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Pumping Station Efficiency: Guidance Document

Project: SC090025/R1

Flood and Coastal Erosion Risk Management Research and Development Programme

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It's our job to make sure that air, land and water are looked after by everyone in today's society, so that tomorrow's generations inherit a cleaner, healthier world.

Our work includes tackling flooding and pollution incidents, reducing industry's impacts on the environment, cleaning up rivers, coastal waters and contaminated land, and improving wildlife habitats.

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Miranda Kavanagh

Director of Evidence

Executive summary

Carbon dioxide is considered to be the most significant greenhouse gas that the Environment Agency needs to manage in its typical day-to-day operations. The Environment Agency has a target to reduce its carbon footprint by a third by the year 2012. Because pumping covers approximately a third of the Environment Agency's overall energy use, with Flood and Coastal Erosion Risk Management representing around half of this, this is an area where significant savings can be made.

This project explored the many ways in which pump efficiency savings can be made across the range of Environment Agency applications and across the UK.

This report describes the findings of this research and proposes a spreadsheet tool for designers, Environment Agency Mechanical, Electrical, Instrumentation Control and Automation (MEICA) teams and other technical staff to better understand their power use and to try to reduce their energy consumption.

Contents

1. Introduction

Carbon dioxide (CO_2) is considered to be the most significant greenhouse gas that the Environment Agency needs to manage in its day-to-day operations. The Environment Agency has a target to reduce its carbon footprint by 33 per cent by the year 2015. Because pumping represents around a third of the Environment Agency's overall energy use, with Flood and Coastal Erosion Risk Management (FCERM) representing around half of this, this is an area where significant savings can be made.

1.1 Overall project aims

The aim of this project is to propose new and innovative solutions to increase the effectiveness and efficiency of operation of existing, new and refurbished pumping systems. These solutions need to meet various business needs of the Environment Agency and other operating authorities.

More efficient pumping operations will clearly help reduce energy consumption and in turn reduce carbon emissions.

1.2 General background

The Environment Agency owns and operates a number of flood defence pumping stations around the UK. Their purpose is to ensure that water levels are maintained at acceptable levels and their respective catchment areas have the minimum risk of flooding at all times. These pumping stations have generally been added to in an ad hoc manner and also changed ownership over the years and as a result have not followed any common basis for pump design, efficiency or delivery duty.

Many engineers rely on software or spreadsheets prepared by others to calculate pumping system losses and select pumps. Whilst this would be acceptable if the engineer fully understood the process, in some cases they do not necessarily have all the information available. This has, over time, resulted in inaccurate system curves, which has in turn lead to oversized pumps being installed.

The Environment Agency has an obligation to reduce the amount of power it uses on a yearly basis across its operations, both to reduce operating costs and to reduce the annual carbon emissions from pumping operations.

Major efficiency savings could be made from replacing all of the older pumping stations with newer and more efficient designs. In practice, however, removing assets which may be many years short of their design lifetimes and replacing them for efficiency reasons is not considered to be economically viable. The Environment Agency must therefore focus on improving the efficiency of assets already in use.

Much work has already been done to address pump efficiency, but has tended to be on a site-by-site basis (Tchobanoglous *et al*., 2003; Atkins Consultants Ltd, 2009). This project aims to provide a common method of establishing where pump efficiency is below that expected and could be improved, so that more sites can be adjusted accordingly. The Environment Agency is not the only authority to use pumping stations in the UK; other operators such as Internal Drainage Boards (IDBs) and water utility companies also operate pumping stations.

Flood defence pumping stations are a major energy cost to the Environment Agency; the figures vary yearly depending on rainfall patterns but are significant in terms of the overall annual operational budget. Pumping represents approximately a third of the Environment Agency's entire operational energy use and thus a notable percentage of its annual energy consumption. Savings in pumping of just a few per cent could result in significant overall reductions in energy use. The primary purpose of this exercise was to investigate ways of reducing energy usage, not to simply reduce costs by, for example, changing to a different utility provider.

1.3 Objectives

The main objectives of this project were to:

- understand the main areas of pump efficiency improvements;
- develop tools for fast diagnosis of efficiency problems;
- conduct a series of tests of the methodology.

This project proposes innovative solutions which will improve pumping station efficiency at new, recently refurbished and older sites. These measures will ideally be employed across the Environment Agency's regions and will help to reduce energy use without compromising pumping effectiveness.

This project will establish what work is currently ongoing, or has been done recently to improve pump efficiency as applied to flood defence applications. Such work will have been carried out by regional Mechanical, Electrical, Instrumentation, Control and Automation (MEICA) teams and may have been done by other special project teams.

This report primarily aims to help the engineer to be independently capable of defining his/her system, to ensure the most efficient pump is selected for a particular application. However, the report also aims to impart sufficient understanding and depth of knowledge to allow the engineer to think beyond the textbook, to the possibility of encountering unusual circumstances in a particular pumping scheme where normal practices do not apply.

Local knowledge of each individual site is invaluable in working towards an optimum design for achieving maximum efficiency. There may be sound reasoning behind an existing arrangement which is not necessarily the most efficient arrangement.

2. Energy usage and evaluation

2.1 Energy terms and units

A wide range of units and measures have been used to describe power, flows and volumes, by manufacturers and by clients alike. Throughout the project, the Systeme International (SI) commonly referred to as the metric system of units has been used for the different variables. Where pumping stations and related equipment were installed long before the widespread use of SI units, conversion of units will be required.

In situations where data relating to pump installations is only available in earlier units, both the original unit and the SI equivalent should be used in order to avoid confusion. In some cases, where record is not available, it will be necessary to take measurements from site. In these cases, measurements will be recorded using the SI system unless there is a valid reason for doing otherwise.

The SI units used within this study are shown in Table 2.1.

Table 2.1: Units used commonly in the pumping industry

	Preferred unit	Legacy units
Power	Watt or kilowatt (W or kW)	Horsepower (HP)
Flo rate	Cubic metres (cumecs) or litres per second (m^3/sec or l/sec)	Cubic feet per second (cusecs) or gallons per hour (cubic feet/sec or gal/hour)
Dimensions	Metres (m) or millimetres (mm)	Inches or feet (inches or feet)
Pressure	Bar gauge or absolute; metres (barg or bara; m)	Inches water or mercury (inches H_2O or inches Hg)
Energy	Joules or kilowatt-hour (J or kWh)	British Thermal Unit, ergs or calories (BTU; ergs or cal)
Time	Seconds (sec)	Seconds (sec)
Force	Newtons (N)	Pounds-force; Dyne (lb; Dyn)

2.2 Carbon usage

Carbon emissions from power generation can be calculated in a number of ways depending on the efficiency of the power transmission system, the method of generation and the ultimate energy source. In order to ensure a fair comparison between different pumping schemes and no artificial advantages from some areas having access to low-carbon power, we decided to use a common and standard figure for carbon emission from power generation.

The Grid Rolling-average Electricity Emissions Conversion Factor (GREECF) between carbon emissions and electricity generation is a common measure of the environmental impact of power generation used by industry when comparing the cost of their power. In June 2010, the conversion factor (Defra, 2009a) was 0.537 kg CO_2e/kWh; this figure was used in the calculations in this report.

A number of factors do not impact directly upon carbon emissions resulting from pumping station operations. Examples of carbon-intensive items which may be encountered at pumping stations include:

- building structure modifications;
- pipework and changes to associated items;
- control systems upgrades;

- staff travel to and from the sites.

Carbon footprints associated with travel are well understood; for example, figures are readily available (Defra 2009b,c,d; Department for Transport 2009) for personal transport, small HGVs and larger vehicles, and as a result little additional work can be done in this area, other than to reduce the number of miles driven for specific tasks. This can produce undesirable consequences as the number of maintenance visits to individual sites will be reduced, with some of the more remote assets suffering the longest periods between maintenance activities.

This project does not investigate the carbon costs associated with this travel or maintenance activities, but focuses only on the pumping operations.

The inefficiency of pumping stations may be caused by a number of factors which may be summarised as follows:

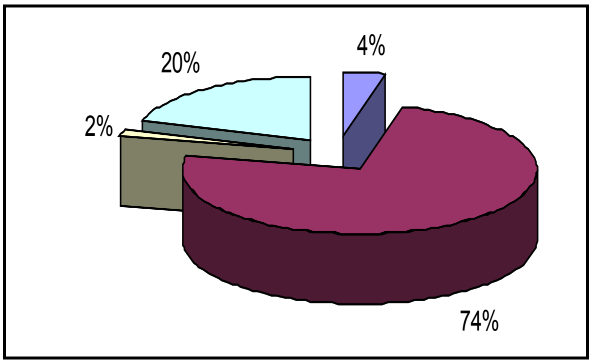
- Incorrect selection and/or sizing of the primary pumping system components.
- Poor design of the pumping system, including intake and sump, pipework layout, discharge.
- Control system and station operating philosophy.
- Deterioration of pump impellers and associated moving parts.
- Deterioration of pump and pipework surfaces in contact with the moving liquid.

Each of these factors may have a significant effect on the efficiency of the pumping station. They may also combine to result in greater inefficiency than the sum total of the individual items. For example, a damaged oversized pump and undersized pipework system would combine to result in a greater inefficiency of the overall system.

2.3 Life cycle costs

It is often thought that fitting oversized pumps does not lead to any loss of performance or increased operating costs as an oversized pump will generally tend to operate for less time; however, this is not always the case as higher delivery flow rates can increase frictional losses in pipelines and hence incur greater operating costs. Further costs may be associated with increased power supply requirements and greater requirements for the control systems.

Flood defence applications (which operate intermittently) tend to have relatively low annual power usage compared with water industry systems (which tend to operate continuously all year round) so the figures below may require some adjustment; however, Figure 2.1 clearly demonstrates that if the most efficient pumps are not selected at the start, an opportunity is missed to contribute to sustainable design.



		Contribution to whole life costs (%)
1	Acquisition costs	4
2	Basic energy costs	74
3	Additional energy costs	2
4	Maintenance costs	20

Figure 2.1: Thames Water ‘Life Cycle Costs Model’

This report primarily aims to help the engineer to be independently capable of defining his/her system, to ensure the most efficient pump is selected for a particular application. However, the report also aims to impart sufficient understanding and depth of knowledge to allow the engineer to think beyond the textbook, to the possibility of encountering unusual circumstances in a particular pumping scheme where normal practices do not apply.

3. Pumping station fundamentals

3.1 Pump selection

Pump selection is largely driven by the requirements of the application in question (Terry 1995). The different types of pump fall into two main categories. Low flow and high head pumps are generally used for transfer of water over long distances or up large height differences and are commonly found in sewer networks, whereas high flow and low head pumps tend to be used on flood defence and are the main focus of this guidance.

Of the pumps encountered in flood defence there are four main designs. These are:

- Archimedean screw pumps;
- axial flow rotodynamic pumps;
- mixed flow rotodynamic pumps;
- centrifugal (radial) flow rotodynamic pumps.

Figure 3.1 shows typical operating ranges for the different pump types. As can be seen, the typical operating ranges of flood defence applications can be serviced by axial flow or mixed flow type pumps. In practice, there will be overlaps between manufacturers' ranges of pump types.

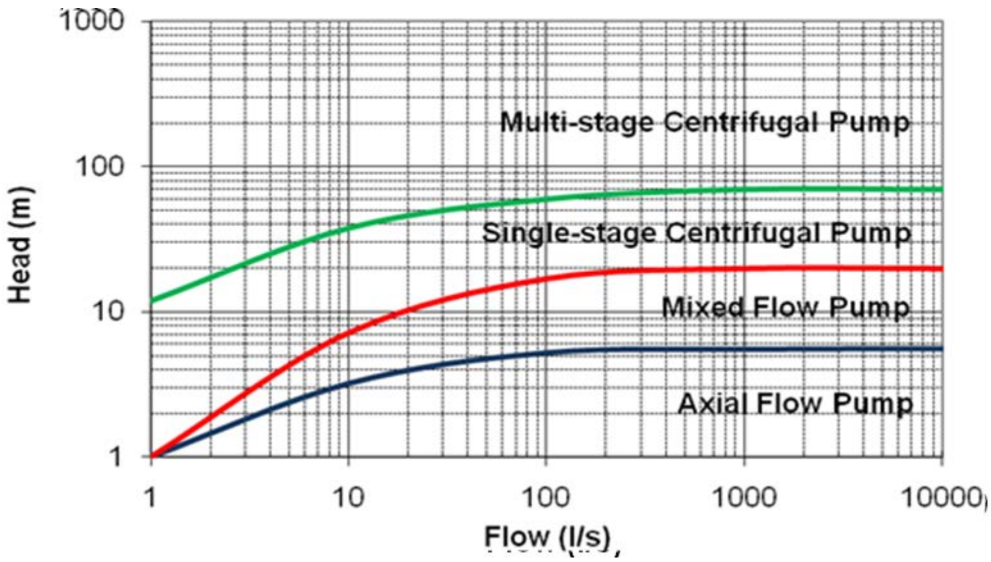


Figure 3.1: Typical operating ranges for different pump types

3.2 Archimedean screw pumps

Screw pumps are based on the Archimedes principle of a rotating shaft upon which a helical blade (or series of blades) fit inside a specially formed channel. As the shaft rotates, a cavity moves along the length of the shaft and any water trapped within the cavity moves as well. These are commonly found where low heads are required, typically less than ten metres.

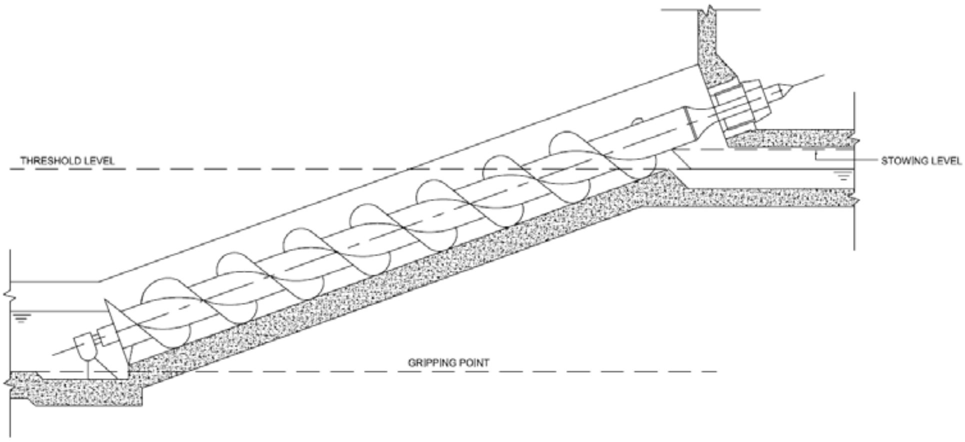


Figure 3.2: Typical Archimedes screw pump

The design is robust and can be found around the world where the reliability inherent with slow moving machinery and simple technology is important. The design is not without drawbacks, however; the main disadvantage of the screw pump concept is that it is difficult to increase the pumping head without considerable structural and mechanical modification, whereas this is easy with other types of pump. Also, since the design is dependent upon minimal leakage from between the flights and the channel, any wear over time significantly reduces efficiency. The screw pump efficiency also depends on the level of incoming flow and if this is below recommended levels the efficiency of the station is greatly reduced, as shown in Figure 3.3. This may conflict with the requirement to maintain channels at the lowest possible level to maximise storage capacity within the system.

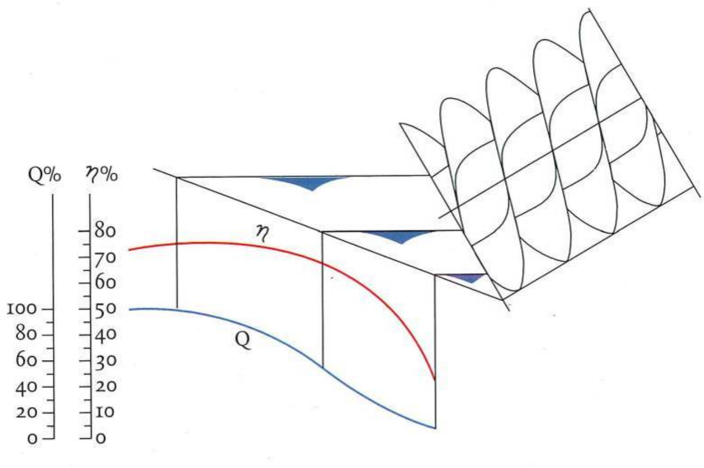


Figure 3.3: Typical screw pump efficiency graph

The bottom bearing has traditionally been a common failure point, which in turn results in wear of the main flights. As bearing technology has improved over the years, the bottom bearing has become less problematic but many older designs still employ a completely submerged bearing which is very difficult to access and hence maintain.

Figure 3.4: Typical screw pump installation

Figure 3.4 shows a good example of a screw pumping station. The intake screens can be seen at the base of the screw channels with a walkway for manual raking and weed removal. The building to the left houses the screw motors and gearboxes plus the control gear. The building sits over the discharge channel, which then flows away to the left. Figure 3.5 shows why it is particularly difficult to alter factors such as discharge height once the station is built.

Figure 3.5: Typical three-flight screw removed for servicing

3.3 Axial flow pumps and mixed flow pumps

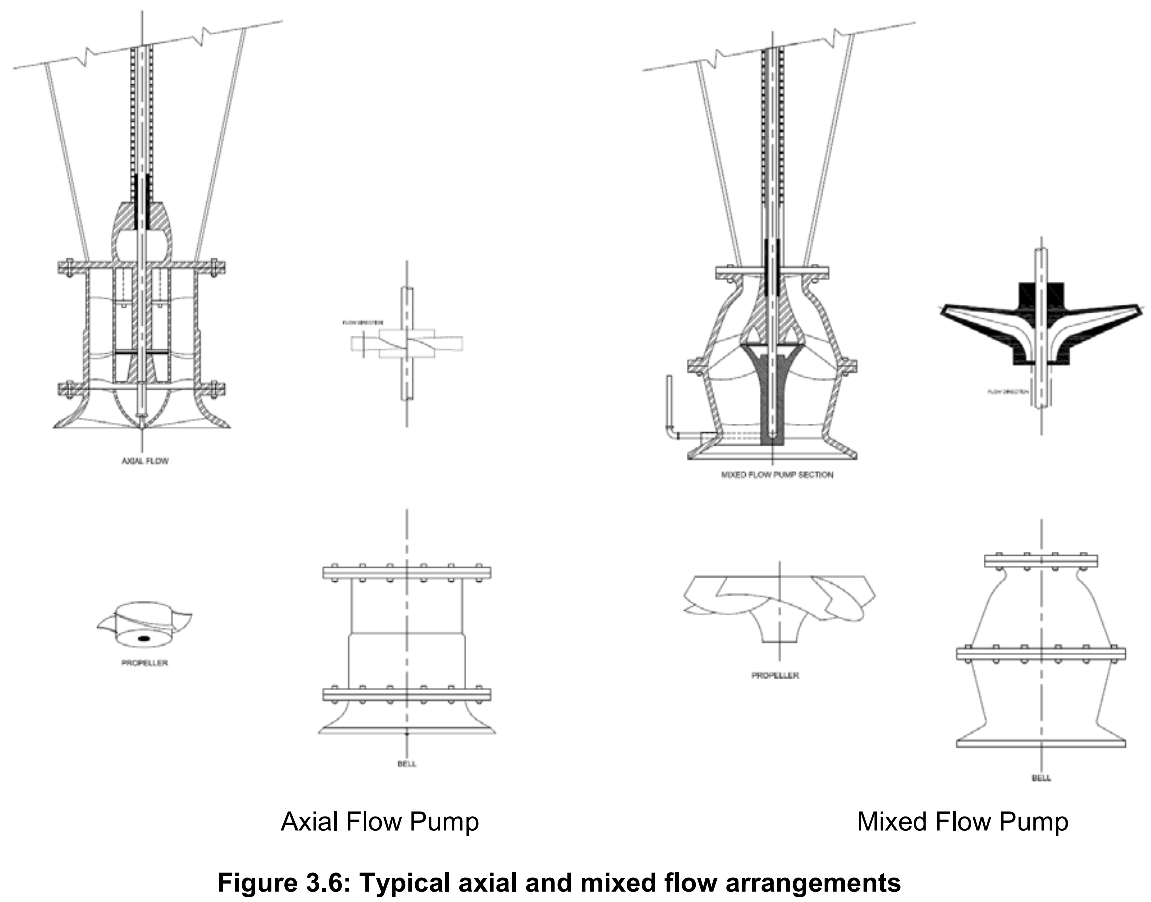
Axial flow pumps and mixed flow pumps are very similar in initial viewing and each is available in various configurations, which may add to the confusion of identifying the particular type.

Axial flow pumps tend to be used where very low delivery heads are required. These pumps operate on the simple principle of a specially shaped impeller rotating within a tube. A close analogy is the propeller used on a boat which propels water in one direction to create thrust.

The pumps may be of varying designs, such as are usually driven by motors mounted on top of the structure by means of a vertical shaft although this can sometimes be included within the tubes themselves (often referred to as a 'canned pump'). Of the pump types, these are generally considered to be the best in terms of efficiency although their application is usually limited to the low head applications described.

Axial flow pumps are commonly found on in-line type pumping stations where a dividing wall or 'dam' is built across the watercourse and provides a natural stilling area for the pump intakes, although they can be mounted off-line if needed.

The pumps can be mounted at any angle, although in the flood defence application they tend to be almost universally mounted in the vertical orientation. Often the whole assembly is mounted within a building and the discharge pipes are connected into a common manifold. Figure 3.8 shows a good example of the motor installation of such a pumping arrangement, with the pumps well above the flood level.



Axial Flow Pump Mixed Flow Pump

Figure 3.6: Typical axial and mixed flow arrangements

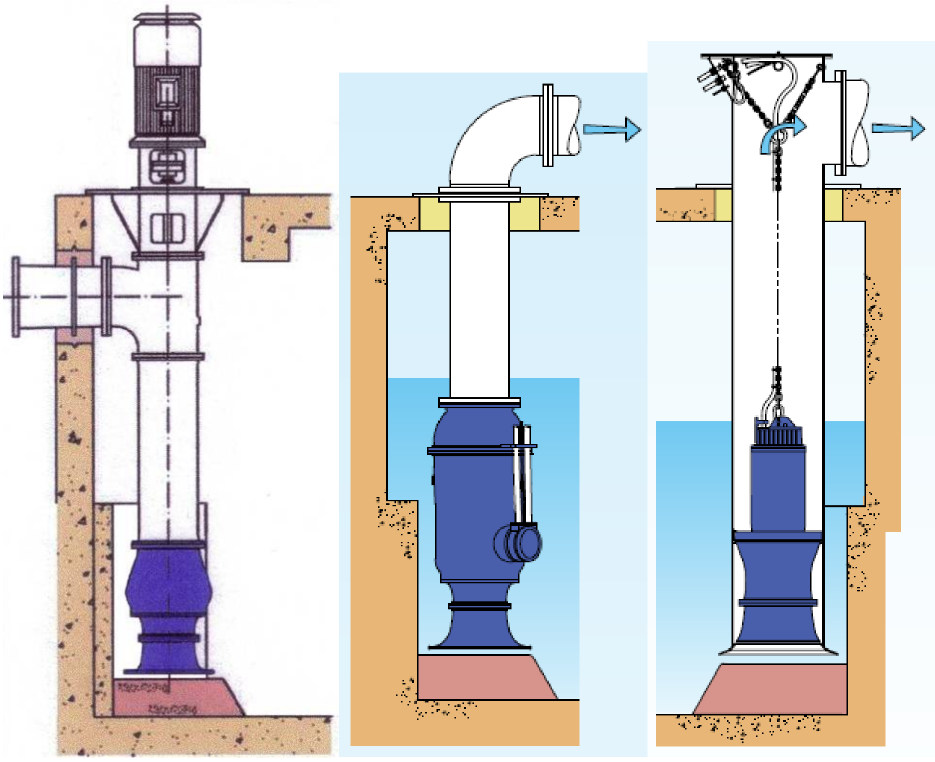


Figure 3.7: Vertical direct drive, suspended and canister pump type installations may be axial or mixed flow pumps

Figure 3.8: Typical vertical axial flow pump installation

3.4 Centrifugal flow pumps

Centrifugal, or radial, flow pumps are generally used across a wide range of applications of head and flow. In the context of flood defence, the older installations tend to be of the horizontal large diameter type, often dual inlet. These rotate at relatively slow speeds to match the low head requirements. As the impellers are raised above the incoming water level, they will normally require a priming system to operate prior to operation.

Figure 3.9: Large radial dual flow installation in flood defence application (top casing removed)

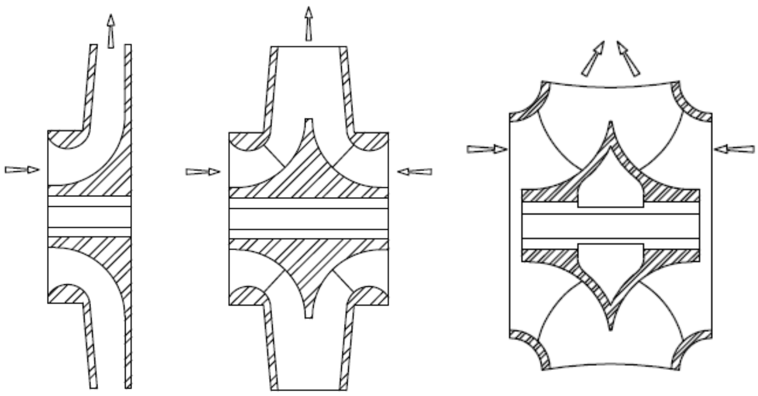


Figure 3.10: Typical centrifugal impeller configurations

Modern types of centrifugal pumps may be configured in a multitude of ways and can be coupled so that the discharge from one pump feeds the intake of a second or third stage, increasing the delivery head. In this way it is possible to construct centrifugal pumps which can deliver heads of hundreds of metres.

Centrifugal pumps tend to be less tolerant of solid material entering the water stream, although lower delivery head pumps suffer less from this problem. It is common to find that in waste water transfer applications, centrifugal pumps are designed to be tolerant of solid material at considerable expense to efficiency.

Generally, modern centrifugal pumps operate at higher speeds than the other types of pump especially when higher pressures are required; speeds typically range between 1,400 rpm and 3,000 rpm. Matching the pump operating speeds with the application is crucial to maximising pump efficiency, as high operating speeds usually require more power and need to be controlled in order to avoid losses.

Modern centrifugal pumps are commonly used for sewage transfer where large solids may be present. Unlike screw type pumps, the centrifugal pump does not readily lend itself to passing large solids. Many pumps of this nature are necessarily very open, with large open spaces within the pump bowl and with generous openings within the impeller.
This is particularly a problem with smaller sewage pumps where the ratio of open space to impeller within the pump bowl is higher (solids tend to be of a similar size regardless of flow when dealing with sewage).

Figure 3.11: Typical submersible transfer pump installation (top cover removed)

Table 3.1 shows a summary of the pump types available for applications such as flood defence or water transfer, with their advantages and disadvantages as a general summary; the table does not cover every pump installation as there are many different types of installation in existence.

Table 3.1: Summary of pump types

Pump type	Typical advantages	Typical disadvantages
Archimedes screw	Solids tolerant Low operating speed	Expensive capital Difficult to modify Hazardous, requires enclosing
Axial flow & mixed flow	Good efficiency if maintained at best efficiency point (BEP) Solids tolerant	Limited delivery head Efficiency drops off away from BEP Performance is very dependent upon providing good inlet flow to bellmouth Intake model tests are advisable
Centrifugal flow	Wide delivery range Compact	Less tolerant of solids Shorter lifetimes Lower efficiency

3.5 Specific speed

Specific speed is a term used to describe the geometry (shape) of a pump impeller. Suppliers, manufacturers or specifiers responsible for the selection of a particular pump for a specific application can use this specific speed information to help them obtain the parameters useful for the following purposes:

- Select the shape of the pump curve.
- Determine the efficiency of the pump.
- Anticipate motor overloading problems.
- Predict net positive suction head (NPSH) requirements.
- Select the lowest cost pump for their application.

Specific speed (N_S) is defined as "the speed of an ideal pump geometrically similar to the actual pump, which when running at this speed will raise a unit volume, in a unit of time through a unit of head".

$$\text{Specific speed } (N_S) = \frac{N \; Q^{0.5}}{H^{0.75}}$$

N = speed of the pump in revolutions per minute (rpm)
Q = flow rate in litres per minute (for single or double suction impellers)
H = total dynamic head in meters.

Figure 3.12 illustrates the relationship between specific speed and pump efficiency. In general, the efficiency increases as N_S increases. Specific speed also relates to the shape of the individual pump curve as it describes head, capacity, power consumption and efficiency.

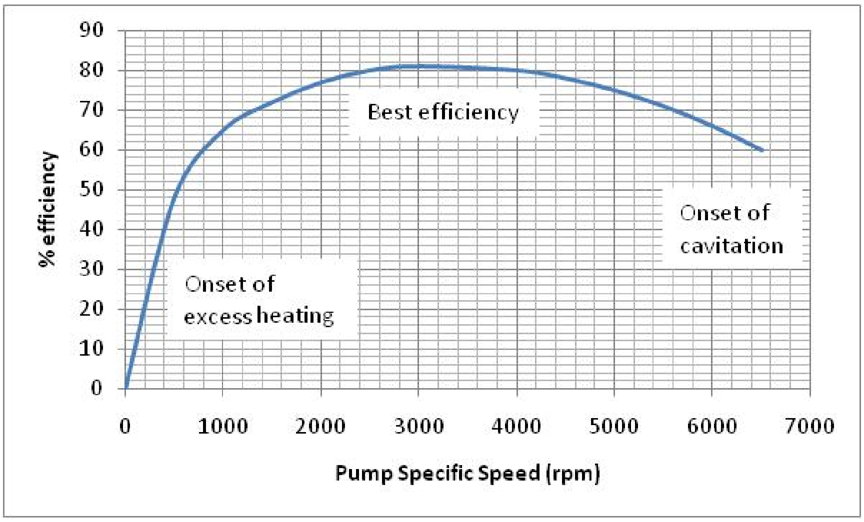


Figure 3.12: Example pump efficiency curve

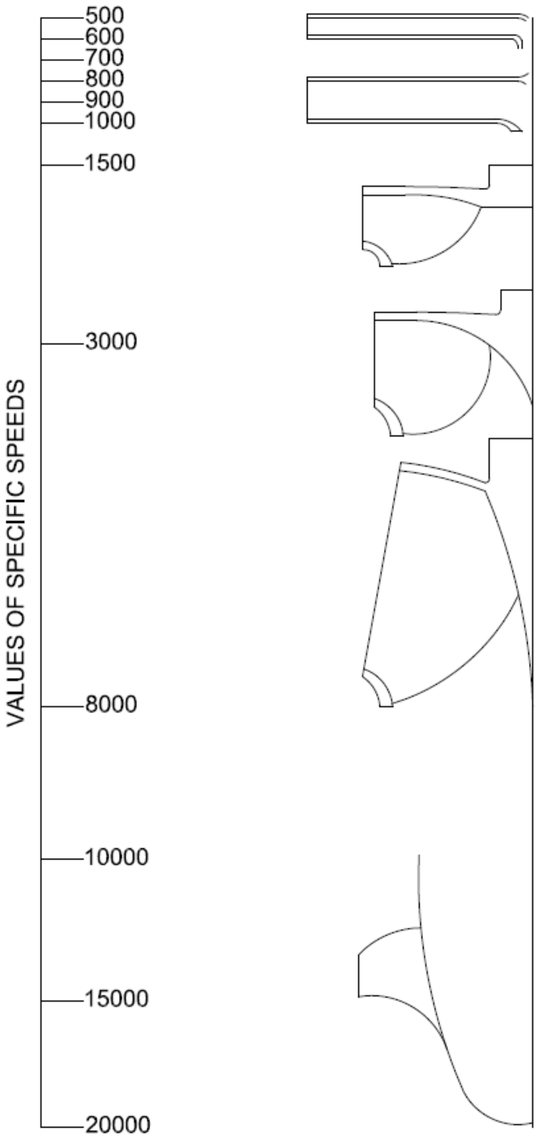


Figure 3.13: Cross-section of pump impeller types

If other units are substituted for flow and head, the numerical value of N_S will vary. The speed is always given in revolutions per minute (rpm). The calculation for deriving specific speeds from different units can be summarised as follows.

- British ....Q = Imp. GPM and H = feet. Divide the N_S by 1.5
- Metric ....Q = m^3/hour and H = metres. Divide the N_S by 1.9

An example of which would be to make a calculation of N_S in both metric and US units:

- Q= 110 l/sec or 396 m^3/ hour or 1,744 GPM
- H = 95 metres or 312 feet
- Speed = 1,450 rpm

Using l/sec: $N_S = \frac{1450\ (110)^{0.5}}{95^{0.75}} = 500$

Alternatively using m^3/hour: $N_S = \frac{1450\ (396)^{0.5}}{95^{0.75}} = 948$

Or using GPM and feet: $N_S = \frac{1450\ (1744)^{0.5}}{312^{0.75}} = 816$

If the above results were describing an actual application with a low specific speed, radial flow pump, it would be a large pump with a low efficiency. Going to 2,900 rpm or higher would increase the N_S to 1,000 or more, meaning a smaller pump with a much higher efficiency, but using a smaller pump at this significantly higher speed would have other possible consequences (both beneficial and disadvantageous) which could include some or all of the following: .

- The higher efficiency would allow the user to use a less powerful driver that would reduce operating costs.
- Associated hardware such as wiring could be reduced.
- A smaller pump makes associated hardware cheaper. For instance, a smaller diameter shaft means a lower cost mechanical seal and lower cost bearings.
- Cavitation could become a problem as the increase in speed means an increase in the NPSH required.
- If pumping an abrasive fluid, abrasive wear and erosion will increase with increasing speed.
- Many single mechanical seals have problems passing fugitive emission standards at the higher pump speeds.
- High heat is a major cause of bearing failure. The higher pump speeds contribute to the problem.

The following diagram (Figure 3.13) illustrates the relationship between specific speed and pump efficiency. In general, the efficiency increases as N_S increases. Specific speed also relates to the shape of the individual pump curve as it describes head, capacity, power consumption and efficiency.

3.6 Pump driver

Pumps can be driven in one of two ways: by electric motors or by internal combustion engines (usually diesel).

Engine driven pumps tend to be used in remote situations where their use is infrequent and where electrical power is not readily available or would be prohibitively expensive. The efficiency of a typical diesel engine ranges from around 20-40 per cent. This results in a very low overall efficiency although static diesel engines can yield better results if optimised. Methods for improving internal combustion efficiency do exist, such as capturing exhaust gas energy via a turbine or making use of waste heat with a sterling cycle device. These usually rely on expensive and specialist equipment and expertise, and hence are not readily available off-the-shelf.

Electric motors are generally more efficient and can usually reach efficiencies of over 90 per cent depending on the type of motor and its condition.

When coupled with the higher efficiency of a typical thermal power station of around 25 per cent, this offers a much higher overall efficiency. In more remote areas, however, transmission losses from long transmission lines may reduce this overall performance.

3.7 Net positive suction head and cavitation

The net positive suction head refers to the head required in the inlet stream to prevent the problem of cavitation (Engineers Edge, 2010) within the pump delivery. When considering rotodynamic pumps, it is important to consider that there will always be a reduction in pressure on the suction side of the pump, where the only pressure forcing water into the pump is atmospheric pressure (Lewin, 1995).

Some pumps have a tendency to create very low pressures, particularly multi-stage centrifugal pumps where the rotational speed is around 3,000 rpm and where localised pressures can easily drop below the vapour point of water. In these cases cavitation will occur as the water boils and re-condenses causing the formation of tiny bubbles which can over time cause significant damage to the pump as well as reducing efficiency. This cavitation is readily observable because of the distinctive noise it produces and sometimes by the presence of fine bubbles evident in the pumped water stream.

3.8 System characteristics

Just as pumps have characteristic curves, the systems into which they deliver flows also have characteristics and these are often plotted as curves as well. Depending on the age of a particular system, the curve can be calculated if the pipe diameters are known and lengths can be estimated, or if the system can be taken out of service, it is also possible to carry out on-site tests to establish the exact system characteristics over a range of flows.

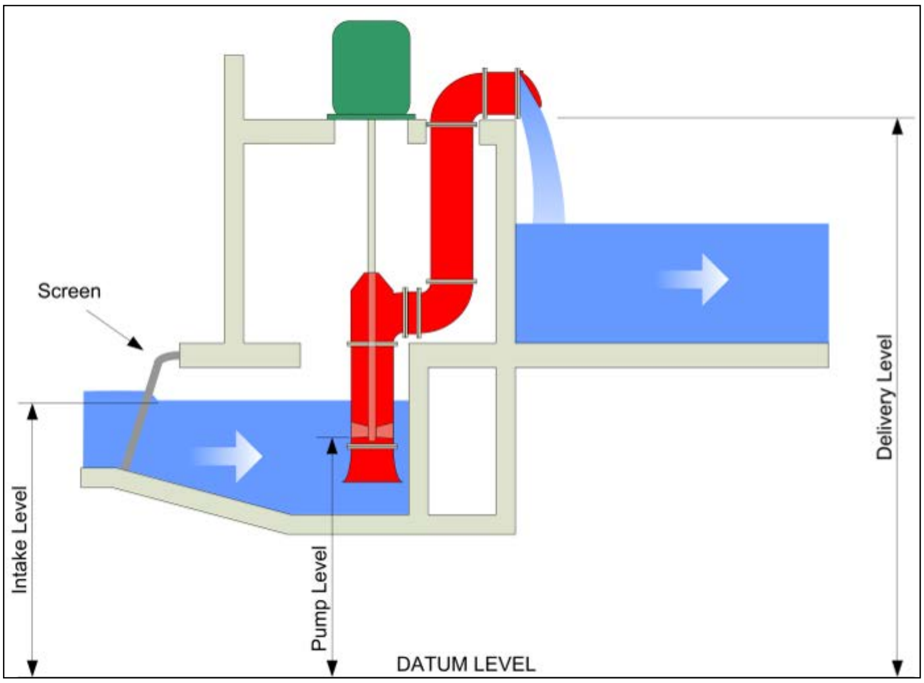
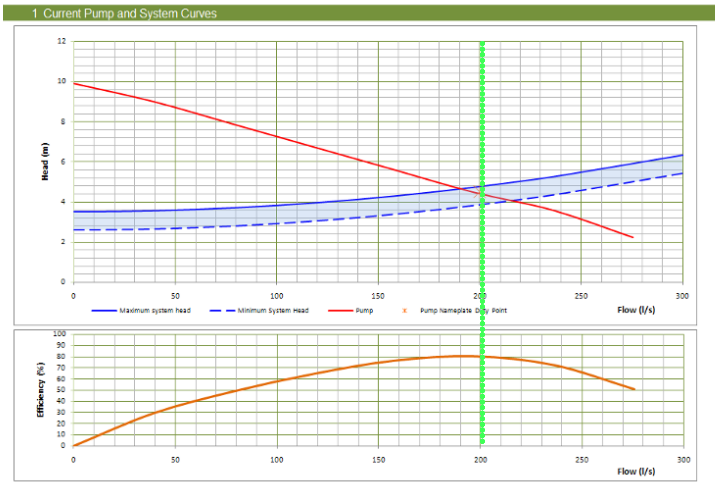


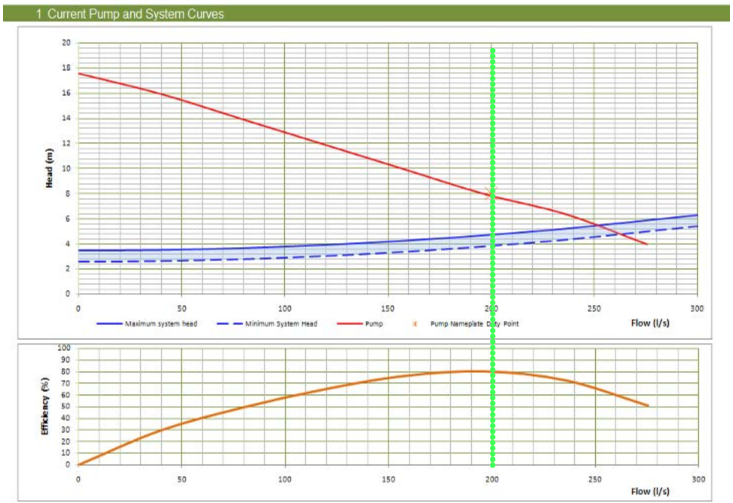
Figure 3.15: Example of typical generic pump system layout

The plotting of the pump curve and system curves on the same graph will provide indication of the theoretical pump discharge rate where the two cross. Where the static head can var,y it will be necessary to plot system curves for high and low levels to check the pump meets all operating criteria.

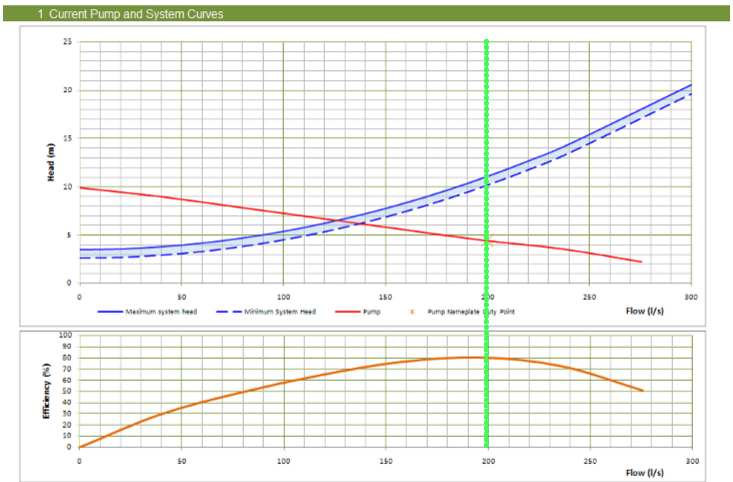
Incorporating the pump efficiency curve will indicate the efficiency at the operating points identified and how this relates to the best efficiency point (BEP) of the pump.



The pump and system curves cross at the best efficiency point. The pump has been matched to the system curve.



The pump and system curves cross to the right of the best efficiency point.



The pump and system curves cross to the left of the best efficiency point.

Figure 3.14: Examples of pump and system curve variations

3.9 System calculations

The calculated head at any given flow rate will be made up of static head and friction head, as explained below.

The static head of a system is simply the difference in height between the input and the highest point. For long complex pumping schemes this may be more difficult to establish, but for simple designs of flood defence pumping stations this is usually very simple as the input and output are close together and readily accessible. In some cases, it is possible to gain some advantage by using the naturally occurring siphon effect of water passing over an enclosed pipe to reduce the overall effort required, in which case the static head is reduced.

Friction head, sometimes referred to as 'pipe losses' is the equivalent head required to transfer the fluid through the pipes and fittings at the given velocity.

Longer pipes with changes of direction, fittings and rough pipe surfaces tend to have higher friction losses than straight pipe runs (Wallingford, 1978). Friction loss is also directly proportional to flow velocity, and hence it is important to increase pipe diameter as far as practicable to reduce the velocity. Generally, flow velocity of less than 1.0 m/sec is an ideal figure for pumping station design, although if the pipe run is very short this can be increased to over 2.0 m/sec.

The pressure head of a system is only used where additional pressure is required at the delivery point, such as in water distribution systems. This is not applicable to flood defence applications.

These factors are all added to determine the overall head for the system.

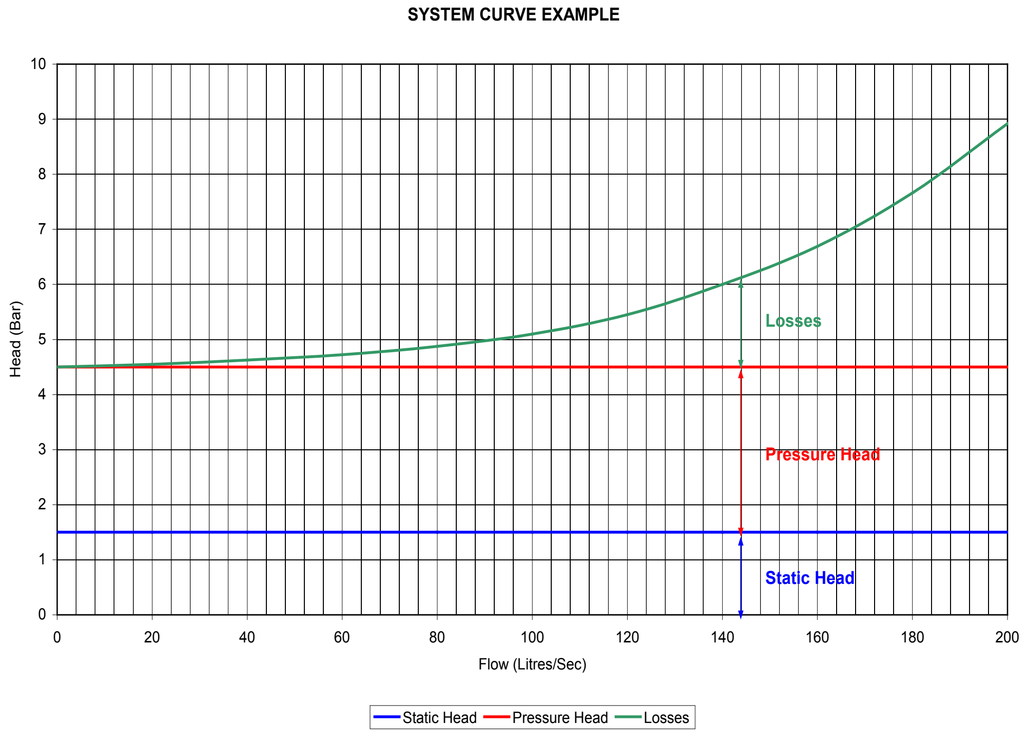


Figure 3.17: System curve components

3.10 Hazen-Williams formula

The Hazen-Williams (Hazen and Williams, 1920) formula is an empirical method applicable to water applications within a temperature/viscosity range in the region of 15°C/1.14 x 10^{-6} m^2/s. This method would have been used traditionally as it would have been simpler to use prior to the development of computers.

The Hazen-Williams formula is as follows:

$$H_f = 1214.6\, L \left(\frac{100}{C}\right)^{1.85} \frac{q^{1.85}}{d^{4.8655}}$$

Where

H_f = friction loss (m head)

L = length of pipe (m)

C = Hazen-Williams friction factor

q = flow (l/min)

d = internal diameter of pipe (mm)

The Hazen-Williams method uses a friction factor method to quantify the type and condition of the pipe. This is different to the surface roughness used in the Colebrook-White equation to quantify the condition of the pipe and cannot be substituted.

The Hazen-Williams method uses representative equivalent lengths in pipe diameters for valves and fittings to ensure these are included in the calculation of the system curve.

3.11 Colebrook-White equation

The Colebrook-White equation (Colebrook and White 1937) is considered to be the more accurate of the two methods for calculating the pressure or head drop due to friction in pipes for Newtonian fluids. This equation relates the friction factor to the Reynolds number and the pipe roughness. The friction factor is then used in the Darcy formula to calculate head drop. For non-Newtonian fluids, which are mostly slurries of one kind or another, the process is much more complicated and many factors are taken into account. As we are dealing with water in this instance we will not need to consider this.

The Colebrook-White equation is as follows:

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left(\frac{\varepsilon}{3.7\,D} + \frac{2.51}{R_e\sqrt{f}}\right)$$

Where

f = friction factor

ε = pipe surface roughness (RMS value)

D = internal pipe diameter

Re = Reynolds number

3.12 Swamee and Jain equation

The Colebrook-White equation is non-factorable in 'f', awkward and difficult to solve. There is also an equation developed from the Colebrook-White equation by Swamee and Jain (Swamee and Jain, 1976). The value of 'f' calculated from this equation differs from f calculated from the Colebrook-White equation by less than one per cent. It has the advantage of not requiring an iterative technique to determine the friction factor.

This equation is therefore used frequently in computer-based programmes to calculate friction head losses in pumping systems, as is the case for the spreadsheet tool.
The Swamee and Jain equation is as follows:

$$f = \frac{0.25}{\left(\log_{10}\left(\frac{\varepsilon}{3.7\,D} + \frac{5.74}{R_e^{0.9}}\right)\right)^2}$$

Where
f = friction factor
ε = pipe surface roughness (RMS value)
D = pipe diameter
Re = Reynolds number

3.13 Design duty – including maximum/minimum demand evaluation

The designer of any pumping station must ensure that the pump curve matches as closely as possible the requirements of the system curve, ideally over a range of flows but more usually within a narrow range of flows over which the system is expected to operate. It is imperative that the maximum and minimum flows are known, as this will define the best and worst case scenarios for the pump. Also of great importance is the need to know the point at which the pump is likely to spend the majority of its operating life.

A pump which can deliver a given flow for 99 per cent of the time is best sized for that particular flow, even if this means sacrificing the ability to deliver much higher flows occasionally.

In situations where there is a great difference between the average and maximum delivery required, there is a strong case for using two pumps, each dedicated to a particular duty rather than trying to make a single pump do both duties.

One approach which is finding favour in recent times is to use variable speed drives to control the speed at which the pump operates, usually to slow a pump from a design speed which is considerably higher than that needed. While this may result in savings, it is also possible that by operating the pump at lower speed than its design speed, a drop in efficiency results, if it is not fully matched to the duty. This is not generally appreciated and the fitment of variable speed drives may actually reduce overall efficiency.

3.14 Siphonic recovery systems

Systems which incorporate 'siphonic recovery' incorporate a high level pipework loop to prevent the potential for backflows from high discharge levels, whilst enabling the pump to only realise minimum possible static heads, thereby reducing power requirements. In designing the system it is important to size the pump on the normal operating levels, whilst ensuring that the pump can achieve the initial head and flow requirements to set up the siphon.

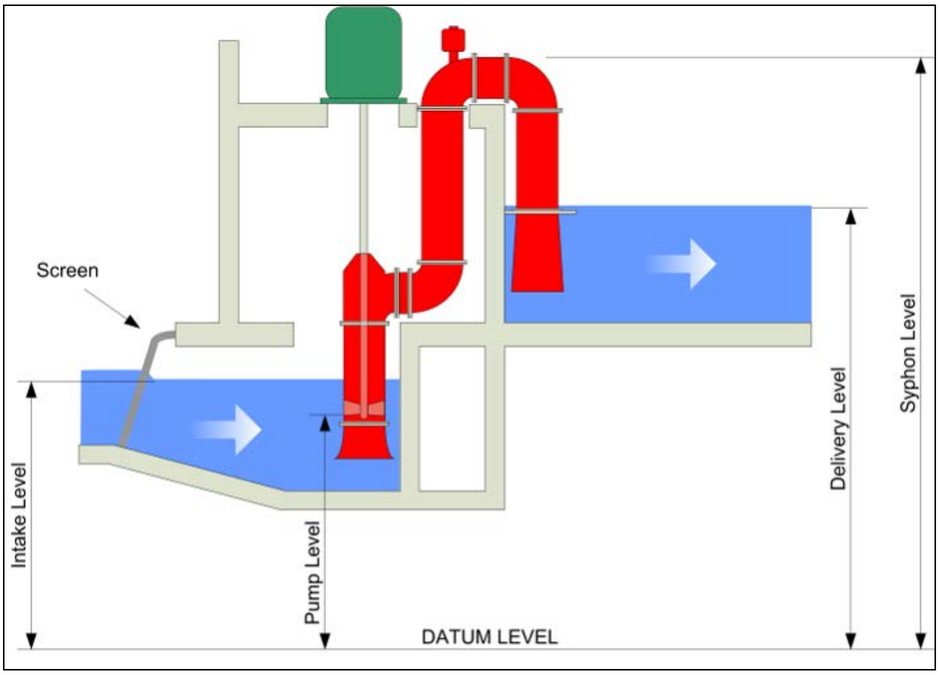


Figure 3.19: Example of typical siphonic recovery pump system layout

3.15 Sump model tests

The importance of the intake and sump design in the overall pumping station efficiency should not be underestimated. Efficiency losses in excess of 15 per cent may be experienced for a poorly designed sump. The difficulty in existing pumping stations is identifying the characteristic signs, on the surface of the water of problems, such a swirls, vortices uneven flow and so on due to their enclosed nature. Some indications, such as high/low current or noise from within the pump, may be present, but the actual causes will be difficult to pinpoint as will any remedial works.

On larger stations it is recommended that model tests are carried out before major refurbishment or new works are undertaken. Although these are often viewed as unnecessary project expenditure, given the well-established sump design manuals available, they can identify serious problems with the sump proposals and the solutions before any works are undertaken.

Figure 3.16: Sump mmodel for an Environment Agency refurbishment project

3.16 Pre-swirl at pump intakes

Most pumps are designed for rotation free inflow. Rotational flow will therefore cause the internal flow inside the pump to depart from the design pattern and cause the performance of the pump to deviate from design parameters. Hence, pre-swirl rotation should be avoided or kept within limits prescribed by the manufacturer.

Rotational flow usually arises from an asymmetrical velocity distribution at the entry to a sump which results in the development of rotational momentum which is then amplified as flow converges into the pump intake.

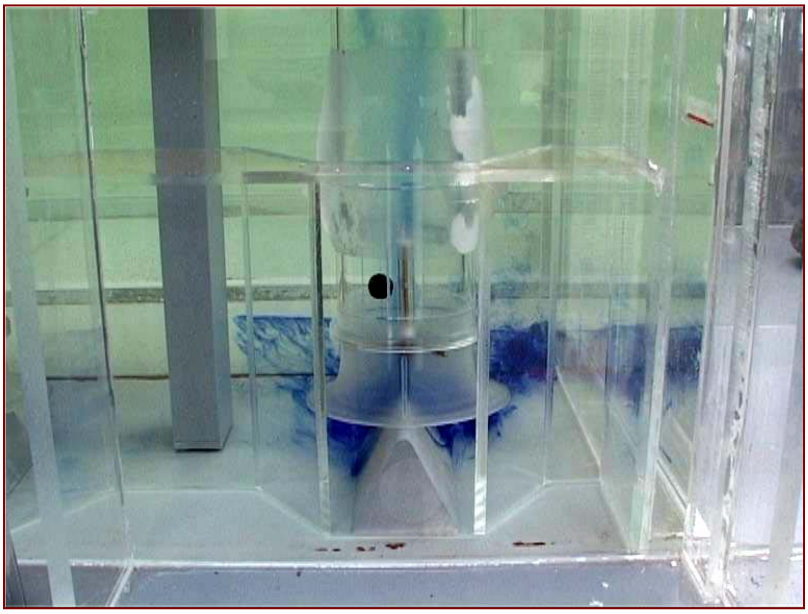


Figure 3.21: Sump model checks for pre-swirl into the pump

3.17 Vorticity

Whereas pre-swirl is a function of bulk rotation at an intake, vorticity is a much more intense form of local rotation which applies shock loadings to the rotating elements of a pump, causing adverse performance and vibration. Vortices may be surface or submerged formations.

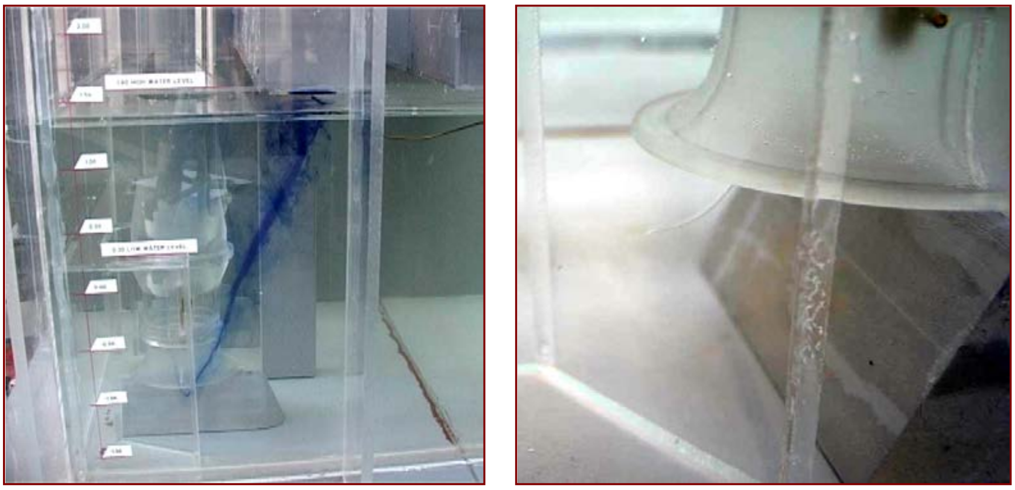


Figure 3.22: Examp

les of surface and side wall vortices identified in sump model test

3.18 Air ingestion

Air ingestion to a pump intake may cause a reduction in pump capacity. It is widely recognised (Prosser, 1977) that ingestion of air concentrations in excess of four per cent by volume may cause a significant reduction in pump capacity. In a typical case, a centrifugal pump ingesting three per cent free air can result in a drop in efficiency of up to 15 per cent. The expansion of ingested air bubbles within the pressure regions of the pump impeller may result in mechanical imbalance forces, which may result in vibration and an acceleration of mechanical wear. In addition, prolonged air ingress may result in air pocket development within the rising main, which may cause instability and blockage.

3.19 Screening

On the majority of pumping stations the incoming flows must be screened to prevent blockages and damage to pump impellors. This is done with trash screens or weed screens and the design and cleaning method will depend on the nature of the watercourse supplying the pumping station.

Trash screens are usually within channels which are used predominantly for storm flows and, as their name suggests, they protect the pumping station from debris (or trash) carried along in the storm flows. The 'first flush' of water along the channel will often carry large quantities of debris, particularly if preceded by long dry spells.

Weed screens are normally not needed all year round but tend to be used intensively during particular periods such as autumn or immediately following watercourse clearances for navigation. Usually in these periods an intense build-up of screenings can completely foul a pumping station unless screens are automatically raked.

These screens are often overlooked as a source of inefficiency, but as they can result in reduced inlet levels and even blockage of the pumps if not correctly designed, they should be carefully considered.
Even larger screens which work correctly can still pass a small amount of solid material to the pumps and (depending on the pump size) this can still reduce efficiency if the material becomes trapped within the impeller.

The sizing of screen spacing is often determined by close consultation with the pump manufacturers. Too small and the frequent blockage of the screens will result in increased operator visits and pump downtime. Too large may result in pump blockages and/or damage to the pump impeller.

3.20 Level control

Level within pumping systems from a wet well or dry well is generally controlled by a number of commonly available methods, including:

- pressure sensors
- level probes
- ultrasonic devices
- float switches.

Each has a particular benefit for different applications. For example, the use of float switches or probes is generally less favourable in situations where the medium being pumped is likely to contain a high percentage of material which may tangle or become caught in the instrument. In such cases, a method which requires no physical contact with the medium is preferable.

In each case, a level probe or instrument is used to indicate the start and stop level for a given water surface and it is the control system's task to operate the pump for long enough to bring the water level to the required value. In most cases this set point is maintained either by the requirements of a local water resource, or by the results of flood risk models. In either case, the set point does not usually change unless changes in circumstances require it to be altered. Even then, the changes are usually minimal (Beckerath *et al*., 1992).

In the case of variable speed drives, these are best employed when working in conjunction with ultrasonic devices or other devices which provide an instantaneous reading of water level. It is possible then to control the water surface with a greater degree of input than for a simple stop/start system such as that found with most simple probe systems. Variable speed drives have an additional benefit that they can be programmed to slowly increase, or 'ramp up', the current to the pump motor on starting and provide a generally much softer start for large electrical loads, reducing the starting current and reducing voltage drops in the nearby network.

The use of variable speed drives is therefore a good way of reducing the required 'headroom' in a supply network if, for example, a pumping system is at the end of a long distribution branch. In fact, by fitting this kind of soft-starting method it may be possible to avoid any expensive power supply upgrades and as a consequence may be beneficial for this purpose alone, even if the actual variable speed control of the pumps during service is not required.

Care must be taken if selecting a variable speed drive system. There are many potential hazards in retrofitting variable speed drives to existing stations as the motors may not be suitable. The characteristics of the existing motors and local network should be investigated by a suitably competent person before making a decision.

3.21 Catchment characteristics

Local knowledge of the catchment is essential when proposing to make changes to the control system. Each pumping station is different in terms of its sensitivity, for example to raising pump control levels, which offer immediate reductions in power requirements, and therefore overall efficiency for the station.

Typical variations in catchment characteristics are as follows:

- rates of flow into the system following a storm event;
- number of at-risk properties or land;
- area of catchment and transfer methods for flows;
- storage capacity of the system;.
- topography of the area.

All the catchment characteristics need to be evaluated and local groups and partners consulted before undertaking any changes.

3.22 Wind pumps

Pumps using the power of the wind date back centuries and are still used throughout the world today. Modern versions are available and have been used to suit applications where moderately low flows are required over a period of time without peak demands.

These have successfully been installed in addition to electrically powered pumps where dry weather flows have required the transfer of water on a regular basis, requiring the electric pumps to continuously start and stop. The use of a wind pump has dramatically reduced the number of starts required by the electric pumps and therefore improved the efficiency of the system.

Any potential for this type of system will vary by site and it is not currently envisaged that wind pumps would replace the need for electrically or diesel driven pumps, only reduce their use.

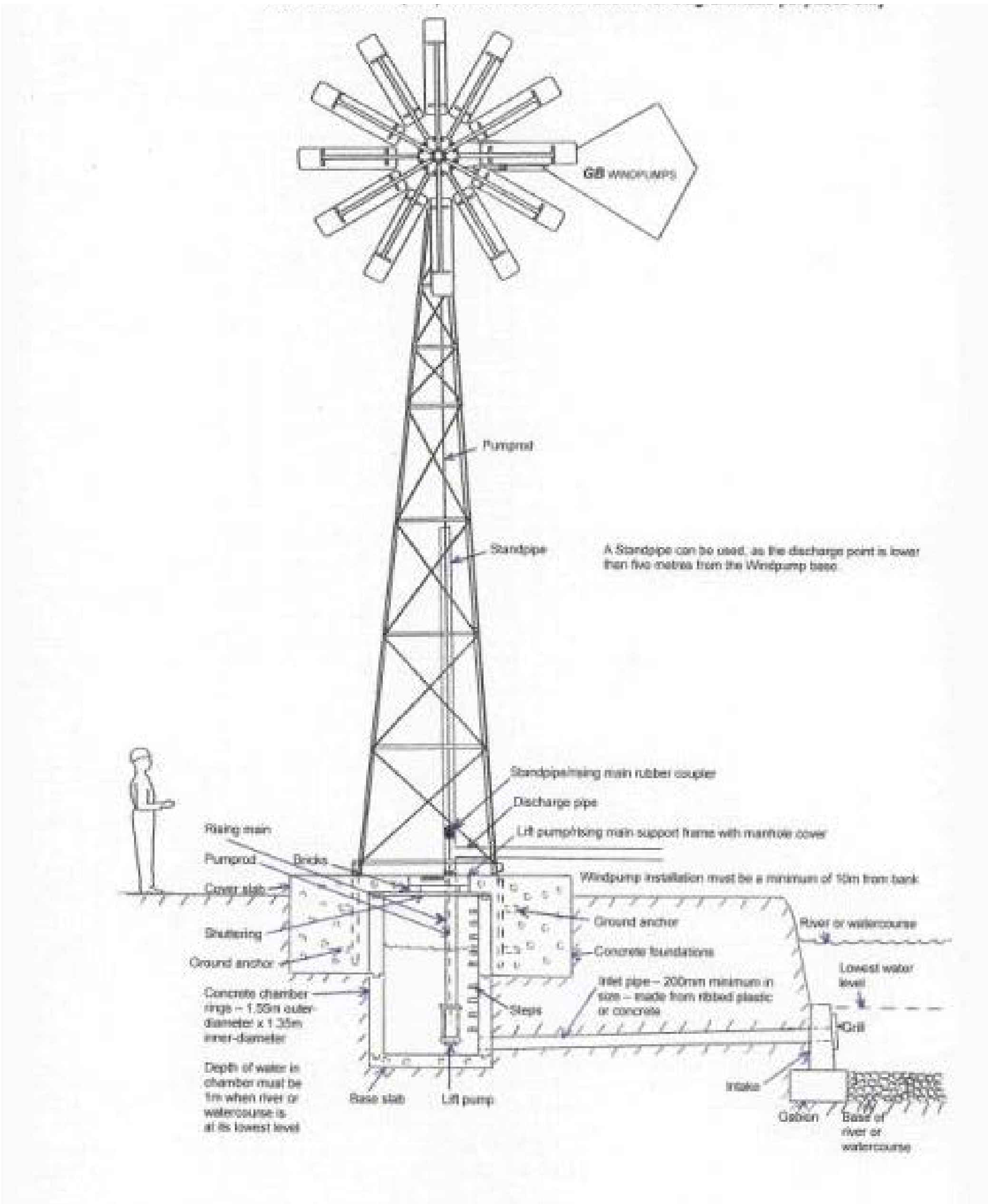


Figure 3.23: Typical wind pump installation

4. Existing pumping stations

4.1 Opportunities

Within the existing pumping stations found across England and Wales, there are many opportunities for improving efficiency. It is, however, also true that generally, pumping stations built at great cost at some point in the past, with considerable useful lifetimes ahead of them, are not always readily altered without significant capital input. Smaller pumping systems can usually be changed by the simple expedient of changing the pump units, but customised larger installations are not so readily changed.

The costs incurred in making major changes to the impeller characteristics of a large pump, for example, might be larger than the efficiency savings resulting from this change. It is a strategic decision as to whether or not the investment is worth the effort.

4.2 Pumps

The Environment Agency operates few large screw pump stations and so they are not considered to offer a significant saving, even if substantial savings on a site-by-site basis can be made. Pumps of the axial flow, mixed flow or centrifugal flow designs are the more common design and it is on these that most of the work should focus.

There is a case for reducing the number of pumping stations by eliminating some completely, particularly where flows are small or where the site is a duplicate of a site elsewhere. However, as previously stated, this has mostly already been done for readily modified sites. It is still worth looking into, however, as it is possible that with a small investment a small and inefficient site can be eliminated by passing flows to a larger site where newer and more efficient pumps are available. The transfer of flows may be possible by means of a new dedicated gravity pipeline or a purpose-built ditch laid at a suitable gradient. In either case, the very nature of the application will tend towards shallow gradients, so gravity transfer of this kind will involve larger assets with attendant problems of siltation and deposition of fine particles.

There are maintenance benefits from reducing the overall number of pumping stations. Environmental benefits from eliminating some sites can be summarised as follows:

- reduced travel for maintenance;
- elimination of multiple power systems;
- elimination of potentially hazardous materials;
- reduction in overall manpower (depending on the nature of the gravity transfer).

The change to a catchment strategy would need to be fully investigated in conjunction with interested and affected groups and partners.

4.3 System characteristics

Within sites with very short pipe runs, typical of many flood defence sites, there is little scope for improving the system characteristics. Small incremental benefits can be achieved by increasing pipe diameters or by ensuring that pipes are clean and smooth, but as friction losses represent only a small percentage of the overall power requirements, there is little benefit to be gained from this. There is, however, a potential benefit from addressing the static head of such systems.

In cases where pipe runs consist of the simple up-and-over designs, it is perfectly possible that the highest point of the pipe is well above the highest point at which the water is ever likely to reach on the delivery side.

While the ideal situation is for a comfortable margin between the highest point in the delivery pipe and the maximum water level (to eliminate the possibility of backflow), having a pipe highest point which is significantly higher than required can result in higher pumping costs than necessary. For low head systems this may represent a significant increase in pumping costs.

By reducing the highest point by (for example) cutting a section out of the pipe and re-inserting it at a lower level, this might make the pumps run faster than their design speed, as previously discussed. In this case, additional work would be required to modify the impellers or replace them altogether.

4.4 Operation and control

Operation and control of pumping stations has received much attention in terms of monitoring pump performance to highlight any changes and optimise the use of pumps.

One approach to improving efficiency is to reduce motor speed by the use of variable speed drives, but this has dangers associated with reducing the speeds to well below the design speeds. In addition to moving the duty point well away from the highest efficiency point, there can be dangers from causing motors to overheat as their cooling fans also operate at lower speeds. In general, flood defence stations transfer flows from a large volume of water stored and in many respects the pumped volumes are relatively small in comparison. At full speed, running variable speed drives are no less efficient than other starting systems.

Discussion continues on changing duty levels as a means of reducing energy use. This would typically be done by increasing the start and stop level in the suction side of the system, thereby reducing the differential static head and the frequency of operation. Whilst changing duty levels can have an impact, there is a danger that the original purpose of the pumping station can be compromised. For example, reducing the pumping volumes by raising the suction side level by a small amount may result in an increased flood risk upstream, even if the change in level is only a few centimetres.

Any changes would require consultation with others. Public perception will always tend to work against this approach as flooding will be deemed to have resulted from the responsible party's actions, regardless of whether there was a demonstrable cause and effect relationship between the two.

One of the major problems with existing pumping stations is the ability of operational staff to understand exactly what is happening on a particular site. In most cases, there is no flow measurement of any sort, and flows have to be estimated from site observations of water movement in open channels or by drop tests of fixed sump volumes. Without flow data, it is not possible to ever know whether pumps are operating correctly or if they are experiencing difficulties. In very short pipe runs, flow measurement is very difficult to retrofit although this can be done with longer pipe runs.

Power measurement and overall power consumption trends are generally not included in pumping station equipment, although it is relatively easy to retrofit this kind of instrumentation (Endress and Hauser, 1992).Measurements of power consumption are not very useful in determining the efficiency of a pumping system anyway, but they may indicate where equipment performance has started to deteriorate.

5. Refurbished pumping stations

5.1 Opportunities

Within refurbished pumping station assets, there are fewer opportunities for introducing savings than might be hoped, usually because of the reluctance of owners and operators to modify an asset which may have only recently been refurbished. Stations which have been refurbished recently may, however, incorporate equipment which will permit changes to be made. Recently upgraded electrical systems, for example, may be more readily adapted to current monitoring systems than the original designs.

5.2 Pumps

Recently refurbished pumps are less likely to be modified to improve efficiency simply because they are more likely to have been sized correctly for new or revised duties. Unless new or refurbished pumps are in fact designed to an inappropriate duty of flow and load, it is reasonable to assume they will have been sized in accordance with the latest criteria for efficiency. Generally, it is not practice to change the duty of a given pump when refurbishing, simply because of the tendency to replace like-with-like. The pump should be checked against its operating duty at the appraisal stage of a project prior to undertaking any refurbishment. This will enable an evaluation to be undertaken considering long-term energy use and efficiency within the appraisal process, whereby an informed decision may be taken.

5.3 System characteristics

System characteristics are unlikely to be suitable for major changes if the pipework, valves and associated equipment were refurbished as part of the project. Refurbishment of pipes can take the form of cleaning or jetting, but since the lifetime of cast iron pipe is often measured in periods of time which can extend to many decades, there is little need to replace the pipes during a routine refurbishment. In any case, the removal and replacement of pipes will constitute a major upgrade to the pumping station and would need to be carefully considered for cost-effectiveness before any decision were taken as to whether or not to carry out this operation.

5.4 Operation and control

The opportunities under operation and control for refurbished pumping stations are the same as with existing stations.

5.5 Sump model tests

If there are obvious or suspected issues relating to the design of the existing sump, such as excessive noise, turbulence or vortices being formed, a sump model should be set up to fully understand the problems and explore modifications to solve these.

6. New pumping stations

6.1 Opportunities

New pumping stations offer practical and exciting opportunities to improve pumping efficiency. There are many new technologies on the market today which if incorporated within pumping stations, can have a major impact on overall energy requirements. These typically include the following items.

6.2 PLC control systems

PLC or Programmable Logic Control systems allow a more complex and efficient control scheme to be put in place; for example, this might take the form of different pumping regimes for different weather conditions. While mechanical timers do exist for this purpose, PLCs offer much greater flexibility with their programs and consequent scope for upgrades.

Some resistance to the use of PLCs is encountered within the water industry. This is often the result of a lack of standardisation across regions, rendering it difficult to make repairs or re-install lost programs. This point must be addressed whenever the use of PLCs is proposed for an area; the hardware and software must be broadly compatible to reduce the amount of equipment and specialist knowledge required for maintenance. Any software must be supported long term, and the Environment Agency would need to be satisfied that a decade after the installation is built, it will be possible to find software (and more importantly software engineers) to support the system.

6.3 Remote control systems

Controlling systems remotely offers the possibility of responding instantly to changes in pump duty during flood events, for example, removing the need to rely on operator involvement or pre-determined control routines which cannot be changed. This is usually adopted in situations where the cost of highly complex PLC control systems is considered to be unfeasible.

6.4 High efficiency motors

The efficiency of older electric motors is usually less than modern types, although still better than for internal combustion engines. In some cases a modern retrofit can be installed into an existing application bringing savings, the extent of which will depend on the condition and type of the older unit being replaced.

6.5 Accurate flow and level monitoring device

One representative example of recent advances in technology for pump control is combined level controllers and pump control systems. Simpler level probes or float switches are considered more reliable and easier to repair or modify in the field since they contain few if any components requiring specialist services, but gradually they are being phased out in favour of electronic devices.

Ultrasonic level devices were often only used in conjunction with more conventional hard-wired level warning probes which would operate in the event of failure. Recent devices are usually considered to be reliable enough to not need this unless the application is critical.
In designing the pumping station, the characteristics of the pump should be carefully defined to ensure the pump is fit for service. If this is not possible, a tender should be made separately for the pump.

6.6 Pumps

The selection of pumps for a new pumping station should be carefully considered and comparisons of different system models and pump types may be needed to find the optimum solution. Quite often the nature of tendering will mean that the final selection of the pump type is made by the contractor and it is important that the correct performance criteria is included within the specification to ensure the selected pump provides optimum efficiency, rather than being selected for financial or other considerations.

The pump manufacturers should be closely involved in this process, as small changes in design may change the pump model or impeller.

If there are significant differences between normal flow requirements and storm event requirements, it may be necessary to consider the use of different pump sizes for each application. The use of a small pump to handle the more frequent low flow requirements may provide greater efficiency for the overall pumping station.

6.7 System characteristics

When designing new pumping stations, there is always the facility to design in changes which can help to reduce the energy demand. In the case of pumping stations with simple up-and-over delivery pipework to the discharge point, there is the facility to incorporate siphonic recovery systems. These remove the need for costly large valves, with their associated friction losses and also maintained pumping over flood walls as a way of eliminating any failure point through a fixed defence.
It is possible to make use of properly profiled pipe sections and smooth bore pipes which retain their efficient surfaces and do not suffer from internal corrosion or fouling on joints. The benefits from this approach are small, but can add up to measurable savings if incorporated across many stations.

6.8 Operation and control

When designing new pumping stations, modern flow measurement devices and other specialist devices can be included to accurately monitor electrical power consumed. These can sometimes be difficult to retrofit, particularly when trying to install flow measurement in existing pipelines that were never intended for any type of measurement devices. When such devices are installed in new pumping stations, a major source of error is eliminated as accurate and real-time data on pump flows and electrical power use can be recorded and transmitted as needed.

New control devices on the market claim to make flow monitoring easier in large diameter pipes, although experience has been that it is difficult to obtain accurate and consistent flow measurement in large diameter pipes with highly turbulent flow.

Remote telemetry monitoring is already widely used within the Environment Agency and the technology is developing further. There should be greater opportunity to monitor and control stations remotely in the future.

6.9 Sump model tests

On larger stations it is recommended that model tests are carried out as part of the design process and recommendations incorporated into the design works (see Section 3.5.1).

7. System testing

When testing pumping stations, there are a number of ways of gathering information, but the most important information is summarised as follows:

- flow rate
- delivery head
- motor speed (impeller speed, if different)
- motor absorbed power.

Flow rates can be easily measured with modern flow meters which operate on the electromagnetic principle. These are extremely accurate (fractions of a percentage deviation from true) and generally not particularly expensive at smaller sizes. Most older pumping stations do not have this kind of flow meter built in owing to their lack of availability when the site was built; more recent installations may have omitted this to save cost and because there is generally no requirement to know the quantity of water discharged. As flood defence pumping stations generally use independent pipework systems, multiple costs would be involved

For existing pumping stations where flow meters are not installed, different types of clamp-on flow meters are available, which provide an indication of the delivery flow, but from tests carried out their accuracy and repeatability may be in question. Experience has shown that delivery from older sites is often significantly lower than expected, usually due to impeller damage, but without any flow measuring equipment this may have gone unnoticed for years.

Delivery head is the simplest of all parameters to measure directly, as a simple drilled and tapped hole in the delivery pipe can be made to accommodate a small pressure gauge. This can be designed to read static or dynamic head, and will show if there are any unexpected restrictions downstream which increase the pumping head. Care must be taken when installing this kind of gauge to avoid venturi effects in fast-flowing pipelines. It is possible to obtain a completely false reading from a pressure gauge if, for example, the hole is drilled into a bend where the rapid change in water direction results in a drop in pressure at one point and an increase in pressure on the opposite side of the pipe. This effect does not occur in static water flows as it is a dynamic effect only.

For best results, this kind of tapping should be made in straight sections of pipe where possible, and if it is unavoidable to tap into a bend, many gauge tappings should be put in place and their readings averaged out.

Motor speed can be measured with a simple stroboscopic measuring device, and will yield useful information on the likely onset of cavitation within the pump chamber. Motor speed may differ from the stated speed on the information plate if, for example, the duty has changed since the original installation. An unexpectedly high motor speed may also provide a clue of other unseen damage such as impeller breakage.

Motor absorbed power is also relatively easy to measure on site, as long as there is access to the control systems and the main power cables feeding the pumps. The difficulty with using the mains meter as a source of this kind of information is that it only provides an average reading and does not necessarily show the instantaneous power requirement.

Modern instrumentation can include ammeters which measure current without needing to cut or interface with the cables in any way, and will provide a reading over a range of operating flows. It is also important to measure the voltage at point of use.

Critically, it is essential to measure the mains supply voltage when the pump is operating. If the supply is measured and found to be a certain value without the pumps operating, it is possible for the figure to drop significantly when the pump is operating due to the high load pulling down the immediate supply network. While not usually major, this may result in a slightly different actual voltage being needed when calculating absorbed power.

7.1 Estimation

Estimation of the above parameters is not advisable, as the entire point of conducting this kind of test is to eliminate the uncertainty associated with estimations. However, in some situations it may not be possible to obtain the information directly. In these cases, some estimation is unavoidable.

The best way of estimating flow rate is by sump drop tests, simply measuring a level drop against time in a given sump, and inferring a volumetric flow rate. This is highly dependent on the geometry of the sump, and must take into account any fixtures or fittings in the sump which will serve to reduce the available volume. Other pumps and pipework, for example, present a complex shape and their contribution to the sump volume is not always easy to calculate.

Alternative methods include studying flow in an open channel. The velocity is relatively easy to measure at various locations across a channel's cross section, and it is therefore possible to gain a velocity profile. By multiplying the velocity by the cross sectional area, the volumetric flow can be deduced. Water velocity meters are readily available, or alternatively visual methods can be used. This method is highly dependent on the operator gaining as many readings as possible at a number of depths and at different points, and while this may be possible in a clean channel, it may be difficult in a fouled channel with obstructions.

7.2 Useful additional information

The above parameters should be enough to derive pump efficiency, and can be refined by taking into account additional parameters such as the temperature (and hence viscosity) of the water, although in most practical applications, this does not vary much.

In addition to temperature, the solids content of the pumped medium will have a noticeable effect on pumping efficiency. In the sewage industry, solids contents of less than one per cent by weight tend not to be noticeable, whereas concentrations higher than three to four per cent by weight result in a more difficult medium to pump. This level is unlikely to be found in pumped surface water or even in very turbid river water, hence it can be ignored for the purpose of most pump efficiency investigations.

7.3 Evaluation of results

Whenever testing is conducted, three major pieces of information are often obtained which do not necessarily conform to the tester's anticipated results.

The most common unanticipated result is that the flow is often reduced, and hence actual overall efficiency is overestimated. The tendency is to take information on the pump's plate as being correct and relevant, even if this is many years old. For the reasons already described, this can be significantly different from the pump's original duty and can go unnoticed for years.

The second unexpected result is that the downstream pipework can be blocked, where biofilms or animals can have taken refuge and can in some cases cause a major increase in pumping head. It is not uncommon, for example, to find freshwater shellfish in large diameter pipes where the flows are relatively gentle and provide a steady stream of nutrients to the developing animals. In cases of this sort, it may be difficult to clear the blockage and unless the original cause of the growth is rectified, the problem will simply re-occur. An example of this would be the eggs or larvae of small animals which can pass through any screens which may be installed. Clearing the adult forms will not provide anything other than a temporary reprieve.

Additionally, various flap valves or non-return valves may jam in the open or closed position, resulting in delivery head values higher or lower than expected. It is not generally practice in the

UK to fit switches to older installations where flap or non-return valves are fitted. As a general rule, particularly in the flood defence industry, it is not possible to know remotely if a valve has stuck in the fully open position since delivery head will not differ from the expected value leaving a potential weakness in the pumping scheme which may go unnoticed.

8. Spreadsheet tool

8.1 Scope and limitations

This guide is designed to help users complete the spreadsheet and calculate the energy savings.

The combined energy consumption from pumping stations makes up a third of the Environment Agency's energy consumption. The pump efficiency toolbox spreadsheet has been created to help identify the energy that could be saved by making changes at these sites.

This calculator provides a simple way of estimating energy savings from making changes to pumping stations and water levels. The spreadsheet is designed to cover the majority of simple flood defence pumping stations found across the country. It can also be used for simple borehole pumping systems such as those used for stream support.

For key sites, such as large transfer stations, it is likely that site-specific calculations will need to be put together separately. The principles used in this sheet could, however, be used as a starting point for this work.

A desktop calculation cannot provide the same level of accuracy and certainty as field testing. However, it is appreciated that the run hours of many Environment Agency stations are too low to justify field testing. There are also problems with accurately measuring the performance of low head pumps in the field.

The calculator is designed to compare different options with the understanding that operation of many stations will need to be simplified to some extent. The spreadsheet is targeted at the regional Mechanical, Electrical, Instrumentation, Control and Automation (MEICA) engineers.

For more information on pumping station design and operation, please refer to previous sections of this report.

8.2 Key points

The calculator is used for individual pumps and assumes that each pump has a separate delivery system. The pump types covered are centrifugal/mixed flow, axial and screw pumps.

The operation is likely to need to be simplified to fit the spreadsheet. There is not enough information available for most stations to allow more detailed analysis to be carried out.

Macros need to be enabled in Excel for the spreadsheet to work correctly.

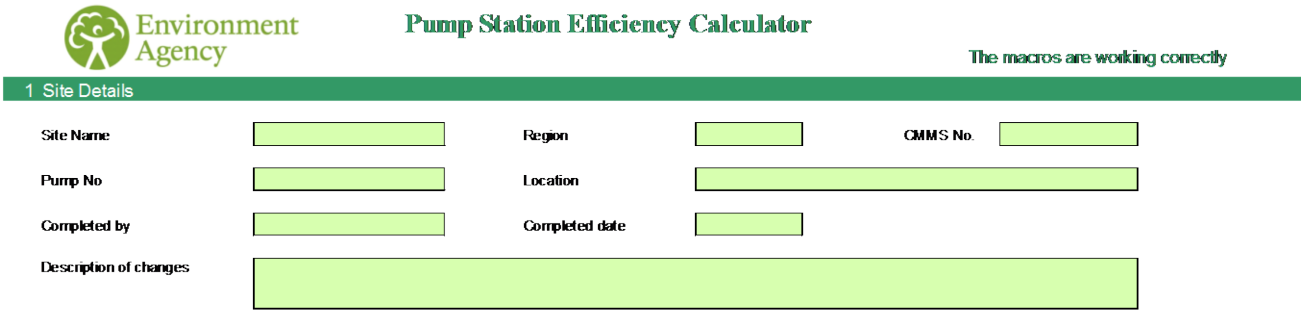
The units for many items can be changed to match the information available. For example, pipe diameters can be entered in mm or inches and flow rates can be in l/s, m^3/hour or gallons per minute.

Tips are provided in the spreadsheet for many items. The user can hover the mouse over any box with a red triangle in the corner to read more about what information is needed.

8.3 Completing the spreadsheet for centrifugal and axial pumps

8.3.1 Site details

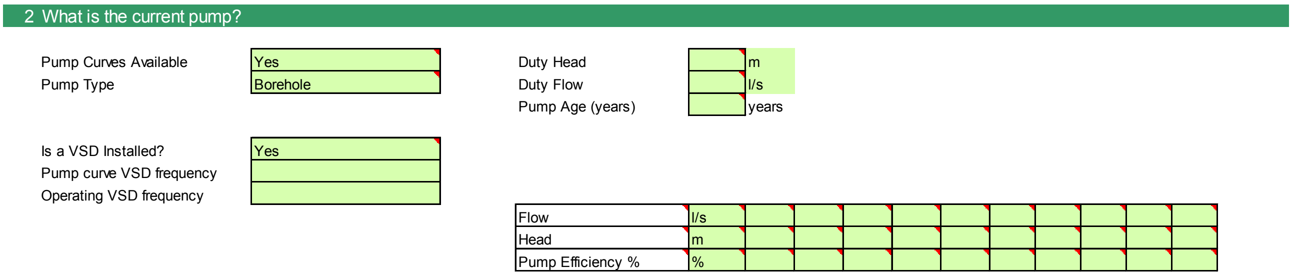
Fill out section 1 with the details of the site


Environment Agency
Pump Station Efficiency Calculator
The macros are working correctly
1 Site Details

Site Name		Region		CMMS No.	
Pump No		Location			
Completed by		Completed date			
Description of changes					

This section allows you to enter the details of the pumping station and the pump that is being checked. This section also allows you to enter your name and the date the sheet was completed and to provide a brief description of the changes.

8.3.2 Put in details of the existing pump


2 What is the current pump?

Pump Curves Available	Yes	Duty Head		m
Pump Type	Borehole	Duty Flow		l/s
		Pump Age (years)		years
Is a VSD Installed?	Yes			
Pump curve VSD frequency				
Operating VSD frequency				

Flow	l/s										
Head	m										
Pump Efficiency %	%										

Pump Curves Available.

If pump curves are available for the pump, select yes. If the pump curves are not available then select no to use the generic curves based on the nameplate duty flow and head. The generic pump curves assume that the best efficiency point of the pump matches the nameplate duty flow and head.

Where possible, use the pump curves for the installed pump.

Pump Type

Select whether the pumps are Axial,Centrifugal flow or Borehole pumps. For this toolbox, the centrifugal option also includes mixed flow pumps.

Nameplate Duty Head

The pumping head stamped on the pump nameplate.

Nameplate Duty Flow

The pumping flow rate stamped on the pump nameplate.

Pump Age

Years since the pump was installed or last received a major factory overhaul. This age is used to estimate the loss in pump performance since it was installed.

Pump Curve

If you have selected “Yes” for “Pump Curves” Available then you will need to put the pump curve details in this section. Enter the details of the pump curve into this section. Up to ten points can be entered on the spreadsheet. It is recommended that at least 5 points are used for accuracy.

To make it easier to enter the details, you can click on the units and change them to match the units on the pump curve. This means that you do not need to convert curve units such as Gal_{US}/min into metric units. The spreadsheet will do this instead.

The efficiency required is the pump efficiency. If the curve only gives the combined pump and motor efficiency (as is often the case on Flygt pumps), enter the combined efficiencies from the sheet and type 100 into the motor efficiency box to set the motor efficiency to 100% and avoid including the motor efficiency twice.

Is VSD Installed

This option is visible when borehole is selected. Select Yes is a variable speed drive is installed on site.

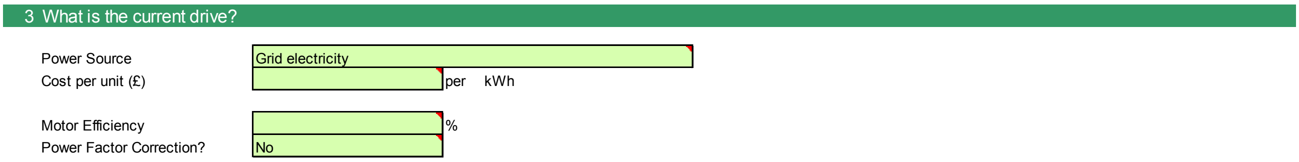
Pump Curve VSD Frequency

If you have provided the pump curve and a VSD is installed this section will appear and ask you to provide the VSD frequency that the pump curve you provided is based on. This will normally be 50Hz. If this box is left blank the default value of 50Hz will be used.

Operating VSD Frequency

If the borehole is being operated at a frequency other than 50Hz, this frequency should be entered here. The spreadsheet will then calculate the speed-corrected pump curve.

8.3.3 Put in details of the existing power source and motor



Power source

Select how the pump is powered. If there are two potential power sources e.g. standby generation, then select the most commonly used power source. For Generators and diesel engines, there are a range of options to select, based on the age and condition of the plant. This allows the reduced performance of old assets to be taken into account. You will need to apply your judgement to decide which item best categorises the assets on site.

Cost per unit

The cost per unit allows you to enter an average cost per unit for the energy used at the site. For electricity from the grid, this will be the cost per kWh. For generators and engines, this is the cost per litre or cubic meter of fuel. The units for the cost can be selected from a list of suitable units.

Motor Efficiency

Use this box to enter the motor efficiency of the pump motor. If this is left blank, a figure of 90% is used across the pump range. Enter this as without a percentage sign. eg 95% should be typed as 95.

Power Factor Correction

Select Yes or No, depending on whether some form of power factor correction is installed and operational on site. This does not affect the spreadsheet calculations, but is a prompt to consider power factor correction when looking for efficiencies on site.

8.3.4 Pipe details

Enter the details of the pipework. Since some systems use a combination of pipe sizes or materials, two pipe sections can be entered, although only one is needed. If both sections are used, the spreadsheet assumes that these sections are connected in series.

4 Current pipes

First Material

			Fittings	No. of
Pipe length		m	Bend 90	
Pipe Diameter - ID		mm	Bend 45	
Pipe Material			Sluice Valve Open	
Pipe Age (years)			Sluice Valve 75% Open	
			Sluice Valve 50% Open	
Inlet	None		Sluice Valve 25% Open	
Outlet	None		Flap Valve	
			Non Return Valve	

The pipework can be split into two sections to allow for systems that combine two different pipe materials or diameters.

Second Material

			Fittings	No. of
Pipe length		m	Bend 90	
Pipe Diameter - ID		mm	Bend 45	
Pipe Material			Sluice Valve Open	
Pipe Age (years)			Sluice Valve 75% Open	
			Sluice Valve 50% Open	
Inlet	None		Sluice Valve 25% Open	
Outlet	None		Flap Valve	
			Non Return Valve	

For each pipe line section, the following information is required.

Pipe length

The length of this section of pipe. You can change the units as required.

Pipe diameter – ID

The internal diameter of the pipe. You can change the units to let you enter the diameter in inches if required. For metallic pipe materials, this is the nominal diameter of the pipe and is normally cast into the sections of the pipe on newer pipes e.g. DN200 = 200mm ID.

Pipe material

Select the closest matching pipe material from the list

Pipe age

Pipe friction normally increases with age. The pipe may often be as old as the pumping station.

Inlet and Outlet

This allows the inlet and outlet losses to be taken into account. If only one section is used, select the inlet and outlet within that section. If both sections are used, select the type of inlet and outlet in the section of pipe that they are attached to. On most stations, the inlet and outlet selection will only have a minor effect on the calculations.

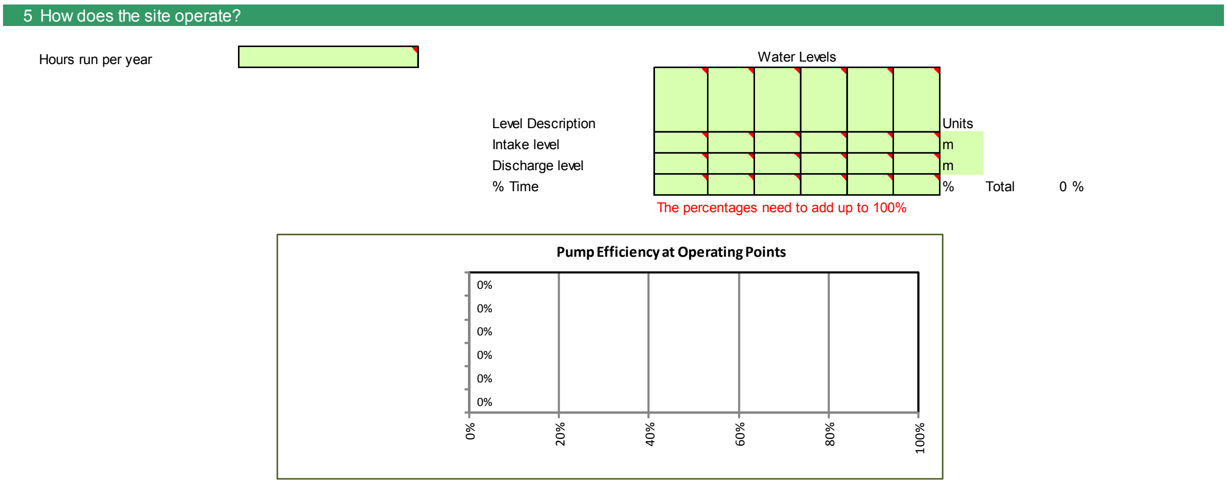
Fittings

Enter the number of fittings of each type in this section of pipe.

8.3.5 How does the site operate?

The height of the intake and discharge water levels affects the flow through the pump. This section is used to calculate the static head.

Each combination of input and output levels needs to be entered as a separate operating condition. The spreadsheet allows you to enter six conditions. Selecting six points will normally be a simplification of the real system. It is useful to include the conditions that cause the maximum and minimum differences in levels in these six conditions. See the diagrams in sections 8.6.4 and 8.6.5 and on the diagrams page of the spreadsheet for more details about the levels.



Hours run per year

The typical number of hours that this pump runs for in a year. The actual hours may vary from year to year.

Level description

Allows you to enter a description. e.g. “Winter Flood” or “Normal Water Levels”

Intake Level

This is the water level adjacent to the pump intake. This should be the level on the pump side of any weed or trash screens. You will need to use your judgement to account for items such as changing intake levels as the level in the sump is pumped down.

See the diagrams in sections 8.6.4 and 8.6.5 and on the diagrams page of the spreadsheet for more details about the levels.

Delivery Level

The water level at the discharge of the system. For submerged discharge this will be the water level on the discharge side. For open discharge the level of the top of the pipe should be used. (Soffit level)

See the diagrams in sections 8.6.4 and 8.6.5 and on the diagrams page of the spreadsheet for more details about the levels.

Percentage Time

An estimate of the number of pump run hours that are completed at this combination of inlet and delivery levels entered from 0 to 100. The percentages for all of the water levels used needs to add up to 100.

Pump Efficiency at Operating Points

This chart shows the calculated pump efficiency of operating the pumping station with these water levels. This chart is also shown on the pump curves sheet and is repeated here for quick reference.

8.3.6 What changes would you like to make?

This allows you to select which parts of the pumping station you would like to change.

6 What changes would you like to make?		
Replace or refurbish the pump	Yes	Please complete section 7
Replace or refurbish the motor or power source	Yes	Please complete section 8
Install a VSD or change the borehole VSD Frequency	Yes	Please complete section 9
Replace pipework and fittings	Yes	Please complete section 10
Change how the site operates	Yes	Please complete section 11

Replace or refurbish pump

Select "yes" if you intend to refurbish or replace the pump. Refurbishing the existing pump will return the performance to close to the original factory performance. Consider replacing the pump if it does not suit the current operating performance. When selecting a new pump more than just the efficiency must be considered. Other parameters to design for include the siphon priming head and handling weed and debris.

You will need to have proposed pump curves for any new pumps that you are proposing to install. Pump manufacturers normally either publish standard pump curves for their models on their websites, or will be able to send them to you.

More information on selecting pumps for flood defence is contained in the main guidance.

If you select "no" in this section the pump selected in section 2 of the spreadsheet will be reused.

Replace or refurbish the motor or power source

Select "yes" if you intend to carry out work to improve the performance of the motor or power source. You will need to provide the details in section 8. For example, if you are replacing the existing motor with a high efficiency model, select yes, then go to section 8 and provide the new motor efficiency and select the correct power source.

If you select "no", the motor and power source details you provided in section 2 will be reused

Install a VSD or change the borehole VSD frequency

If you selected Borehole as the pump type in section 2, you will be asked whether you want to change the VSD frequency, or install a VSD if a VSD starter is not already installed.

If you have selected a pump type of centrifugal or axial, this option is not available.

If you select yes in this section, then provide the VSD details in section 9. If you select no, either the Operating VSD Speed you gave in section 2 will be used, or if this was not provided, the default 50Hz will be applied.

Replace pipework and fittings

Select "yes" if the pipework will be replaced. Installing new or larger diameter pipework will reduce the dynamic head. If the pipeline includes a siphon then care needs to be taken to ensure that the siphon can still be primed with the new pipe system.

Provide the new details in section 10.

If you select "no", the pipework and fittings that you entered in section 4 of the spreadsheet will be reused.

Change how the site operates

This allows you to change the water levels on either side of the pumping station. This will need to be set to “yes” if an open discharge system is being converted to a siphonic discharge.

Provide the new details in section 11.

If you select “no”, the previous water levels will be reused.

8.3.7 What pump would you like to install?

This section will only appear if you have selected “Replace or refurbish pump” in the changes section above. When this is not visible, the current pump information will be used.

7 What pump would you like to install?

Pump Type	Borehole		Duty Head		m
Apply High Efficiency Coating	Yes		Duty Flow		l/s
Coating Efficiency Improvement		%			

Flow	l/s									
Head	m									
Pump Efficiency %	%									

Input the details of the new pump that you intend to install. The pump curve is needed for this section. Pump suppliers should be able to provide pump curves on request. The rest of the details required mirror the section for the current pump.

Apply High Efficiency Coating
If you are considering the option of getting a high efficient coating to the pump, select Yes.

Coating Efficiency Improvement
If the efficiency improvement is not included in the pump curve you provided, enter the percentage efficiency improvement here. Coating manufacturers typically indicate improvements of between 2% and 6%. Enter 2% as the number 2.

8.3.8 What power source will be used?

This section will only appear if you have selected “Replace or refurbish motor or power source” in the changes section above.

8 What motor and drive will be used?

Power Source	Grid electricity	
Cost per unit (£)		per kWh
Motor Efficiency %		
Power Factor Correction?	Yes	

Input the details of the equipment that you intend to install. If you are just replacing the motor, you will also need to select the power source.

Power Factor Correction

Select Yes or No, depending on whether you plan to install power factor correction on site. This does not affect the spreadsheet calculations, but is a prompt to consider power factor correction when looking for efficiencies on site.

8.3.9 What frequency will the VSD operate at?

9 What frequency will the VSD operate at?

Pump curve frequency	
Operating frequency	

This section only appears if you have selected “Install a VSD or change the borehole VSD frequency” in the changes section above. When this section is not visible, either the Operating VSD Speed you gave in section 2 will be used, or if this was not provided, the default 50Hz will be applied.

Pump curve Frequency

If you have provided a new pump curve in section 7, or a VSD is not installed in the current pump station, you will be asked to provide the pump curve frequency.

Operating Frequency
Enter the frequency that you will operate the VSD drive at in Hz.

8.3.10 What pipe and fittings will be in the new system?

This section only appears if you have selected “Replace pipework and fittings” in the changes section above. When this section is not visible, the current pumping station pipe information is used.

10 What pipe and fittings will be in the new system?

First Material

			Fittings	No. of
Pipe length		m	Bend 90	
Pipe Diameter - ID		mm	Bend 45	
Pipe Material			Sluice Valve Open	
			Sluice Valve 75% Open	
			Sluice Valve 50% Open	
Intake			Sluice Valve 25% Open	
Outlet			Flap Valve	
			Non Return Valve	

The pipework can be split into two sections to allow for systems that combine two different pipe materials or diameters.

Second Material

			Fittings	No. of
Pipe length		mm	Bend 90	
Pipe Diameter - ID		m	Bend 45	
Pipe Material			Sluice Valve Open	
			Sluice Valve 75% Open	
			Sluice Valve 50% Open	
Intake			Sluice Valve 25% Open	
Outlet			Flap Valve	
			Non Return Valve	

This allows the details of the new pipework to be entered into the spreadsheet. Fill this section out in the same way as Part 3 – Pipe Details

8.3.11 Proposed Operational Details?

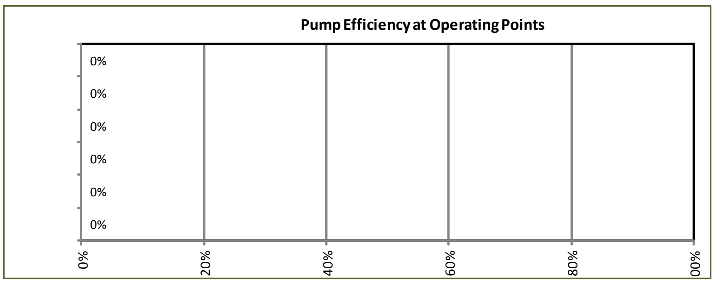
This section only appears if you have selected “Change how the site operates” in the changes section above.

11 Proposed Operational Details

Water Levels

Level Description							Units		
Intake level							m		
Discharge level							m		
% Time							%	Total	0 %

The percentages need to add up to 100%



Fill this section out in the same way as the one for the current conditions. The spreadsheet does not ask for the typical hours run in this section. Instead it bases the calculation on pumping the same volume of water in a year as the original system.

8.3.12 Annual Energy Savings from Changes

This section displays the results available from making the changes. The results are displayed in terms of energy saving, carbon savings and the reduction in energy consumption costs. This section also provides details of the annual energy consumption for the original and proposed operation.

This section also list any errors to help you find any problems that may stop the sheet calculating the savings available.

12 Annual Energy Savings From Changes

Energy Savings		**Cost Savings**		**Operating summary**		
Total Energy Saving (kWh)	0.00	Cost of Making Changes		Annual Pumped Volume	0	m^3
Carbon Saving (kg CO_2)	0.00	Financial Saving (£)	£0.00	Current Hours Run	0.0	hours
Percentage Reduction CO_2	Not Calculated	Payback Period (Years)	Never	New Run Hours	lot Calculated	hours

Current Operation			**Proposed Operation**		
Total Energy (Calculated)	0	kWh	Total Energy (Calculated)	0	kWh
Total Carbon Consumption	0	kg CO_2	Total Carbon Consumption	0	kg CO_2

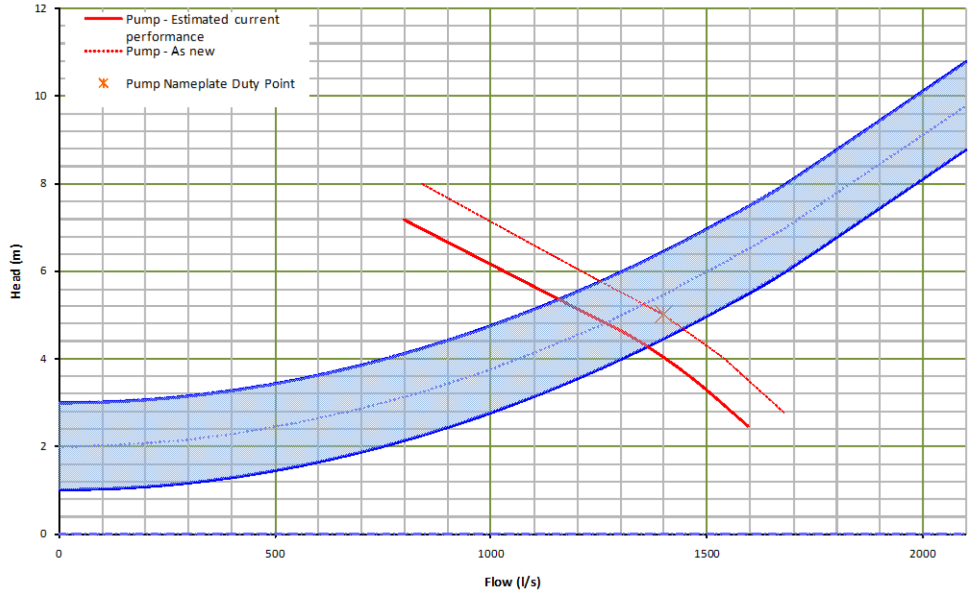
Errors with current details	The annual hours run has not been entered The percentage times for the operating water levels do not add up to 100. No water levels have been given - please provide water levels.
Errors with proposed details	The percentage times for the operating water levels do not add up to 100. No water levels have been given - please provide water levels.

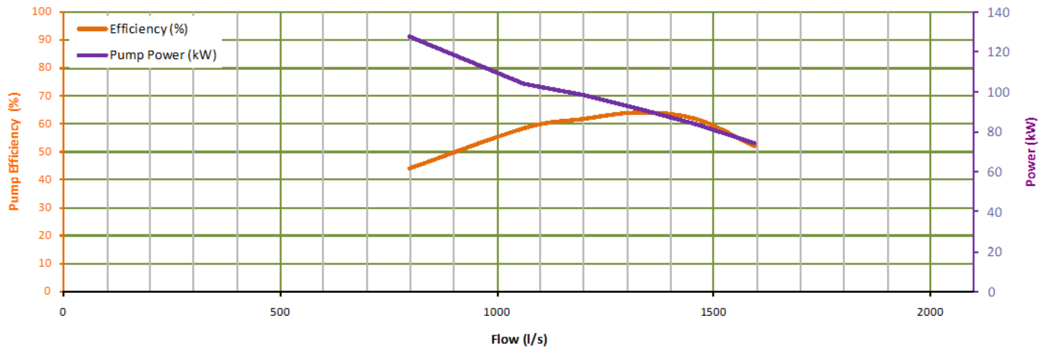
Version 12 19 Jan 2012

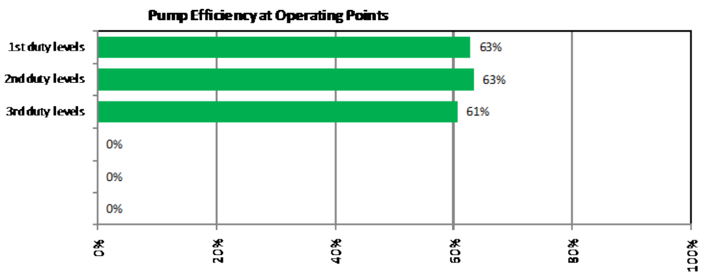
8.3.13 System graphs

The performance of the current and proposed systems can be shown graphically. This helps with the diagnosis of various problems. The graph page shows the curves for the current and proposed systems.

1 Current Pump and System Curves







<u>Pump Curve</u>

The solid red line shows flows that the pump can generate when pumping against a range of heads. This line includes the impact of the estimated wear on the pump performance. The dashed red line shows the pump curve for the pump when it was new.

<u>The maximum and minimum system curves</u>

The system head is a combination of the static head and the dynamic head. The static head depends on the inlet and delivery levels. The dynamic head increases as flow increases. The solid blue lines shows the maximum and minimum combinations of static and dynamic head across the range of flows. The dashed blue lines shows the other operating levels entered in the sheet

Pump Nameplate Duty Point

This is the duty point stated for the pump. This operating point was used to select the existing pump and therefore provides an indication of whether the operating conditions have changed significantly since the pump was installed.

Efficiency Curve

The orange curve shows the efficiency of the pump across the flow range, including the effect of estimated wear.

Power curve

The purple curve shows the estimated pump power across the flow range. This includes the impact of estimated wear and is calculated from the head, flow and efficiency curves. This does not include motor or drive efficiencies.

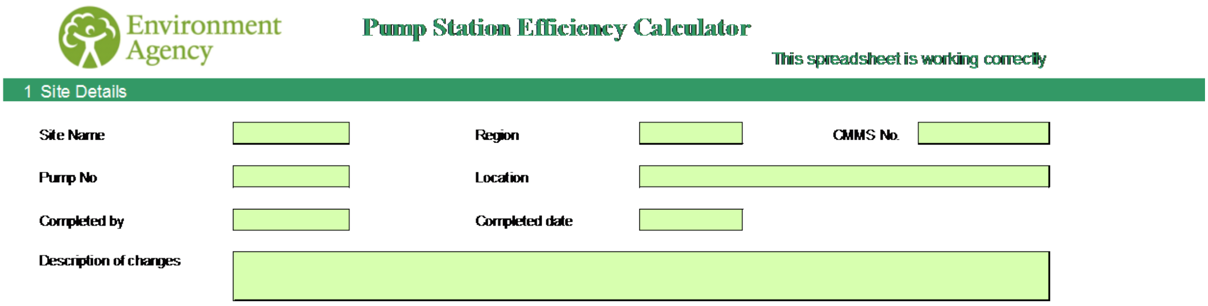
Pump Efficiency at Operating Points

This provides a visual display of the pump efficiency at the points where the pump curve intersects the system curves for the different operating water levels.

8.4 Completing the spreadsheet for Archimedean screw pumps

8.4.1 Site details

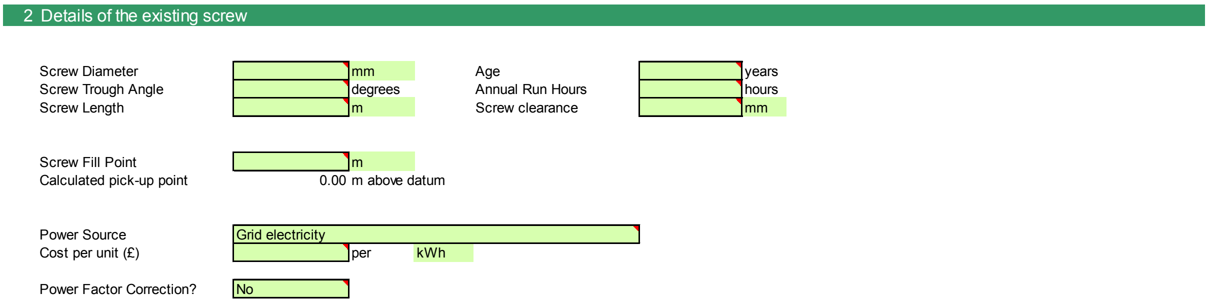
Fill out section 1 with the details of the site


Environment Agency
Pump Station Efficiency Calculator
This spreadsheet is working correctly
1 Site Details
Site Name
Region
CMMS No.
Pump No
Location
Completed by
Completed date
Description of changes

This section allows you to enter the details of the pumping station and the pump that is being checked. This section also allows you to enter your name and the date the sheet was completed and to provide a brief description of the changes.

8.4.2 Details of the existing screw

Enter the details of the existing screw


2 Details of the existing screw
Screw Diameter mm
Screw Trough Angle degrees
Screw Length m
Age years
Annual Run Hours hours
Screw clearance mm
Screw Fill Point m
Calculated pick-up point 0.00 m above datum
Power Source Grid electricity
Cost per unit (£) per kWh
Power Factor Correction? No

Screw diameter
The diameter of the screw

Screw trough angle
This is the angle of the screw to horizontal (normally 25-35 degrees).

Screw length
The length of the bladed section of the screw.

Screw fill point
The intake water level at which the maximum volume is being lifted by each blade. This is the top of the screw shaft at the lower end of the screw. This level is shown on the diagram in the next section as a red line.

Calculated pick-up point
This is the minimum intake water level at which the screw pump will pick up any water from the intake. This is calculated from the fill point and the geometry of the screw.

Age
The number of years since the screw pump was installed or given a major overhaul.

Annual run hours
_The typical number of hours that the screw runs for each day.

Screw clearance
This is used to calculate the loss in performance due to wear. If no value is entered here, the wear is calculated based on the age and run hours of the screw. Measured clearances will provide more accurate results, since different screws and troughs will wear at different rates. When measuring the clearance, it is important that the screw is stopped and electrically isolated.

Power source
Select how the pump is powered. If there are two potential power sources, such as standby generation, select the most commonly used power source. For generators and diesel engines, there are a range of options to select, based on the age and condition of the plant. This allows the reduced performance of old assets to be taken into account. You will need to use your judgement to decide which item best categorises the assets on site.

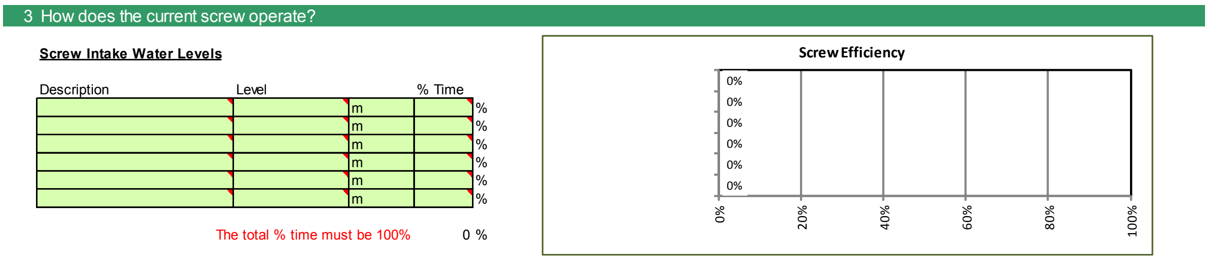
Cost per unit
The cost per unit allows you to enter an average cost per unit for the energy used at the site. For electricity from the grid, this will be the cost per kWh. For generators and engines, this is the cost per litre or cubic metre of fuel. The units for the cost can be selected from a list of suitable units.

Power Factor Correction

Select Yes or No, depending on whether some form of power factor correction is installed and operational on site. This does not affect the spreadsheet calculations, but is a prompt to consider power factor correction when looking for efficiencies on site.

8.4.3 How does the current pump operate?

The screw pump calculator assumes that the screw discharge level will always be above the water level on the outlet side. Therefore, only the intake water levels need to entered into the spreadsheet.



Up to six intake levels can be entered. For each one, type in the following:

Description
A description to refer to the level e.g. “Winter flood”.

Level
The level above the datum,

Percentage time
An estimate of the percentage of the pump annual run hours that are completed at this inlet level, entered from zero to 100. The total of the percentages for all of the water levels used needs to add up to 100.

8.4.4 What would you like to change?

This section allows you to select which parts of the pumping station you would like to change.

4 What would you like to change?

Refurbish existing screw?	No	
Replace screw?	No	Section 5 has been hidden and the existing screw will be used
Change operating levels?	No	Section 6 has been hidden and the curent water levels will be used

<u>Refurbish screw</u>
Refurbish the existing screw to return to the factory tolerances between the trough and screw. The new screw performance will be calculated using current screw details and no wear.

<u>Replace screw</u>
Select “yes” if you intend to refurbish or replace the pump. Consider replacing the screw if it does not suit the current operating conditions. When selecting a new pump, more than just the efficiency must be considered.

<u>Change operating levels</u>
This allows you to change the water levels on either side of the station.

8.4.5 Details of the new screw

This section is only visible if you have selected “Replace screw” in the section above. It allows you to enter the details of a proposed new screw pump. When the section is not shown, the details of the existing screw are used.

5 Details of the new screw

<u>Screw Data</u>

Screw Diameter		mm
Screw Trough Angle		degrees
Screw Length		m
Screw Fill Point		m
Calculated pick-up point	0.00	m above datum
Power Source	Grid electricity	
Cost per unit (£)		per kWh
Power Factor Correction?	No	

Fill this section out in the same way as Section 2 – Details of Existing Screw. Screw age is not shown as it is assumed that a worn screw will not be installed.

8.4.6 How would you like to change the way the site operates?

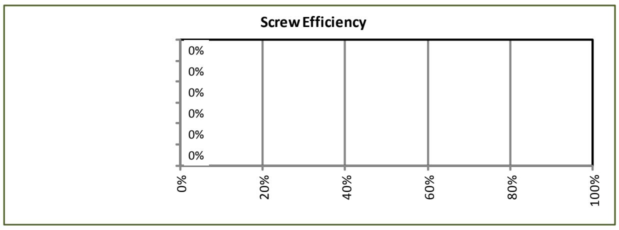
This section will only be visible if you have selected “Change the operating levels” in the section above. When section is not shown, the details of the existing water levels are used.

6 How would you like the new screw to operate?

<u>Screw Intake Water Levels</u>

Description	Level		% Time	
		m		%
		m		%
		m		%
		m		%
		m		%
		m		%

The total % time must be 100% 0 %



Complete this section in the same way as Section 3 – How does the current site operate?

8.4.7 Annual energy savings from changes

This section displays the results from making the changes. The results are displayed in terms of energy savings, carbon savings and the reduction in energy consumption costs. This section also lists any errors to help you find any problems that may stop the sheet calculating the savings available.

7 Annual Energy Savings From Changes

Energy Savings		**Cost Savings**		**Operating summary**	
Total Energy Saving (kWh)	0.00	Cost of Making Changes (£)		Annual Pumped Volume	0 m^3
Carbon Saving (kg CO_2)	0.00	Financial Saving (£)	£0.00	Current Hours Run	0.0 hours
Percentage Reduction CO2	0.0%	Payback Period (Years)	0.00	New Run Hours	0.0 hours

Current Operation		**Proposed Operation**	
Total Energy	0 kWh	Total Energy	Not Calculated kWh
Total Carbon Consumption	0 kg CO_2	Total Carbon Consumption	Not Calculated kg CO_2

Errors with current details	The percentage times for the operating water levels do not add up to 100. No water levels have been given - please provide water levels.
Errors with proposed details	The percentage times for the operating water levels do not add up to 100. No water levels have been given - please provide water levels.

Version 12 19 Jan 2012

8.5 Using the pump start calculator

This calculator sheet provides a simple calculator to work out the worst case number of pump starts in a small intake sump chamber.

8.5.1 Site details

Fill out section 1 with the details of the site

Environment Agency

Pump Station Efficiency Calculator

The macros are working correctly

1 Site Details

Site Name		Region		CMMS No.	
Pump No		Location			
Completed by		Completed			
Description of changes					

This section allows you to enter the details of the pumping station and the pump that is being checked. This section also allows you to enter your name and the date the sheet was completed and to provide a brief description of the changes.

8.5.2 Sump details

2 Sump Details - Plan Area

Rectangular		**or**	**Circular**		or	**Area**		
Length		m	Diameter		m	Area		m^2
Width		m						

Provide the plan dimensions of the sump that you are looking at. Either provide the length and width or the sump, the circular diameter, or provide the plan area for other shapes of sump.

8.5.3 Start and stop levels

3 Start and stop levels

Start level		m
Stop level		m

Provide the pump start and stop levels being considered.

8.5.4 Pumping flow rate

4 Pumping flow rate

Flow rate		l/s

Enter the pumping flow rate being considered. The flow rate will decrease as the level in the sump drops. For this calculation, use the average pumping flow rate.

The flow rates at the start and stop levels can be found by intersecting the system curves for each level with the pump curve.

5 Results

Sump working volume		m^3
Worst case inflow rate		l/s
Combined number of starts per hour		

Note. This is the total number of pump starts per hour and may be split between the pumps depending on the arrangement for changing the duty pump

8.6 Troubleshooting

If “not calculated” is shown in the results section, there has been a problem calculating the results. This is normally caused by the macros not being enabled, or a missing piece of information. Read the error messages and then go back over the details that you have entered to check that you have provided all of the information needed. For the centrifugal pumps, checking the system graphs may help identify the problem. Check that the pump curve, efficiency curves are shown and that the system curves are shown and rise from left to right.

No system curve
Go back and check the information that you provided for the pipework and fittings, and operating conditions.

Horizontal system curve
Check that you have provided the correct pipework and fittings information.

No pump flow/head curve
Check that you have provided the correct pump information.

No efficiency curve
If you have entered the pump curve details, make sure that you have provided efficiency figures and that these are between zero and 100 and that you have not typed percentage (%) signs in the boxes.

The system curves and pump curves do not cross each other
If the pump and system flow/head curves do not intersect, the spreadsheet cannot calculate the operating points of the pump. It is likely that some of the information entered is incorrect or that the pump is operating outside of its operating envelope.

If the curves all look correct, and the results are still not being calculated, and macros are enabled, check that you have entered the annual hours and time percentages correctly in the operational details sections.

8.7 Definitions and background information

8.7.1 Level from which all heights are measured

The level from which all heights are measured
This can be any agreed level. This could be the Ordnance Survey datum if all levels are taken as metres above Ordnance datum (mAOD) or it could be the floor level of the pumping station. The intake, delivery, pump and siphon levels are then all measured as heights above (+) or below (-) this level.

8.7.2 Pump nameplate

This plate is mounted on or near the pump and gives details of the pump. Depending on the type of pump, there may also be a separate nameplate on the motor.

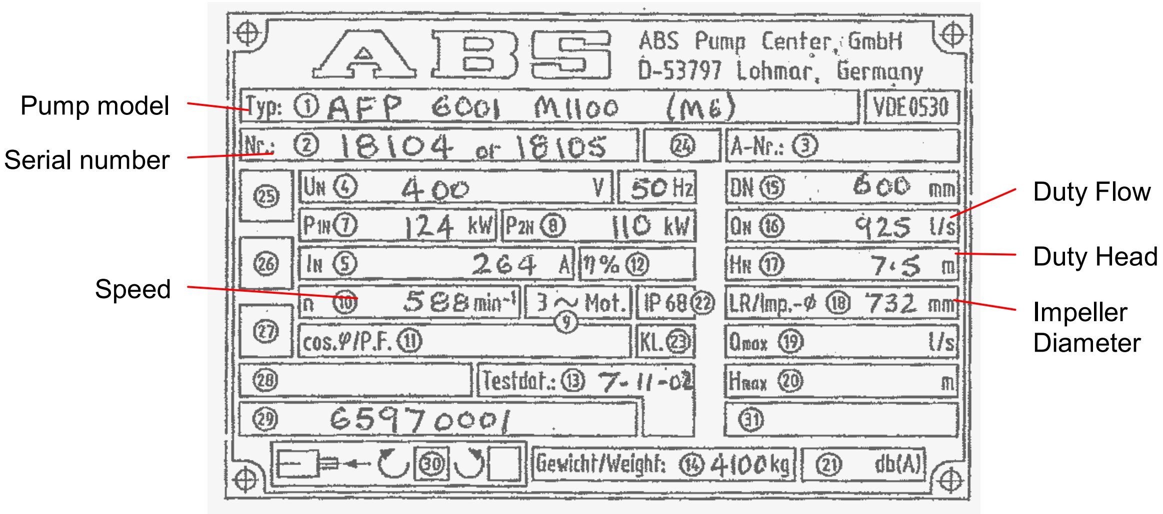


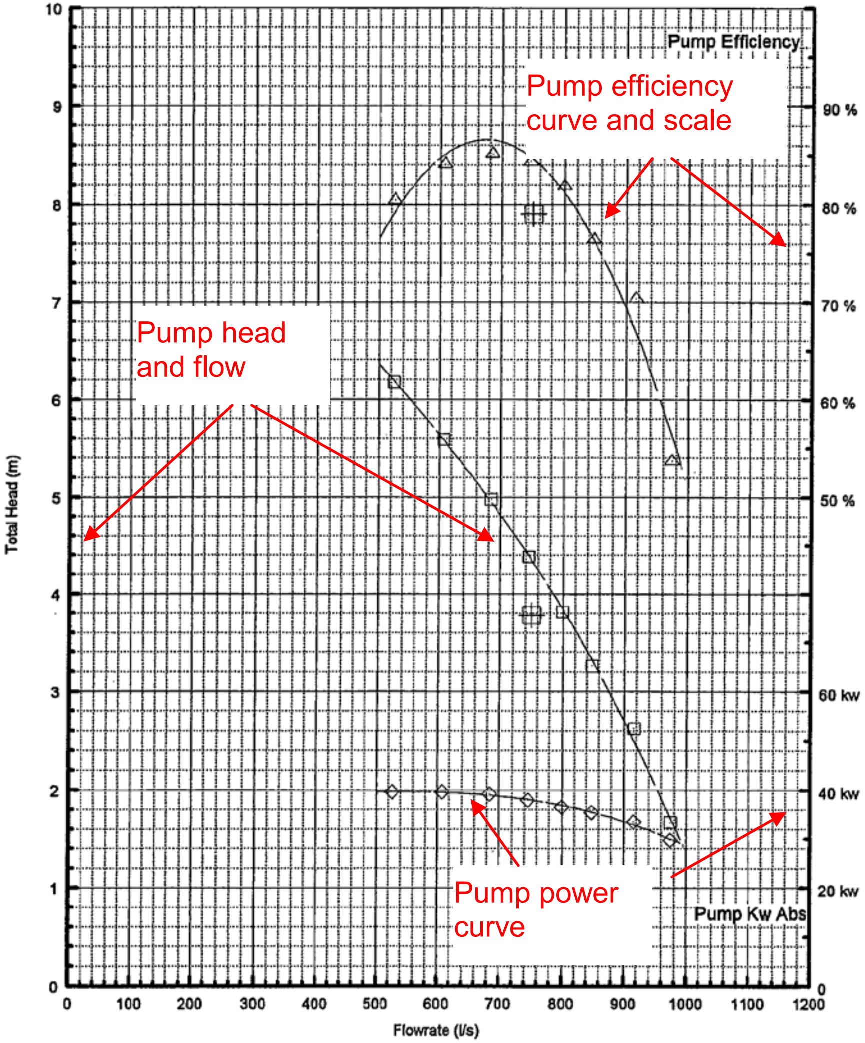
Figure 8.1: Typical pump nameplate

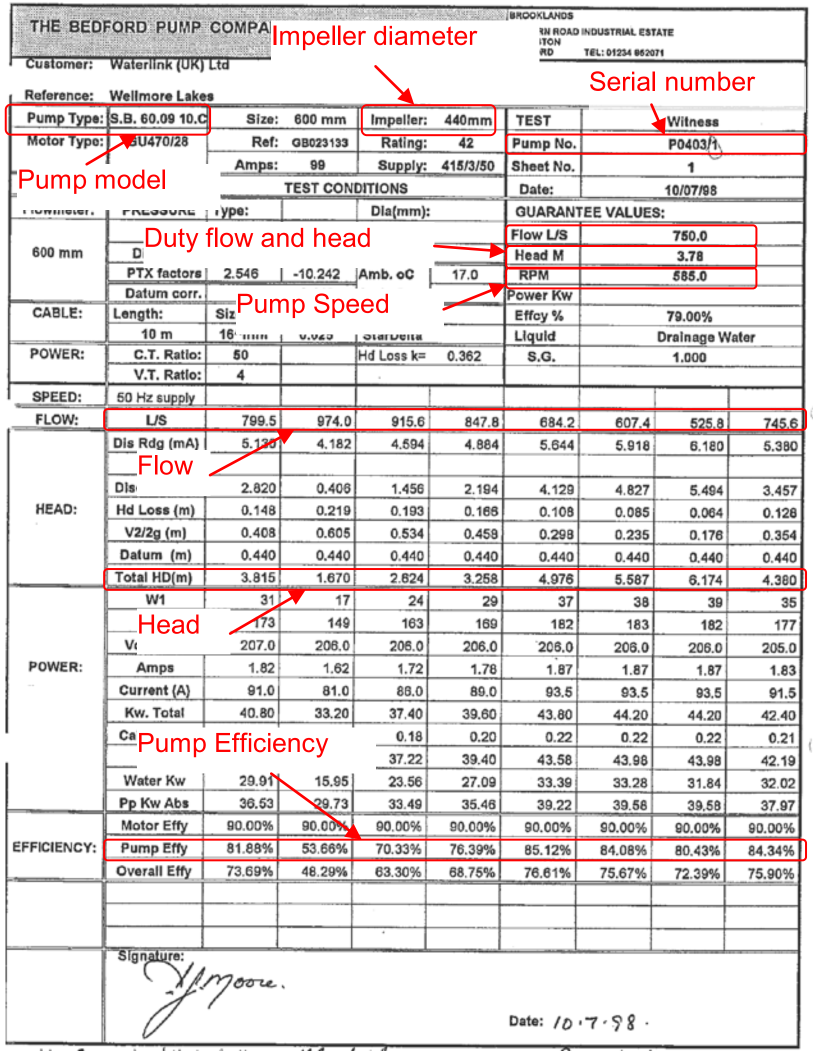
8.7.3 Pump curves and test data

Pump performance is normally described using pump curves or sometimes in tables of test data. These curves and tables are normally based on either the original factory acceptance testing or standard performance data for the pump model.

These figures provide the “as-new” performance of the pump. Over time, wear will alter these characteristics, which is why the spreadsheet includes a wear calculator.

For many older sites the original test data will have been lost. To allow for this, the spreadsheet can create generic curves based on the pump type and the duty head and flow. Where possible, the actual pump curves should be used. Pump manufacturers often hold copies of the test records, especially for newer pumps or may hold curves from other tests on the pump model.





THE BEDFORD PUMP COMPA

BROOKLANDS
RN ROAD INDUSTRIAL ESTATE
TON
RD TEL: 01234 852071

Customer: Waterlink (UK) Ltd

Reference: Wellmore Lakes

Pump Type:	S.B. 60.09 10.C	Size:	600 mm	Impeller:	440mm	TEST	Witness
Motor Type:	GU470/28	Ref:	GB023133	Rating:	42	Pump No.	P0403/1
		Amps:	99	Supply:	415/3/50	Sheet No.	1
		TEST CONDITIONS				Date:	10/07/98
	PRESSURE	Type:		Dia(mm):		GUARANTEE VALUES:	
600 mm						Flow L/S	750.0
	D					Head M	3.78
	PTX factors	2.546	-10.242	Amb. oC	17.0	RPM	585.0
	Datum corr.					Power Kw	
CABLE:	Length:	Siz				Effcy %	79.00%
	10 m	16 mm	0.025	StarDelta		Liquid	Drainage Water
POWER:	C.T. Ratio:	50		Hd Loss k=	0.362	S.G.	1.000
	V.T. Ratio:	4					

SPEED:	50 Hz supply								
FLOW:	L/S	799.5	974.0	915.6	847.8	684.2	607.4	525.8	745.6
HEAD:	Dis Rdg (mA)	5.130	4.182	4.594	4.884	5.644	5.918	6.180	5.380
	Dis	2.820	0.406	1.456	2.194	4.129	4.827	5.494	3.457
	Hd Loss (m)	0.148	0.219	0.193	0.166	0.108	0.085	0.064	0.128
	V2/2g (m)	0.408	0.605	0.534	0.459	0.298	0.235	0.176	0.354
	Datum (m)	0.440	0.440	0.440	0.440	0.440	0.440	0.440	0.440
	Total HD(m)	3.815	1.670	2.624	3.258	4.976	5.587	6.174	4.380
POWER:	W1	31	17	24	29	37	38	39	35
		173	149	163	169	182	183	182	177
	V	207.0	206.0	206.0	206.0	206.0	206.0	206.0	205.0
	Amps	1.82	1.62	1.72	1.78	1.87	1.87	1.87	1.83
	Current (A)	91.0	81.0	86.0	89.0	93.5	93.5	93.5	91.5
	Kw. Total	40.80	33.20	37.40	39.60	43.80	44.20	44.20	42.40
	Ca			0.18	0.20	0.22	0.22	0.22	0.21
				37.22	39.40	43.58	43.98	43.98	42.19
	Water Kw	29.91	15.95	23.56	27.09	33.39	33.28	31.84	32.02
	Pp Kw Abs	36.53	29.73	33.49	35.46	39.22	39.58	39.58	37.97
EFFICIENCY:	Motor Effy	90.00%	90.00%	90.00%	90.00%	90.00%	90.00%	90.00%	90.00%
	Pump Effy	81.88%	53.66%	70.33%	76.39%	85.12%	84.08%	80.43%	84.34%
	Overall Effy	73.69%	48.29%	63.30%	68.75%	76.61%	75.67%	72.39%	75.90%

Signature: J Moore.

Date: 10·7·98·

Figure 8.2: Example pump curves and test data

8.7.4 Pumping levels - Pumping station with syphonic or submerged discharge

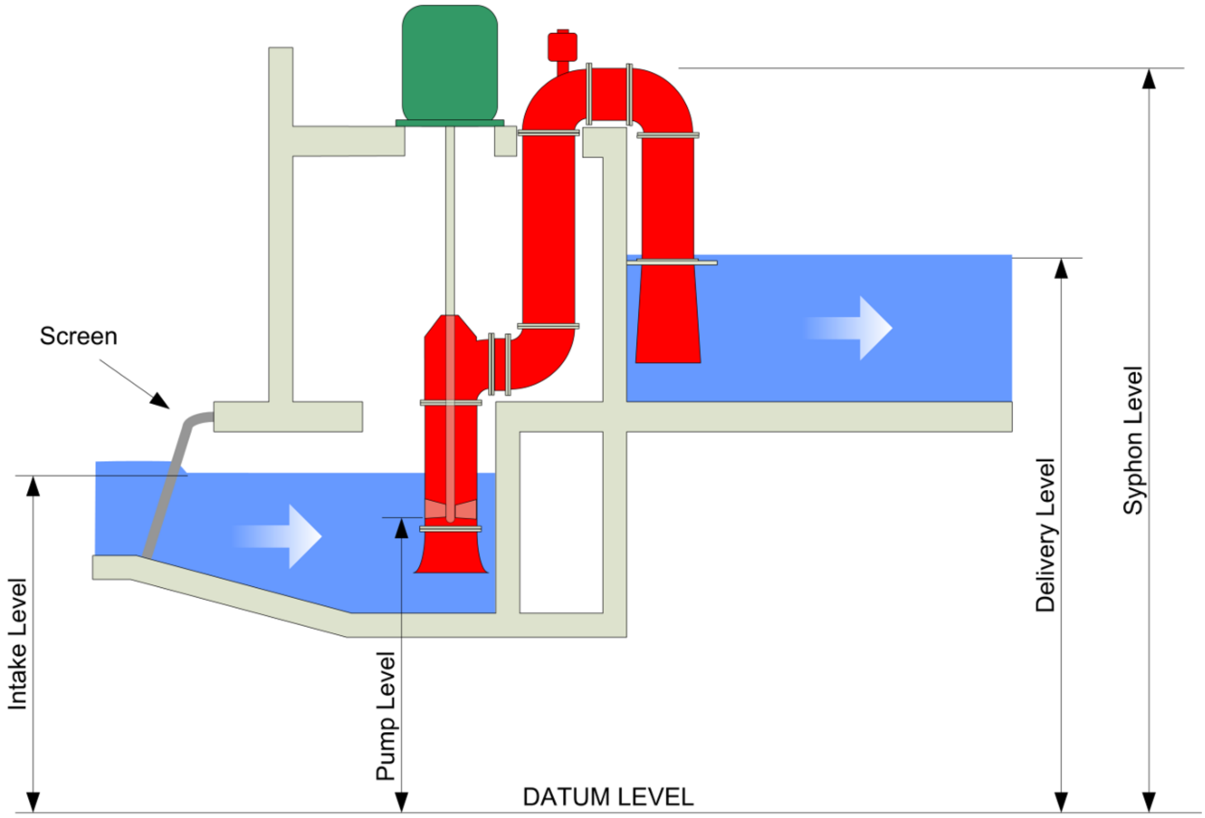


Figure 8.3: Diagram showing syphonic discharge pump layout

For pumping stations with a siphonic discharge, the intake level is the difference in height between the water level in the pump intake sump and the datum level. The discharge level is the difference in height between the delivery side surface water level and the datum level. The pump level is the height of the impeller intake above the datum level. The siphon level is the height of the siphon above the datum. When considering installing a new pump in a system with a siphon, it is important to take into account the pumping head required to prime the siphon.

8.7.5 Pumping levels - Typical pumping station with free discharge

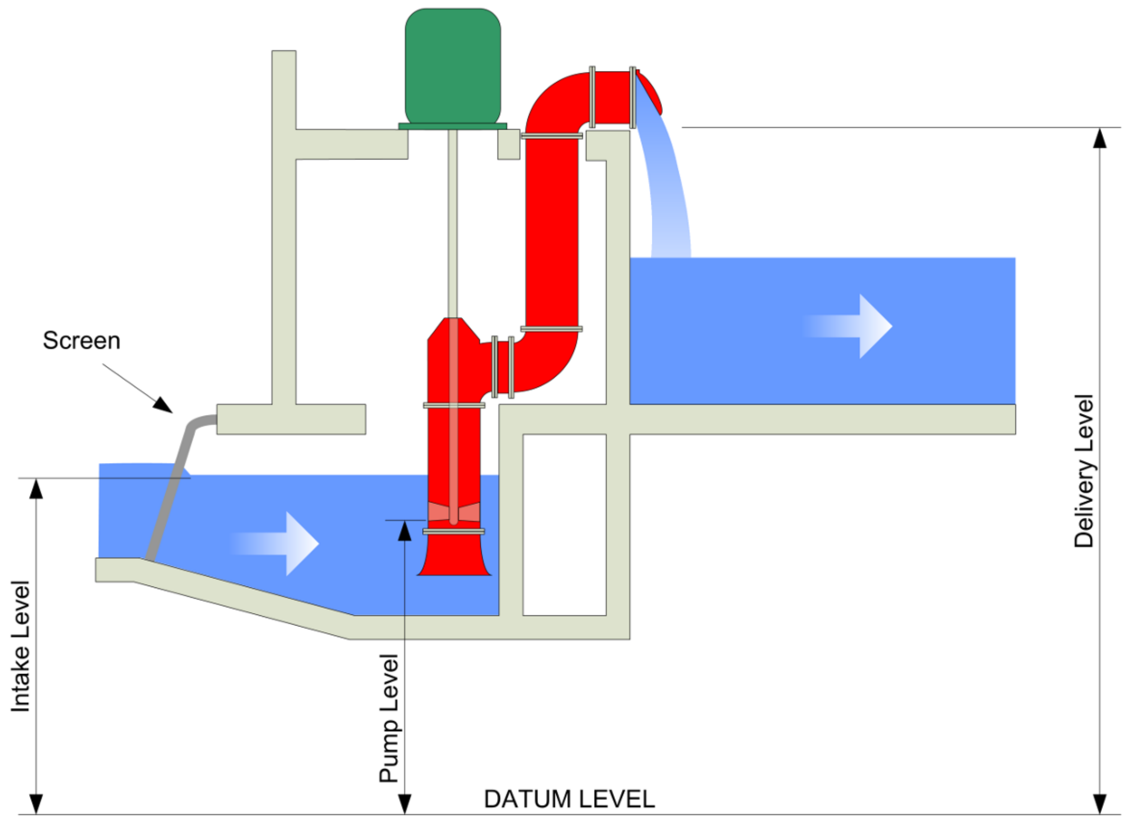


Figure 8.4: Diagram showing free discharge pump layout

For pumping systems with a free discharge, the intake level is the difference in height between the water level in the pump intake sump and the datum level. The discharge level is the difference in height between the invert level of the discharge pipe and the datum level. The pump level is the height of the impeller intake above the datum level.

8.7.6 Pumping levels – General comments

Where the discharge is sometimes submerged and sometimes exposed, for example on systems that discharge to tidal waters, the discharge level should be taken as the invert level when the pipe is exposed and the discharge water level when the outlet is submerged.

If there is not sufficient flow into the intake sump, the intake water level will fall while the pump is running. Engineering judgement will be required when selecting the intake levels to be used. When pumping into tidal waters, the same principle will need to be applied. An example would be using high tide, low tide and mean tide discharge levels. With two intake levels, this would provide six operating points.

8.7.7 Common delivery mains

Where sites have more than one pump pumping into one main, with both pumps operating together in a duty-assist arrangement, it is possible to use this toolbox spreadsheet to get an indication of the performance as long as the common delivery main is long compared to pipework upstream of the join.

If only one pump runs at a time as duty/standby, simplify the pumping station and treat it as though each pump pumps to a separate main.

For these situations, you will need to take the flow/head curves of each pump and add the flow of the two pumps for different heads. For example, find where the curve for each pump crosses 10-m head and read off the flow for each pump. Add these flows together as shown below (Table 8.1) to create a combined pump curve equivalent to the two pumps operating in parallel. Use this combined curve as the pump curve to enter into the spreadsheet.

Table 8.1: Pump curve calculation for combined pumps

Head (m)	10	8	6	4
Pump A flow (l/s)	40	100	165	240
Pump B flow (l/s)	20	50	80	120
Combined equivalent pump flow	60	150	145	360

8.7.8 Pumping levels – Screw pumps

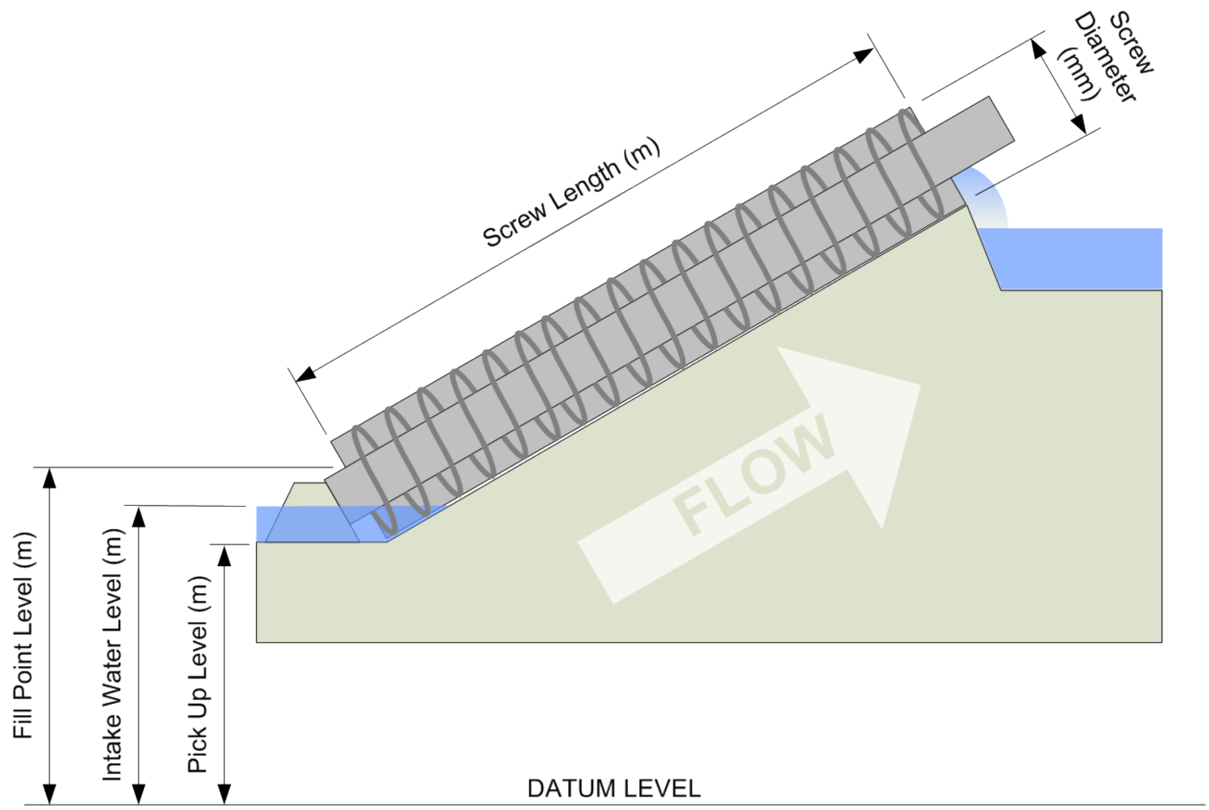


Figure 8.5: Screw pump layout

The flow through a screw pump depends on the intake water level. The optimum water level is when the intake water level is the same as the fill point level. It is important to ensure that the water level in the channel on the discharge side does not rise above the discharge of the screw.

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