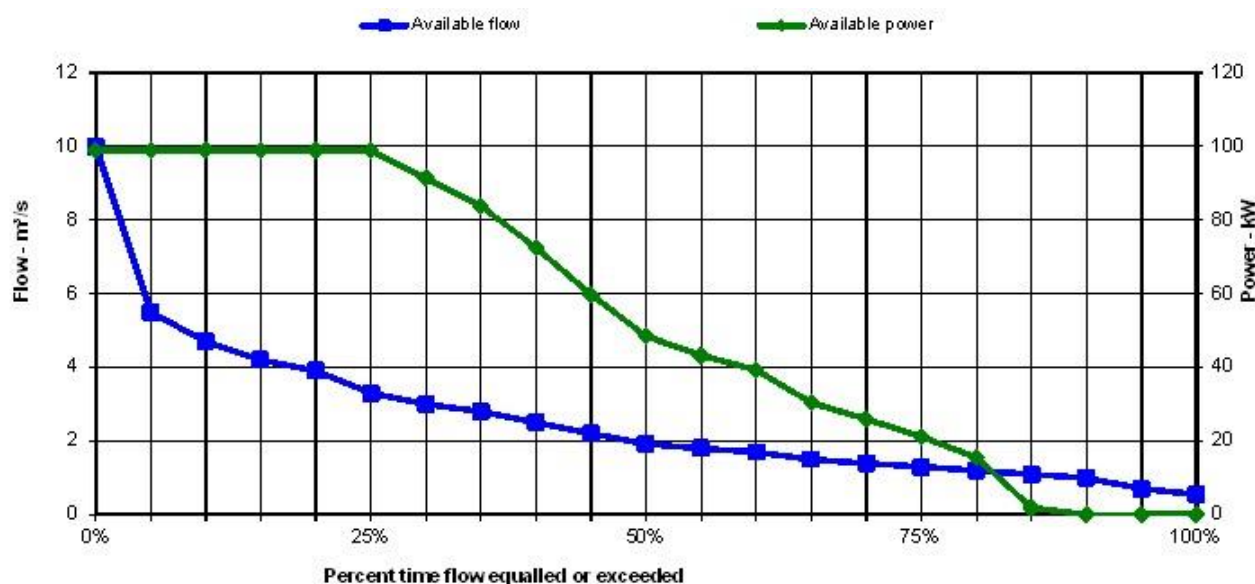


### OSSBERGER Double Regulated Kaplan Turbine

Design flow 2.5 m<sup>3</sup>/s

Rated Capacity 100kW

Estimated annual energy production 472,000 kWh Energy production profile:

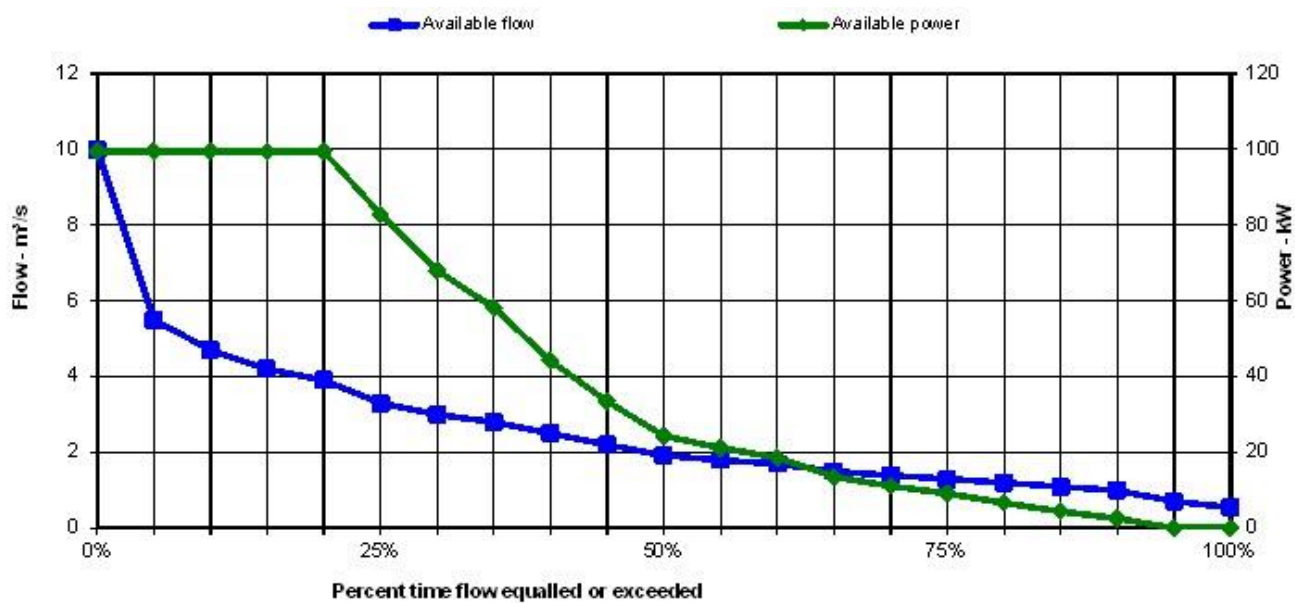


## Archimedes' Screw

Design flow 2.9 m<sup>3</sup>/s

Rated Capacity 100kW

Estimated annual energy production 372,000 kWh  
Energy production profile:



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