Trial Site Audit Summary Report

PHASE 1

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Version Control

Version Number	Date issued	Author	Checker	Approver	Changes
P1	21.01.20	NT	JB	NJ	EARLY DRAFT FOR CONTENT/LAYOUT DISCUSSION
P2	02.03.2020	NT	JB	NJ	FULL DRAFT FOR COMMENT
P3	24/04/2020	NT	JB	NJ	UPDATED DRAFT FOR COMMENT

Content

Abbreviations

Abbreviation	Definition
AC	Asbestos Cement
AI	Artificial Intelligence
API	Automate Programmable Industriel
BEP	Best Efficiency Point
DN	Diamétre Nominal (Nominal Diameter)
FLC	Full Load Current
GPRS	General Packet Radio Service
Green WIN	Greener Waterway Infrastructure
GSM	Global System for Mobile communications
HDPE	High Density Polyethylene
HMI	Human Machine Interface
HPPE	High Performance Polyethylene
N/A	Not Applicable
NPSH	Net Positive Suction Head
NPSHr	Net Positive Suction Head Required
NWE	North West Europe
OD	Outside Diameter
PE	Polyethylene
PLC	Programmable Logic Controller
PN	Pression Nominal (Nominal Pressure)
PS	Pumping Station
PVC	Polyvinyl Chloride
PVC-U	Unplasticised Polyvinyl Chloride
SCADA	Supervisory Control And Data Acquisition
SDR	Standard Dimensional Ratio
SME	Small and Medium-sized Enterprise
TBC	To Be Confirmed
TT	Terre-Terre
UK	United Kingdom
UoL	University of Liège (Université de Liège)
VNF	Voies Navigables de France
VSD	Variable Speed Drive
WI	Waterways Ireland
WMO	Waterway Management Organisation

Symbols & Units

Symbol / Unit	Definition
%	Percent
€	Euro
A	Ampere (Amp)
CO_2	Carbon Dioxide
Hz	Hertz
km	Kilometre
kg	Kilogram
kW	Kilowatt
kWh	Kilowatt-hour
l	litre
m	metre
m^3	Cubic metre
Ml	Megalitre
mm	Millimetre
s	Second

1 Introduction

Project Green WIN is a collaborative project being undertaken by Waterway Management Organisations (WMOs) and partner organisations across North West Europe (NWE) with the aim of addressing excess energy use and high carbon emissions causes. The participating partner organisations are:

- Canal and River Trust, United Kingdom (UK) – Lead Partner.
- Waterways Ireland, Ireland.
- Ministerie van Infrastructuur en Waterstaat, Netherlands.
- Université de Liège, Belgium.
- Voies Navigables de France, France.
- Vlaamse Landmaatschappij, Belgium.

The WMOs rely on pumping equipment and systems to keep waterways operational but need to adapt and make this infrastructure more carbon efficient. Cost pressures restrict WMOs from taking such steps. The project will tackle this by jointly trialling such technologies on their behalf and seeking more efficient ways of deploying them. Pumping water has a substantial carbon impact across NWE, accounting for an estimated 25 % to 33 % of WMO's annual electricity use and circa 20 % of total emissions.

The project focuses on waterways in Belgium, France, Ireland, The Netherlands, and UK, which are used for freight and for recreational uses and has three stages:

1. Audit current equipment/scope for improvement.
2. Pilot technologies and test their potential for adaptation.
3. Investment, procurement, and business planning guidelines.

Green WIN aims to demonstrate net changes of 778,000 kWh energy saved, and 195-tonnes CO_2 emissions reduced. Main outputs and pilots will be an infrastructure audit, technology trials, investment, procurement, and business planning guidelines (a Greener Pumping Technologies Toolkit) and an established support network.

Arcadis Consulting (UK) Ltd (Arcadis) have been appointed by The Canal and River Trust (the Trust) as a technical consultant to support the Green WIN project. This report summarises the findings of Phase 1 stage focussed on audits of the current equipment at the nominated trial sites, and potential scope for improvement.

Further details of particular site assessments can be found on the site-specific Phase 1 audit assessment reports provided in Table no. 1.

Waterway Partner	Site Names	Reference
Canal and River Trust	Caen Hill Pumping Station (PS)	10031024-00516
	Tinsley PS	10031024-00519
	Seend PS	10031024-00517
	Calcutt PS	10031024-00518
Waterways Ireland	Leinster Aqueduct PS	10031024-00524
	Locks 16,17,18 on Grand Canal	10031024-00525
	Shannon Harbour Locks 35 and 36	10031024-00526
	Richmond Harbour PS	10031024-00527
	Drumleague PS	10031024-00528
	Drumshanbo PS	10031024-00529
Voies Navigables de France	Crissey PS	10031024-00522
	Briare PS	10031024-00521
	Stock PS	10031024-00523

Table no. 1: Site Specific Audit Assessment Reports

2 Canal and River Trust Audit Findings

2.1 Caen Hill Pumping Station

2.1.1 Description

Caen Hill PS is located near Devizes, Wiltshire, UK. Its purpose is to supply water up from Lock 22 to Lock 50 on the Kennet and Avon Canal.

Figure no. 1: Caen Hill PS Photos

The audit assessment was based upon the following inputs:

- Telemetry data provided by the Trust.
- Archive drawings.
- Maintenance reports.
- A preliminary site visit undertaken in June 2019.
- A site audit investigation by Arcadis and pump performance testing by Arcadis' SME subcontractor, Samatrix, in September 2019.

Constructed in 1996, Caen Hill PS is of a dry well construction, housing two dry well submersible pumps that normally run in parallel operation (2-pump operation). The pumps are automatically controlled based on canal level.

The level in the flight above Lock 50 is monitored with a signal transmitted back to Caen Hill PS. A PLC controller runs both pumps when the Lock 50 flight level signal falling to a pre-set low level. The Controller stops both pumps upon a pre-set high level being reached.

Parameter	Description
Pumps & Motors	Xylem (Flygt) CT3240 535mm impeller 215 kW standard efficiency motors
No. & Configuration	2 - Parallel (Duty / Duty)
Drives	Variable Speed (Mitsubishi)
VSD Operation	30 s ramp & 48 Hz Operating Frequency
Local Pipework	300 mm diameter ductile iron
Rising Main Length	3602 m
Elevation Rise	72 m
Rising Main	600 mm diameter ductile iron
Controls	PLC - Automatic start/stop control on delivery flight level signal
Communications	Telemetry and SCADA Pumped Flow rate Delivery Pressure Fault Alarms
Notes	2 no. intermediate non-return valve chambers located in rising main

Table no. 2: Caen Hill PS Summary Technical Details

2.1.2 Key Observations

2.1.2.1 Pump/System Curve Hydraulics

The derived pump and system curves are shown in Figure no. 2. These indicate a higher than expected friction loss as indicated by a steeper curve. Arcadis suspect a possible restriction at one or both intermediate non-return valve may be a reason for this.

The pump best efficiency point (BEP) is at a higher flow rate than the actual operating points under both 1-pump and 2-pump operation. The pump efficiency is lower and specific energy higher under 2-pump operation than under 1-pump operation.

The operating duty head is very high for a “sewage type” centrifugal pump with a non-clogging designed impeller. No alternative similar pumps have been found which can meet the required duty points.

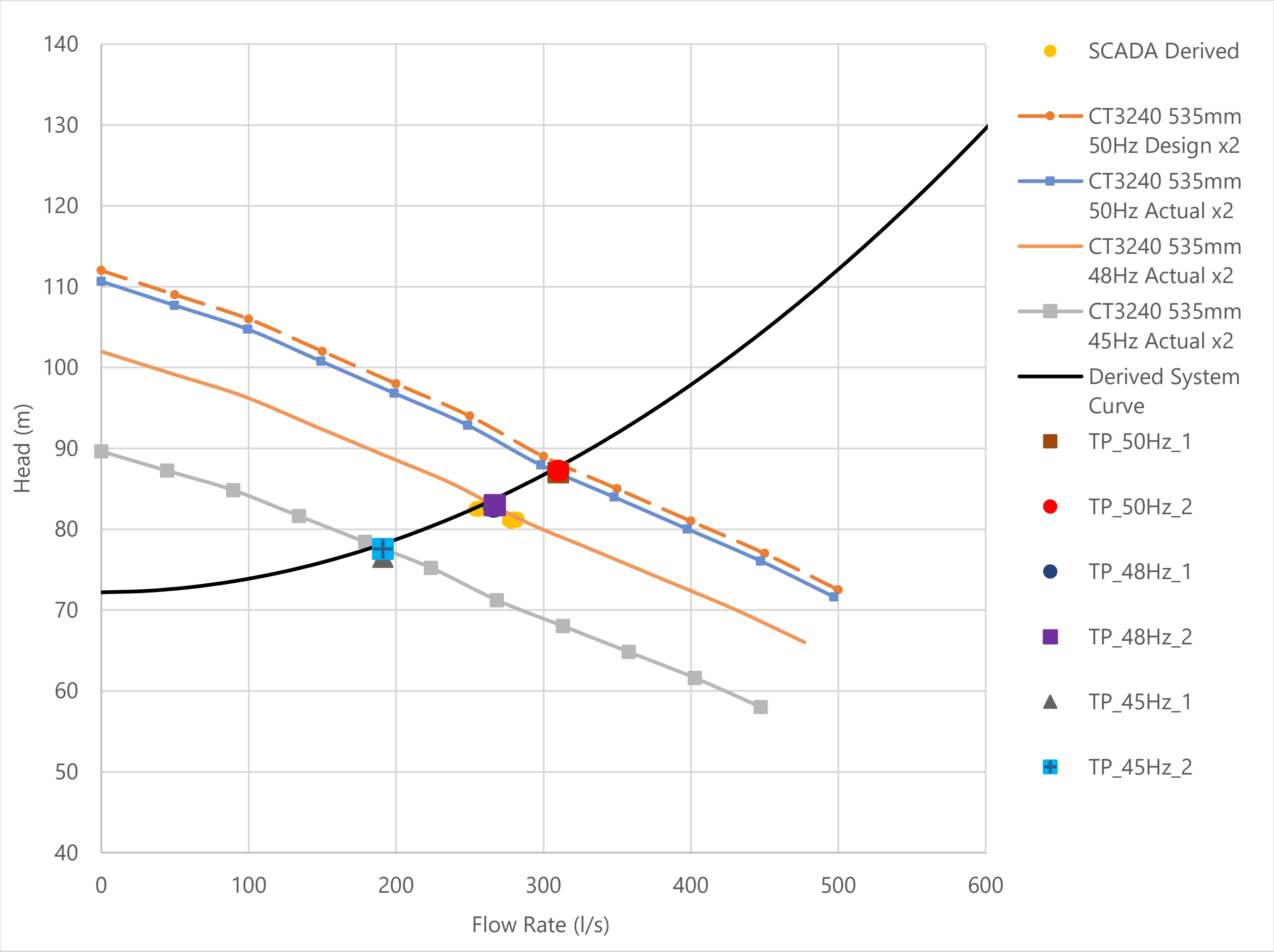


Figure no. 2: Derived System Curves for Parallel Operation at Caen Hill PS

2.1.2.2 Operation and Control

The pumps were tested at 45 Hz, 48 Hz, and 50 Hz drive frequencies. From the test results it was concluded that 48 Hz was the most energy efficient running frequency (from the three frequencies tested).

Flow rate is measured via an on-site electromagnetic flowmeter, but it is not utilised for control. Additionally, both pumps have relay protection[1] and low level (suction) protection.

Key pumping station data is available on the Trust's central SCADA facility.

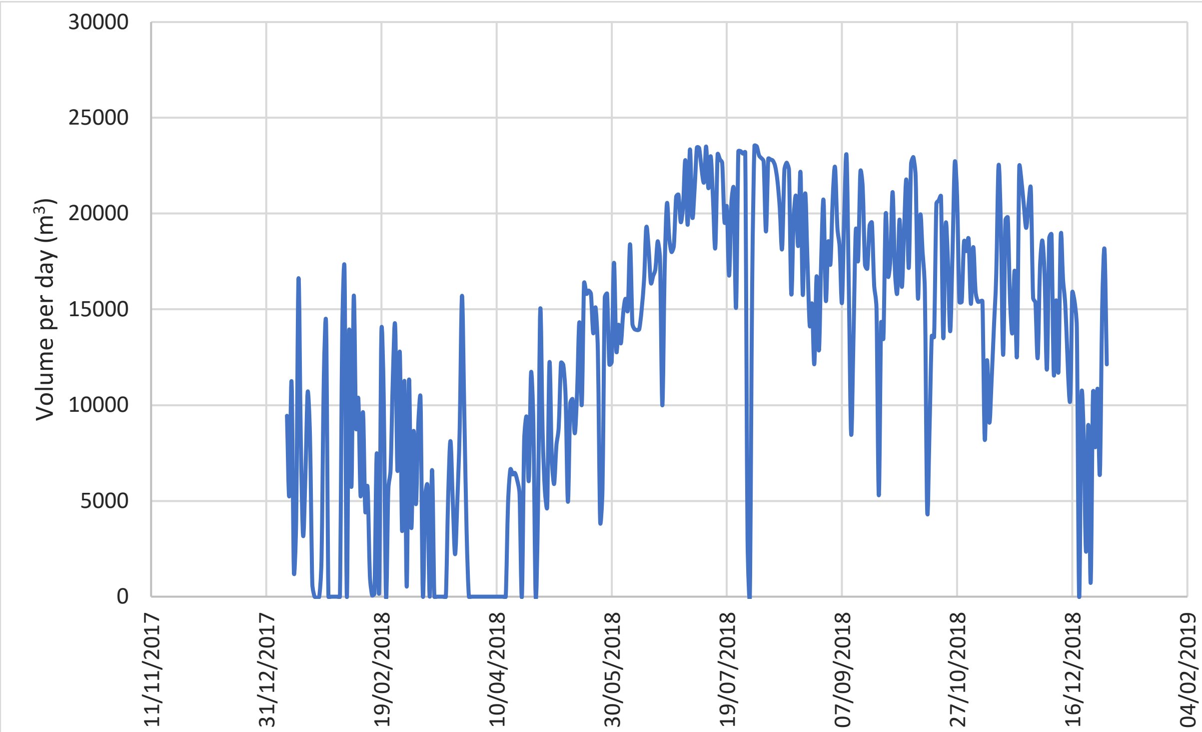


Figure no. 3: Daily Volume Pumped during 2018 (Estimated from SCADA data)

The daily output volumes for 2018 in Figure no. 3 are shown to be variable and this suggests it is not necessary for the pumps to operate continuously or always in parallel. Given that single pumping is more energy efficient, opportunities may exist for optimising control and operating just a single pump where able.

2.1.2.3 Reliability

The pumping station has a generally poor reliability history. For example, the typical pump bearing life is typically 2,000-hours to 3,000-hours, against a design life expectation of 50,000-hours. This is indicative of excessive vibration, and very high vibration levels were measured and confirmed at the site audit test.

[1] Protection Relay is a Xylem MAS 711 unit

From the maintenance records, there are two occasions since November 2017 when significant debris has been found jammed in the pump impellers and necessitated reactive maintenance removal.

2.1.2.4 Other Potential Issues

Other potential issues include:

- Pipework gasket failures – possibly linked to transients, NRV selection and restraint design
- Wet Well silt build up - where it was reported that:
  - Both pump intake screens had 30 % loss due to silt build up with the well.
  - Total volume of silt, brick, concrete rubble, and vegetation removed during an August 2019 inspection was approximately 40-tonnes.

2.1.2.5 Missing Information

Missing Information:

- Sump Internal Dimensions.
- Intermediate Valve Chamber inspections.
- Internal Layout Dimensional Information / Point Cloud.

2.1.3 Possible Improvements

A summary of potential solutions/considerations for improvement is provided in Table no. 3.

A 15 % reduction in energy requirement is considered achievable pending further investigations.

Item or Issue	Potential Improvement Action	Potential Impact on Energy/CO_2
Rising Main Head Loss	Inspect intermediate check valves for condition and if in bypass. Remove or replace if defective.	-7 %
Pump Selection	Review Flygt selection, drives, and impeller diameter based on minimum peak flow rate needed.	-5 % to -10 %
Pump Motor	Consider premium efficiency motor	-2.3 %
Pump Control	Consult with University of Liege and finalise the levels and flowrates required to maintain the system in operation before finalising the pump selection and duty configuration. Implement a 2-level pump control system which allows pump flow rate to vary with Lock 50 flight levels. For example, reducing flow rate when levels are approaching the existing "Stop pump" level.	-5 %
Pipework Failures	Replace the existing ball check valves with a resilient hinge disc check valve and redesign pipework branches to achieve a better separation of pump and NRV if possible.	Reduced call outs
Vibration	Urgently review pump plinth construction, including a structural assessment. Depending on the existing structural design, the new plinths need to be integrated into the existing foundations.	Reduced failures and associated carbon footprint of transportation/and premature replacement parts.
Silt Build up & Blockages	Provide benching improvements to minimise dead spots. Review potential for reducing existing screen bar spacing.	Reduced call outs

Table no. 3: Caen Hill PS Potential Solutions

2.2 Seend Pumping Station

2.2.1 Description

Seend PS is situated near Devizes, Wiltshire, UK. Its purpose is to supply water up from Lock 17 to Lock 21 on the Kennet and Avon Canal.

Figure no. 4: Seend PS Photos

Constructed in 1986, it consists a wet well housing two Xylem submersible pumps that normally operate in parallel (i.e. a 2-pump operation).

The audit assessment was based upon the following inputs:

- Telemetry data provided by the Trust.
- Archive drawings.
- Maintenance reports.
- A site audit investigation by Arcadis and pump performance testing from Samatrix, in September 2019.

Parameter	Description
Pumps & Motors	Xylem (Flygt) NP3301.180 444 mm impeller 55 kW standard efficiency motors
No. & Configuration	2 - Duty / Duty
Drives	Variable Speed (Mitsubishi)
VSD Operation	30 s ramp & 47.5 Hz Operating Frequency
Local Pipework	300 mm diameter (250 mm outlet on pumps)
Rising Main Length	1129 m
Elevation Rise	13 m
Rising Main	Assumed 630 mm PE PN10
Controls	PLC - Automatic start/stop control on delivery flight level signal
Communications	Telemetry and SCADA Pumped Flow rate Fault Alarms

Table no. 4: Seend PS Summary Technical Details

2.2.2 Key Observations

2.2.2.1 Pump/System Curve Hydraulics

The derived pump and system curves are shown in Figure no. 5, Figure no. 6, and Figure no. 7.

The key observations from the derived system curves are as follows:

a) The head losses for the rising main pipework downstream of the flow meter correlates with a design curve for PN10 630 mm Polyethylene (PE) main.

b) The site tests revealed that the installed pumps have a dissimilar performance, in terms of capacity and efficiency, and that the actual flow rates as measured were lower than the expectation for an "as new" installation (3 % for Pump P1 and 10 % for Pump P2).

c) The derived operating points confirm that the pumps operate within the preferred operating region (80 % to120 % x BEP Flow Rate) for 2-pump operations up to 50 Hz and 1-pump operation to 47.5 Hz.

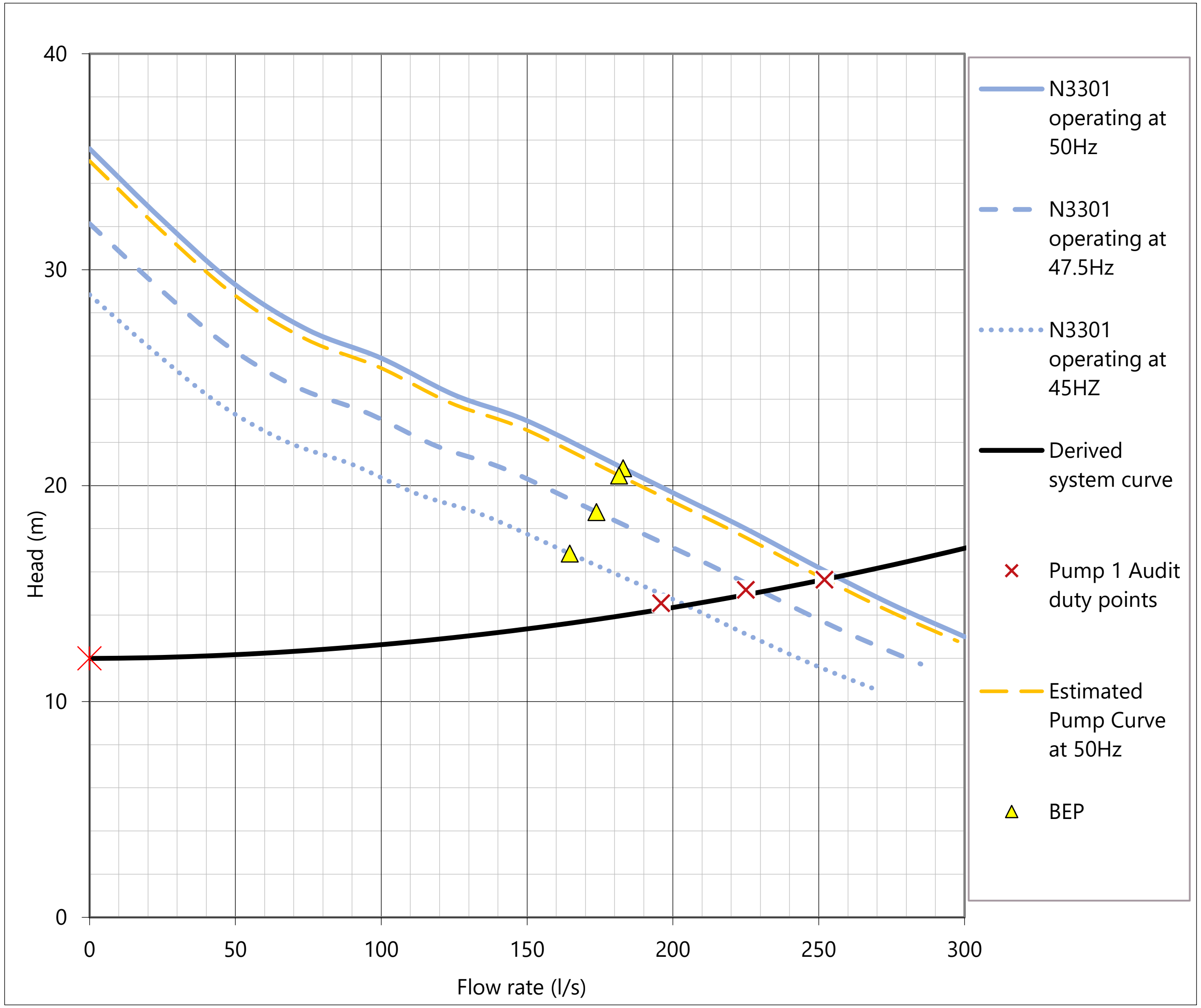


Figure no. 5: Derived System for Pump 1 Only Operation at Seend PS

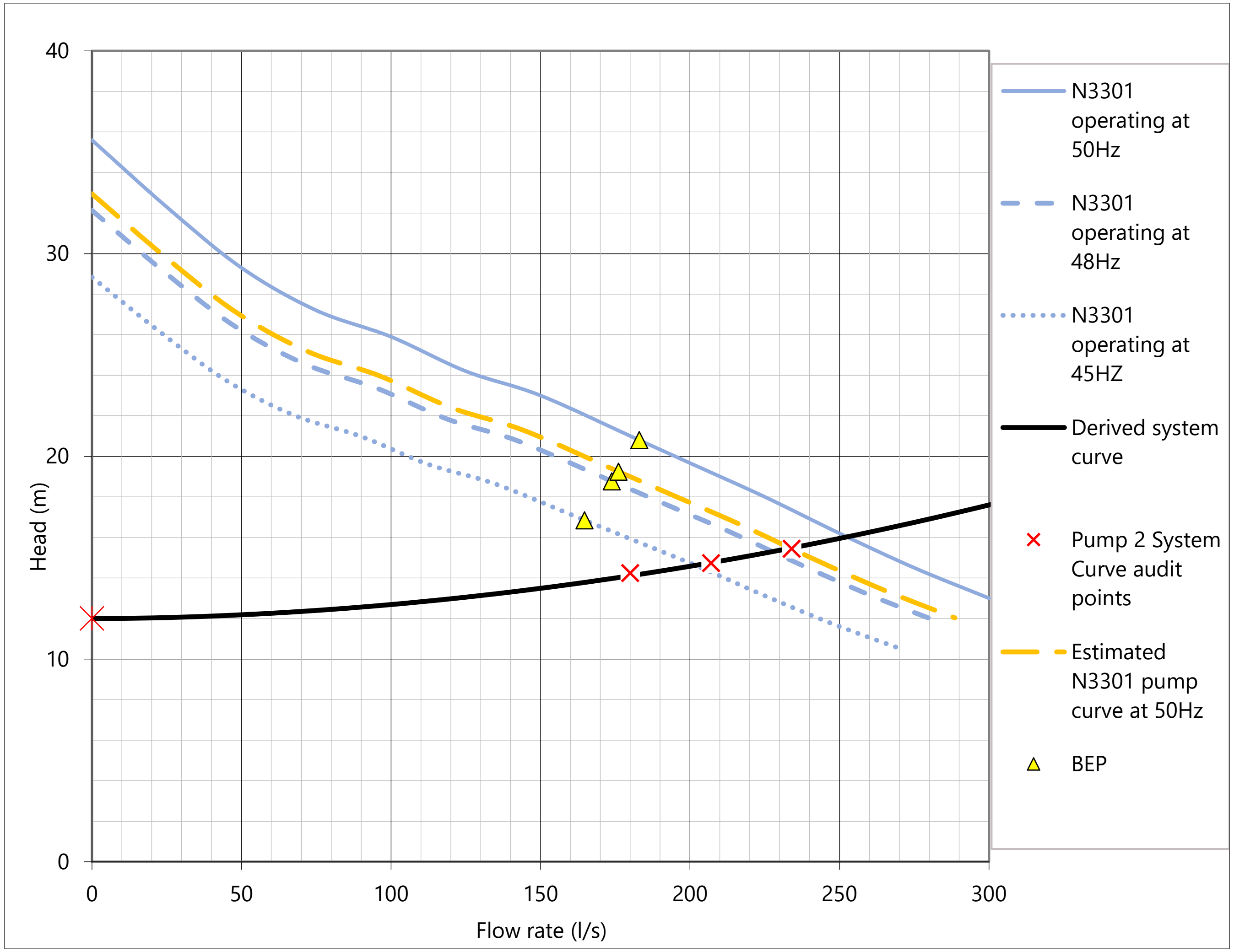


Figure no. 6: Derived System Curves for Pump 2 Only Operation at Seend PS

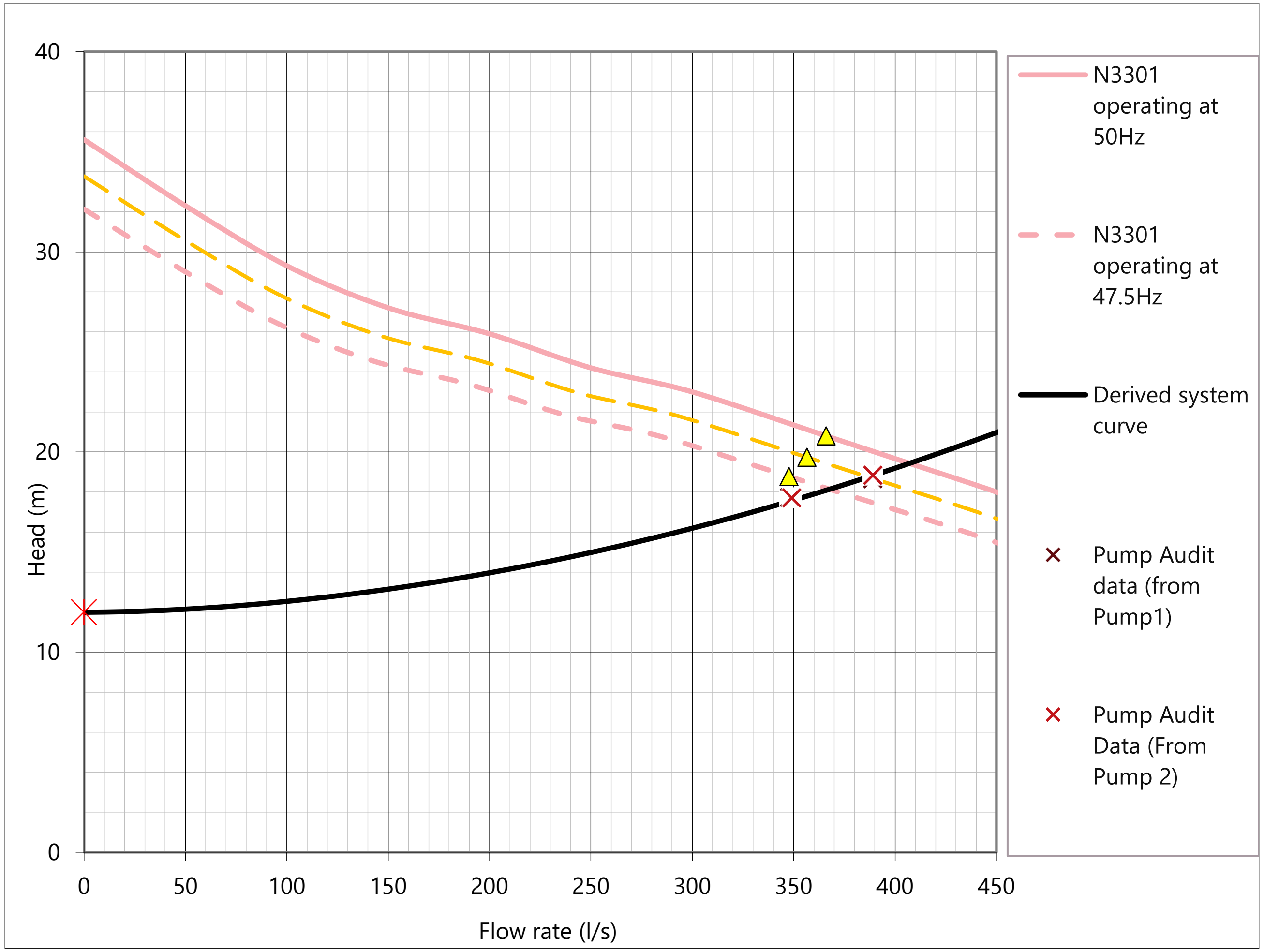


Figure no. 7: Derived System Curves for Parallel Operation at Seend PS

2.2.2.2 Operation and Control

The Lock 21 flight level (discharge location) is monitored and transmitted to Seend PS via telemetry. Upon this level falling to a pre-set low level, the pumps are started. Each pump ramps up on the VSD and both pumps operate in parallel (2-pump) at 95 % speed. When the discharge lock flight 21 level signal reaches its stop set point, the controller ramps down and stops both pumps.

2.2.2.3 Reliability

The pumps have known reliability and overheating issues. Pump No.2 recently (2015) was removed following a failure of top bearing and a burnt-out stator after only 3-years operation.

Due to the shallow wet well floor level, the pump motors are exposed above the liquid surface for long durations and there are historic issues with the pumps overheating. The pump design is not suitable for this exposure. Replacement with new pumps fitted with cooling jackets should resolve the overheating issues.

During the pump audit, Pump 2 was noticeably vibrating when operating in single duty mode. Although running within its preferred operating region, it is possible that the pump stool/guide rail mountings have loosened and require inspection.

2.2.2.4 Other Potential Issues

Surface vortices and vortex shedding were observed at the audit visit, especially during the 50 Hz operation. Submergence calculations suggest that during 1-pump operation the water depth is susceptible to vorticity. During 2-pump operation, as the individual pump flows are lower, the effect is reduced.

2.2.2.5 Missing Information

Missing information:

- Correct As-Built Layout and Dimensional Information / Point Cloud for wet well and valve chamber.
- Correct As-built drawing information for rising main, including long section.

2.2.3 Possible Improvements

A summary of potential solutions/considerations for improvement is provided in Table no. 5.

A 10 % reduction in energy requirement is considered achievable pending further investigations.

Item or Issue	Potential Improvement Action	Potential Impact on Energy/CO_2
Pump Selection	Review pump selection (including cooling jacket, duty/standby vs duty-assist configuration), drives, and impeller diameter based on minimum peak flow rate needed. Assess the cost-benefit opportunities for these options.	-5 % to -10 %
Pump Motor	Consider premium efficiency motor	-2.3 %
Pump Control	Confirm the levels and flowrates required to maintain the system in operation before finalising the pump selection and duty configuration. Possible in tandem with University of Liege modelling study. Implement a 2-level pump control system which allows pump flow rate to vary with Lock 21 flight levels. For example, reducing flow rate when levels are approaching the existing “Stop pump” level.	-5 %
Rising Main	The rising main diameter should also be further investigated to confirm the assumptions within this report.	
Vibration	Investigate the vibration issues on Pump 2 and assess the pump stool fixing.	Reduced failures and associated carbon footprint of transportation/and premature replacement parts.
Instrumentation Monitoring	Inspect and potentially recalibrate the existing flowmeter and SCADA values.	

Table no. 5: Seend PS Potential Solutions

2.3 Tinsley Pumping Station

2.3.1 Description

Tinsley Pumping Station PS is situated in the Northeast of Sheffield, UK and is located downstream of Tinsley No 9 Lock on the Sheffield & Tinsley Canal, which is part of the Sheffield and South Yorkshire Navigation.

Figure no. 8: Tinsley PS Photos

The audit assessment was based upon the following inputs:

- Telemetry data provided by the Trust.
- Archive drawings.
- Maintenance reports.
- A preliminary site visit undertaken in July 2019.
- A site investigation by Hidrostal and AMCO in July 2019.
- A site audit investigation by Arcadis and pump performance testing by Arcadis' SME subcontractor, Samatrix, in September 2019.

Tinsley PS comprises two fixed-speed, submersible pumps that are provided with soft-start drives and are automatically controlled on upstream level on a duty/standby basis.

Water is abstracted from the River Don via an intake with a bar screen and a 70 m long culvert that connects to the wet well. The level in the Tinsley Top Lock (Upper Flight) No.1 is monitored with a signal transmitted back to Tinsley PS. A PLC controller runs both the duty pump when the upper flight level signal falls to a pre-set low level. The controller stops the duty pump upon a pre-set high level being reached.

Parameter	Description
Pumps & Motors	Flygt NP3301.180 HT 55 kW standard efficiency motors
No. & Configuration	2 - (Duty / Standby)
Drives	Soft start
Drive Operation	5 s ramp to full load current (FLC) and 10 s run-off.
Local Pipework	250 mm and 300 mm diameter ductile iron
Rising Main Length	1300 m
Elevation Rise	22.7 m
Rising Main	24” diameter cast iron
Controls	PLC - Automatic start/stop control on upper flight level signal
Communications	Telemetry and SCADA Pumped Flow rate Fault Alarms

Table no. 6: Tinsley PS Summary Technical Details

2.3.2 Key Observations

2.3.2.1 Pump/System Curve Hydraulics

Pump and system curves were derived from provided information and on-site audit tests (Figure no. 9 and Figure no. 10). The site tests revealed that the installed pumps have a dissimilar performance, in terms of capacity and efficiency, and that the actual flow rates as measured were lower than the expectation for an “as new” installation.

This could be due to heavy tuberculation due to the pipe age or pump wear. It is also thought that the pumps are fitted with different impellers sizes although they are the same pump unit model.

The pumps are operating with a narrow NPSH safety margin which has the potential to cause issues with long-term operation and functionality.

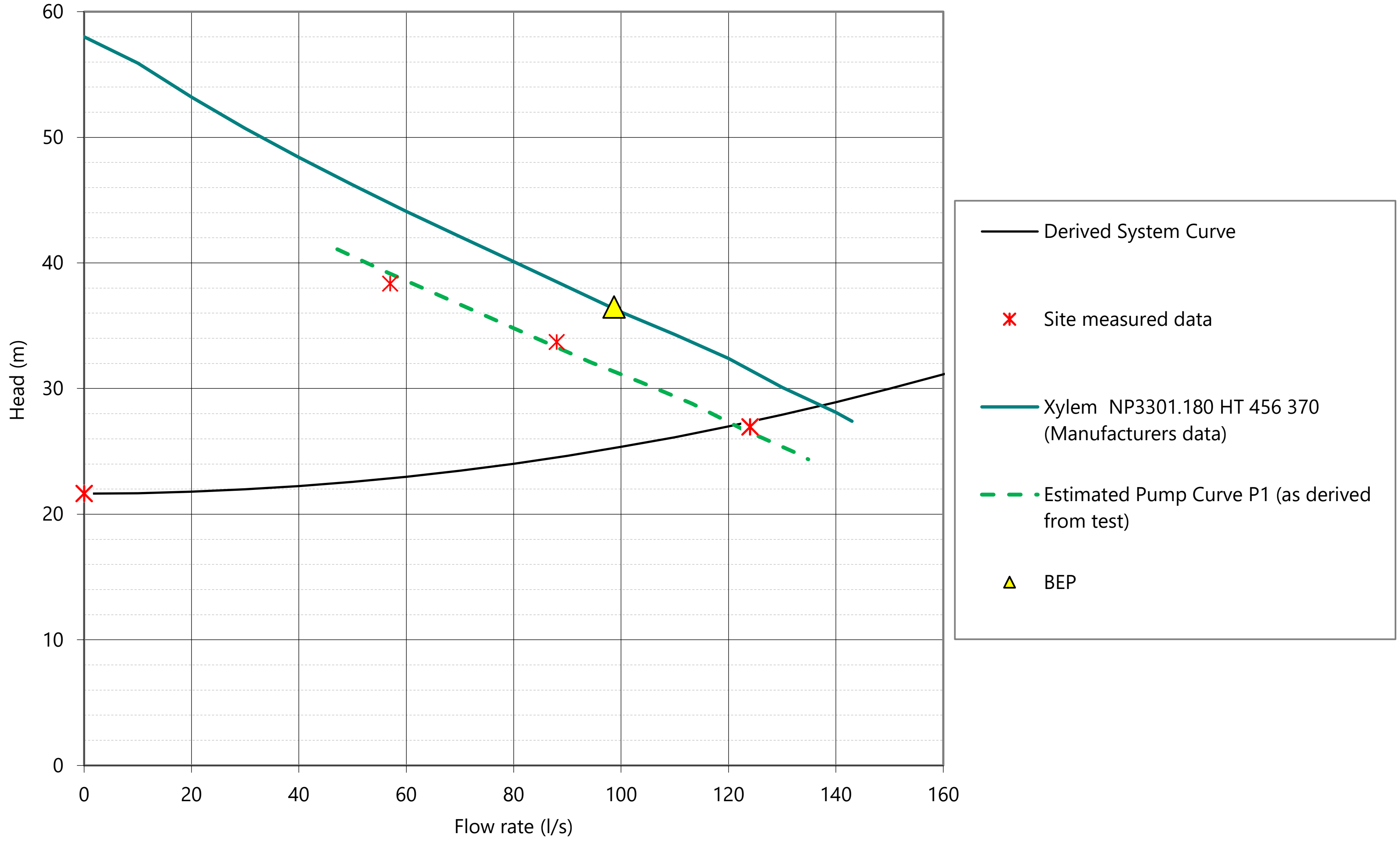


Figure no. 9: Derived System Curve for Pump 1 at Tinsley PS

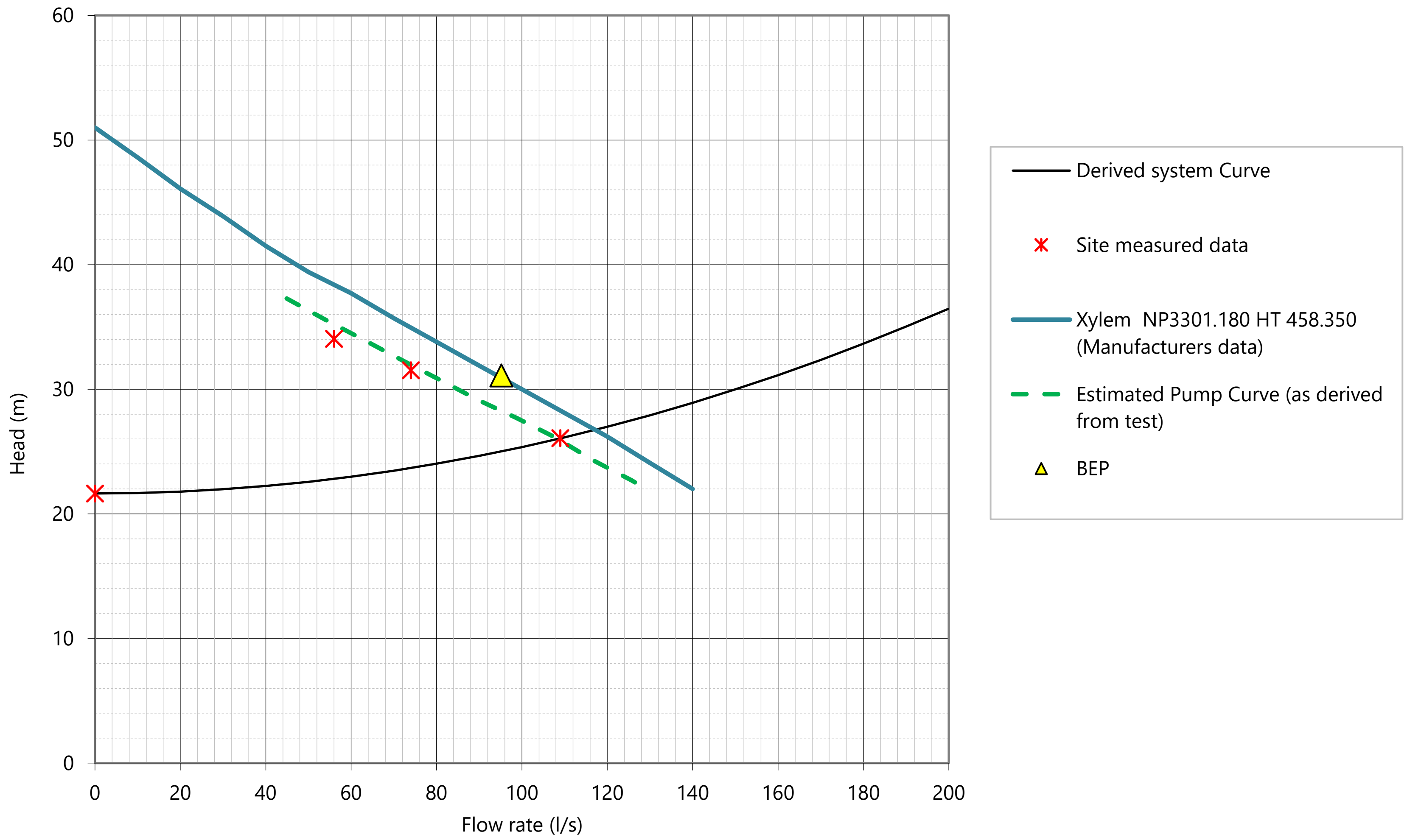


Figure no. 10: Derived System Curve for Pump 2 at Tinsley PS

2.3.2.2 Operation and Control

Due to leakages at the summit pound, Tinsley PS needs to operate all year round to ensure that the canal remains navigable. At present only pump 1 can deliver enough flow to maintain/recover the upstream level. Increasing the pump flow rate to a minimum target of 130 l/s to 140 l/s is required.

The pumps are currently operated using soft start drives. However, the use of variable speed drives (VSDs) would help accommodate the differences in river levels by adjusting output at low level. It would also provide the capability for adjustment over the operational life of the pump units to maintain flow rate, allowing for pipeline deterioration and pump wear.

There is currently no level measurement in the wet well and pump pressure gauges were not functional at the time of the site audit. Providing level instrumentation within the wet well and pressure instrumentation on the rising main would help provide real-time monitoring and facilitate pump system control and protection.

2.3.2.3 Reliability

Historically, the pumping station has suffered from instances of pump failures and blockages, mainly due to debris and rubbish entering the wet well. Providing new pumps with a large open passage, non-clogging, hardened impellers should reduce the frequency of issues with pump blockages.

2.3.2.4 Other Potential Issues

The exact rising main age and condition are unknown but is reported to be original cast iron which could be up to 200-years old and has historically suffered two major blowouts. Frequent inspection and 'smart' monitoring of the rising main may be required to help identify leakages and, or pipeline failure/bursts. Completely replacing the rising main is not likely to be cost effective at this time.

The tangential orientation of the inlet culvert to the pumps may cause rotation of the flow presentation at the pump intake, possibly causing the possibility of a reduced and/or unsteady pumped flow rate. However, it is anticipated that the effect should be minor as the pumps do not operate in parallel. Bespoke baffles could be retrofitted if necessary, should adverse flow performance patterns with the new replacement pumps be evident.

2.3.2.5 Missing Information

Missing information includes:

- Sump Internal Dimensions
- As-Built Layout and Dimensional Information / Point Cloud for wet well and pump station building
- As-built drawing information for rising main, including long section, and outfall
- Trial hole information

2.3.3 Possible Improvements

A summary of potential solutions/considerations for improvement is provided in Table no. 7.

A 23.2 % reduction in energy requirement is considered achievable pending further investigations.

Item or Issue	Potential Improvement Action	Potential Impact on Energy/CO_2
Pump Selection	Purchase Hidrostal F06G-EMU1+FEVV4-GSEK1AA pumps and retrofit into the well, modifying the existing pipework to accommodate as required	-21.6 %
Pump Drives	Install VSDs for optimum control	-1.6 %
Pump Control	Develop control algorithms/function blocks to monitor performance and automatically run at maximum efficiency / lowest specific energy or during off-peak tariff periods	TBC
Rising main	Consider feasibility of options to replace rising main	-16,000 kWh per annum *(estimated based on 1.3 km long, 600 mm internal diameter HDPE/PE100 pipe)*
Silt/Debris Build up & Blockages	Provide wet well benching to minimise dead spots Review intake bar screen maintenance procedures	Reduced call outs
Wet well hydraulics	Monitor pump performance and efficiency of new installation – review the wet well/intake hydraulics and pump orientation to determine if potential improvements to the arrangement can be made should issues arise/persist	TBC

Table no. 7: Tinsley PS Potential Solutions

2.4 Calcutt Pumping Station

2.4.1 Description

Calcutt PS is situated near Southam, Warwickshire, UK and is the last in the chain of a series of eleven pumping stations along the Grand Union Canal.

Figure no. 11: Calcutt PS Photo

The audit assessment was based upon the following inputs:

- Telemetry data provided by the Trust.
- Archive drawings.
- Maintenance reports.
- A preliminary site visit undertaken in July 2019.
- A site audit investigation by Arcadis and pump performance testing by Arcadis' SME subcontractor, Samatrix, in October 2019.

Calcutt PS comprises a single, fixed-speed submersible pump within a wet well with a valve chamber and a flow meter. A small, brick-built hut with a metallic, domed roof houses the electrical and control equipment for the pumping station.

The pump is automatically controlled on level. Level probes are located within the in wet well and pressure transducers are provided for measurement of downstream and upstream canal water levels in the lower and upper pound.

A PLC controller runs the duty pump when the upper pound level signal falls to a pre-set low level. The controller stops the duty pump upon a pre-set high level being reached in the upper pound. The pump is also inhibited upon a pre-set low level being reached in the lower pound.

The pump station intake is direct from the lower pound downstream of Calcutt Bottom Lock No.3 and the pump discharges to the upper pound, upstream of Calcutt Top Lock No.1. The inlet is submerged and has a bar screen.

Parameter	Description
Pumps & Motors	KSB KRTK 200-330/414 UG (Noted post installation impeller revision) 41 kW standard efficiency motors
No. & Configuration	1 - (Duty only)
Drives	Fixed Speed (Star-Delta)
Drive Operation	N/A
Local Pipework	250 mm diameter ductile iron
Rising Main Length	390 m
Elevation Rise	6.73 m
Rising Main	450 mm diameter HPPE/PE100 Black (assumed SDR17)
Controls	PLC - Automatic start/stop control on delivery flight level signal
Communications	Telemetry and SCADA Pumped Flow rate Wet well Level Upper pound (top lock) water Level Lower pound (bottom lock) water Level Fault Alarms

Table no. 8: Calcutt PS Summary Technical Details

2.4.2 Key Observations

2.4.2.1 Pump/System Curve Hydraulics

The existing KSB Amarex pump was modified following its original installation in 2012. KSB have confirmed the modification scope comprised a change of impeller only. The impeller was changed in January 2012 with a larger diameter impeller although the trim diameter has not been recorded by KSB.

The derived pump and system curves are shown in Figure no. 12. The site tests revealed that the suggest an operating duty point of around 247 l/s at 14.8 m head and a specific energy of 52.3 kWh/Ml. This sits between the anticipated performance of a 300 mm and a 310 mm diameter impeller.

The pipework between the valve chamber and flow meter is assumed to be 250 mm OD PE pipework (based on site observations and measurements) and the pump station discharge pipework is DN200/DN250. The flow rates recorded during the site audit result in high velocities occurring in these sections of pipework and, consequently, increased head losses.

Velocities in excess of 3.5 m/s can cause increase the risk of damage due to hydraulic shock and erosion from the abrasive action of particles in the water. Achieving lower velocities below 3.0 m/s would improve the long-term, economical operation of the pumping station and the rising main.

The test data and derived system curve suggest a required design duty point of 200 l/s at 10.4 m head.

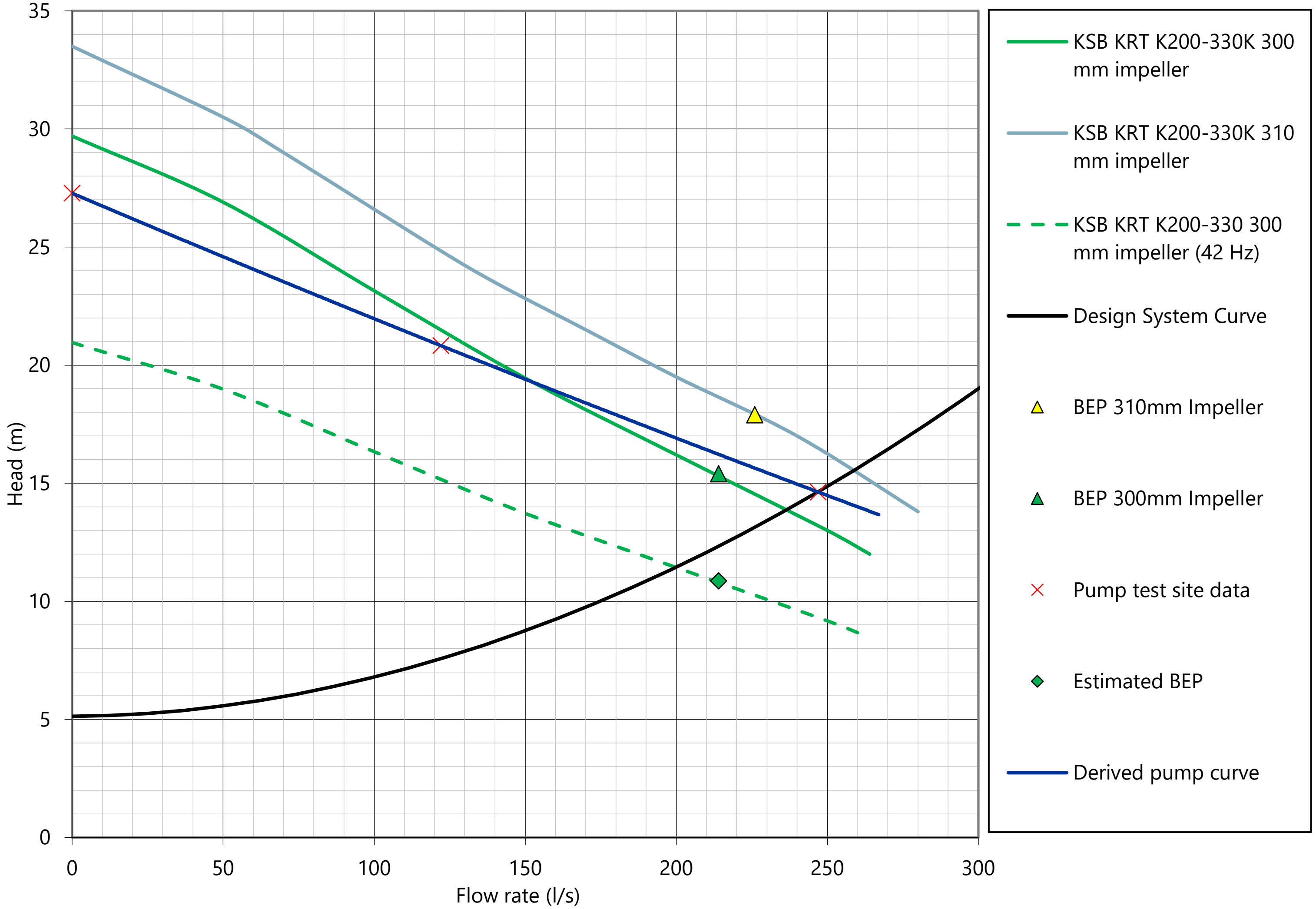


Figure no. 12: Derived System Curve for Calcutt PS

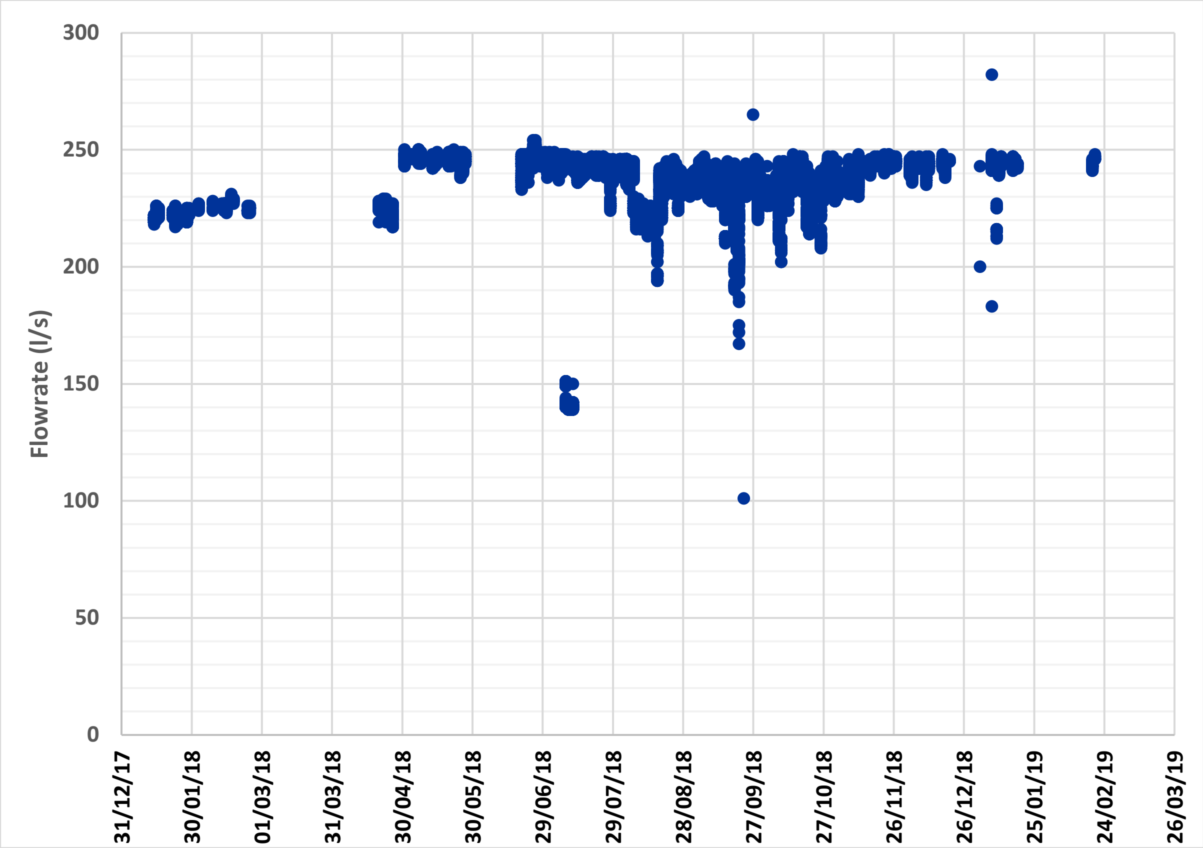


Figure no. 13: Calcutt PS SCADA Flow rate Data 2018/2019

2.4.2.2 Operation and Control

The required peak flow rate at Calcutt PS is approximately 200 l/s; however, flow rates in excess of 250 l/s have been observed which is supported by the SCADA readings (Figure no. 13) and site audit data. The pump is therefore over-capacity.

After reviewing several options, the installation of a suitably selected pump with high efficiency motor is suggested and this would provide benefits in terms of improved efficiency and CO_2 reduction.

2.4.2.3 Reliability

The current pump installation is duty only therefore this does not provide much resilience against pump failure. Provision of a 2-pump installation would provide operational flexibility and improve pumping resilience.

It is reported by the Trust that there is a history of phase imbalance at site and burnout, and issues with the power supply incorporating a TT earthing system. As such, the number of starts at Calcutt PS is limited to 5 per hour.

2.4.2.4 Other Potential Issues

If a single pump arrangement is adequate for canal operations, then the existing 2.4 m diameter wet well should be able to accommodate a single pump unit. However, should a duty/standby configuration be required for resilience, then a new wet well and valve chamber would be required.

Depending on pump selection a duty/assist arrangement may also fit within the existing wet well; however, a larger valve chamber would be required to accommodate the two sets of pump discharge pipework and valves.

Construction of a new intake would potentially cause disruptions to the waterway. This is considered avoidable, although the existing pumping station would still be unavailable at times while the works are being undertaken and require isolation of the intake to stop flows from the canal.

2.4.2.5 Missing Information

Missing information includes:

- Existing pump impeller diameter.
- Topographical and utilities survey data for pumping station area.
- As-Built Layout and Dimensional Information / Point Cloud for wet well, valve chamber and flow meter chamber.
- As-Built Layout and Dimensional Information / Point Cloud for intake.
- As-built drawing information for rising main, including long section, and outfall.
- Trial hole information.
-

2.4.3 Possible Improvements

A summary of potential solutions/considerations for improvement is provided in Table no. 9.

A 41 % reduction in energy requirement is considered achievable pending further investigations.

Item or Issue	Potential Improvement Action	Potential Impact on Energy/CO_2
Rising Main Head Loss	Confirm specification details/diameter of existing plastic pipework and consider upsizing existing pipework upstream of flowmeter to lower head losses.	TBC
Pump Selection	Provide fixed speed duty only (single) pump or duty/standby pump installation Undertake desktop review to determine if two different sized pumps could provide operating efficiency benefits compared with duty/standby or duty/assist configurations	-39 % to -41 %
Pump Drives	Provide premium efficiency motor (IE3)	TBC
Pump Control	Consult with University of Liege and finalise the levels and flowrates required to maintain the system in operation before finalising the pump selection and duty configuration.	TBC

Table no. 9: Calcutt PS Potential Solutions

3 Waterways Ireland Audit Findings

3.1 Leinster Aqueduct Pumping Station

3.1.1 Description

Leinster Aqueduct PS is situated on the River Liffey, approximately 2 km north east of Donore, Co. Kildare. The pumping station lifts water from the River Liffey into the Grand Canal Lock system to replenish the system during the summer months.

Figure no. 14: Leinster Aqueduct PS (viewed from Grand Canal)

The Phase 1 audit assessment was based upon the following inputs:

- Initial Technical Assessment paper by Waterways Ireland.
- Pump datasheet.
- A site audit investigation and pump performance testing by Arcadis and Samatrix in September 2019.

Leinster Aqueduct PS comprises three KSB Amarex fixed-speed, submersible pumps, each located within dedicated pump bays. The pumps are protected by a 50 mm spaced bar screen and low-level suction protection probes.

The pumps are controlled in 'hand', with no other instrumentation present (flow meter, pressure transducer, etc.).

The pump station typically operates between approximately March and September with the sluice gate drain in operation for the remainder, draining excess water from the canal network. The sluice is manually operated.

No isolation valves or check valves are present within the system, as these were all removed as part of refurbishment works in 2010. The three. rising mains free discharge into a common concrete outfall chamber on the Grand Canal approximately 20 m away, passing through the pump house en-route.

In addition to the concrete outfall chamber, there is a sluice gate chamber complete with level sensor connected to a 600 mm dia. PVC line to return water from the Grand Canal to the River Liffey over the winter months. The level sensor only serves for indication only.

Parameter	Description
Pumps & Motors	KSB Amarex KRT K200-401/266
No. & Configuration	3 - Parallel (Duty / Assist / Standby)
Drives	Fixed Speed Star Delta
Local Pipework	200 mm diameter ductile iron
Rising Main Length	20 m
Elevation Rise	6.9 m
Rising Main	200 mm diameter ductile iron (3No.)
Controls	Manual only Pump Protection - Low level suction protection and electrical overloads
Communications	N/A

Table no. 10: Leinster Aqueduct PS Summary Technical Details

3.1.2 Key Observations

3.1.2.1 Controls and Operation

There is currently no instrumentation measuring pump performance such as a flow meter. With no instrumentation there is little way of knowing how the pumps are operating day to day and gives no opportunity for any proactive maintenance or trends to be ascertained for the system.

Based on the site pump performance test data, system curves have been derived for the single pump operation as there is no common main within this system. As no pressure data or drawings are available the losses have been estimated.

The pump curve shown is the manufacturers “as new” pump curve. The site tests revealed that the actual flow rates as measured were lower than the expectation for an “as new” installation. There is no obvious reason for this given the absence of drawings and pressure data, although it could be due to wear, leakage, measurement error, or some other unknown restriction/loss.

The return line from the Aqueduct was found to have small but continuous flow back onto the Liffey.

3.1.2.2 Pump/System Curve Hydraulics

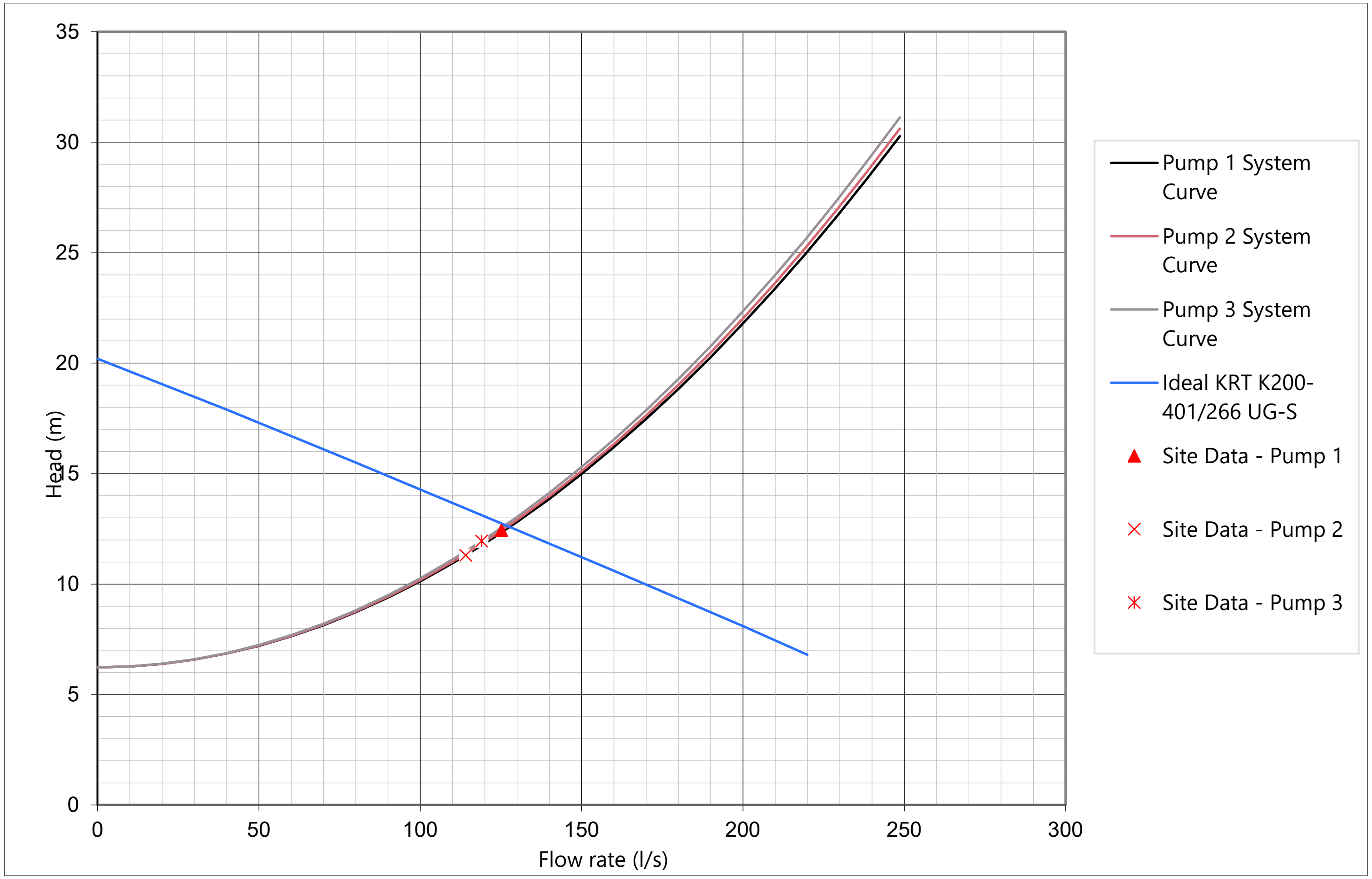


Figure no. 15: Leinster Aqueduct Derived System Curve – All Pumps

3.1.3 Possible Improvements

A summary of potential solutions/considerations for improvement is provided in Table no. 11.

Item or Issue	Potential Improvement Action	Potential Impact on Energy/CO_2
Pump Performance	Lift and investigate Pump 2 and Pump 3 impellers. Remove any soft blockages	
Instrumentation and Controls	Install level sensors on discharge canal flight. Install magnetic flowmeters on all three pump delivery lines Install threaded process connection on all three pump delivery lines Install a 'smart' pump controller including power metering that can automatically control the pumps using inputs from above instrumentation measurements together with optimised efficient running and callouts.	TBC
SCADA / Telemetry	Install 'smart' controller (as above) with communication capability and remote data access via GPRS/GSM signal in lieu of more expensive SCADA and telemetry at PS.	
Return Sluice Gate	Repair leakage from sluice gate	-2.5 %

Table no. 11: Leinster Aqueduct Potential Solutions

3.2 Grand Canal Locks 16. 17, 18 Pumping Stations

3.2.1 Description

For Locks 16, 17 & 18 on the Grand Canal, three pump houses operate in a chain to supply water to the summit pound of the Grand Canal during dry periods to maintain navigable water levels.

The Phase 1 assessment is based upon the data provided by WI and a site audit visit undertaken in September 2019.

Pump testing was undertaken at the site visit using calibrated instrumentation as follows:

- Power (using Fluke power meter).
- Flow rate (using Panametrics PT878 ultrasonic flow meter).
- Levels and dimensions (laser/tape measure).
- Delivery pressure (using pressure logger) where possible.

The measurement parameters taken at the site visit are shown in Table no. 12.

PS Site	Power	Flow Rate	Rising Main Entry Pressure	Levels / Dims
Lock 16	✓	✓	×	✓
Lock 17	✓	✓	✓	✓
Lock 18	✓	✓	✓	✓

Table no. 12: Measured Parameters at Locks 16, 17 & 18 Site Audit Visit

Lock 16 is located near Digby Bridge, Sallins, Co. Kildare and discharges across the Lock gate towards Lock 17.

Lock 17 is located near Landenstown Bridge, near Donore, Co. Kildare.

Lock 18 is located near Goatstown, Denore, Co. Kildare. The pump house is the last of a chain of pumping stations along the Grand Canal designed to maintain an upstream level within the canal.

Figure no. 16: Lock 16 on the Grand Canal PS (viewed from Digby Bridge)

Figure no. 17: Lock 17 on the Grand Canal PS (viewed from Digby Bridge)

Figure no. 18: Lock 18 on the Grand Canal PS (viewed from Canal Path)

All three pumping stations comprise a wet well with fixed intake bar screen housed within the confines of a superstructure building. An ultrasonic level probe is located within the wet wells for pump suction protection. Each building also houses a control panel and fixed lifting beam. All three sites each comprise a single KSB submersible pump, of the same model and size, which date back to around 2010. The delivery pipework is comprised of 250 mm diameter ductile iron flanged pipework. There are no isolation or check valves contained within the pump stations.

The rising main arrangements differ between the three sites.

At Lock 16, the 300 mm diameter rising main free discharges to an outfall chamber approximately 10 m away from the pump house. The flow then gravitates approximately 20 m to the outfall into the canal via a 600 mm diameter cast iron pipe.

Unlike Lock 16, the rising main for Lock 17 discharges into the canal over a weir board approximately 30 m away from the pump house.

Lock 18 rising main is similar in nature to that of Lock 16 with the rising main free discharging to an outfall chamber approximately 10 m away from the pump house. The flow then gravitates approximately 20 m to the outfall into the canal via a 600 mm diameter cast iron pipe.

Figure no. 19: Lock 16 PS Outfall

Figure no. 20: Lock 17 PS Outfall

Figure no. 21: Lock 18 PS Outfall – located behind pumping station

Parameter	Description
Pumps & Motors	KSB KRT K250-400/206UG-S
No. & Configuration	1 - Duty Only
Drives	Direct
Local Pipework	250 mm diameter ductile iron in wet well
Rising Main	300 mm diameter cast iron
Controls	Manual only Pump Protection - Low level suction protection and electrical overloads
Communications	N/A

Table no. 13: Additional Lock 16, 17, and 18 PS Summary Technical Details

3.2.2 Key Observations

Based on the site pump performance test data, individual system curves have been derived (Figure no. 22, Figure no. 23, and Figure no. 24).

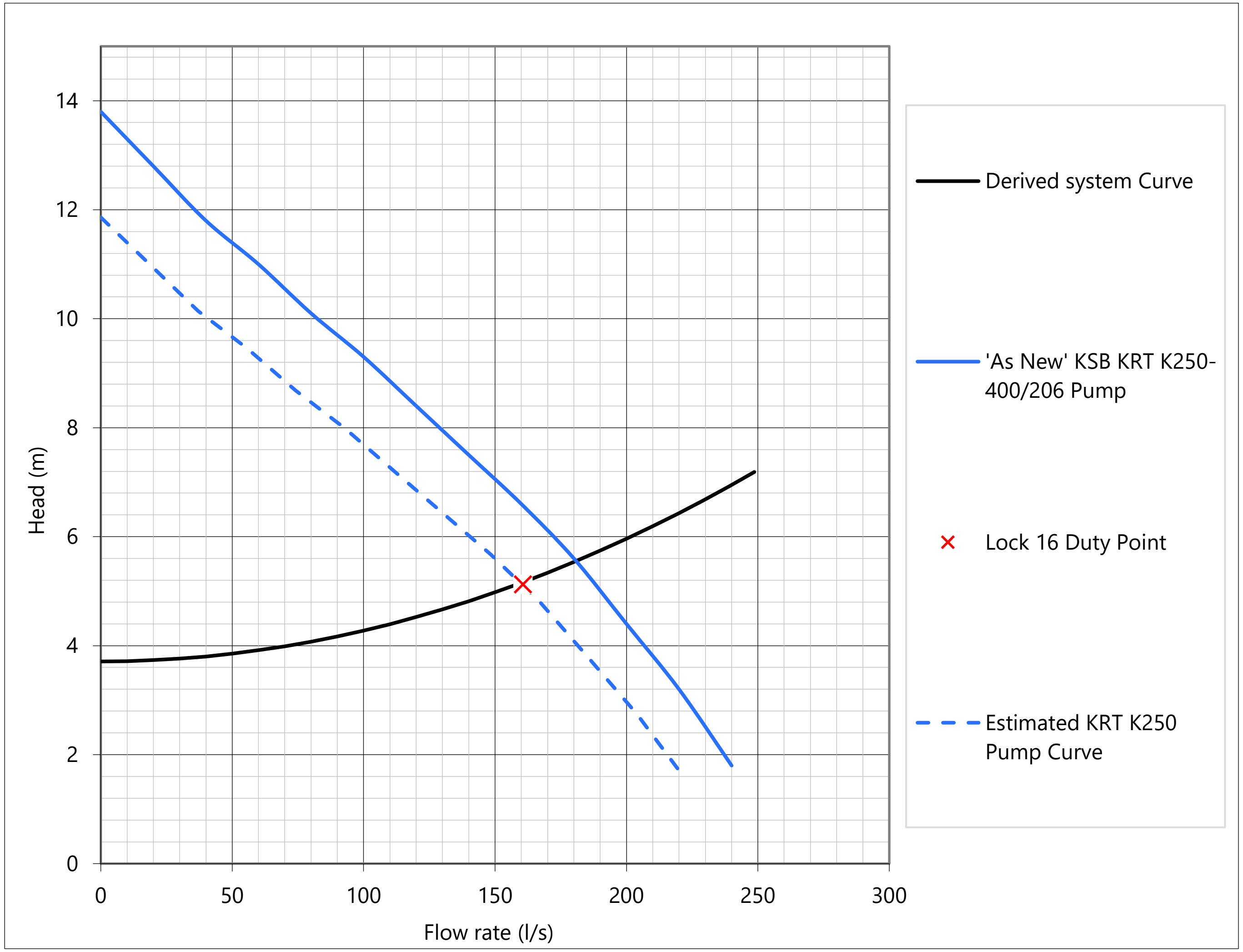


Figure no. 22: Lock 16 PS Derived System Curve

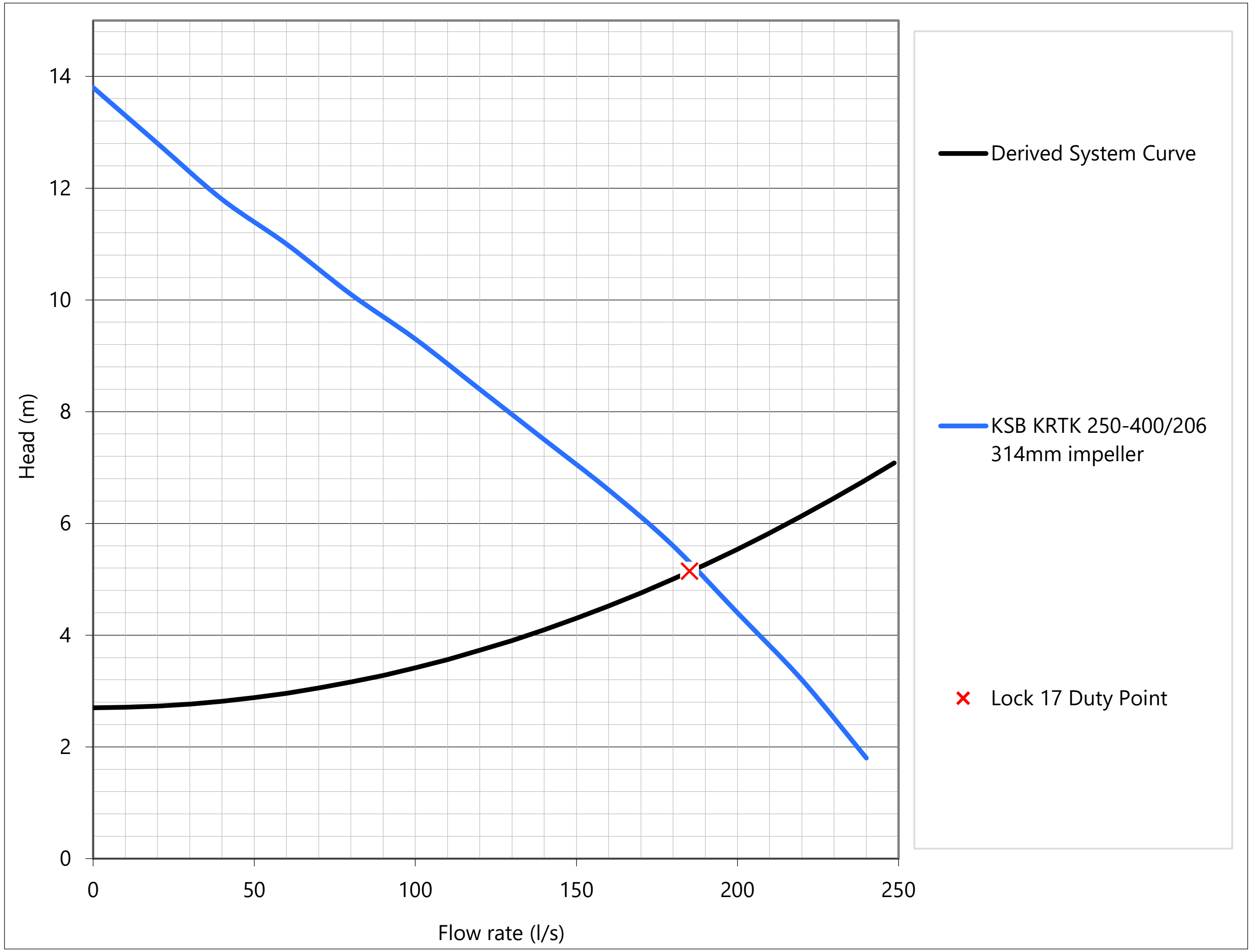


Figure no. 23: Lock 17 PS Derived System Curve

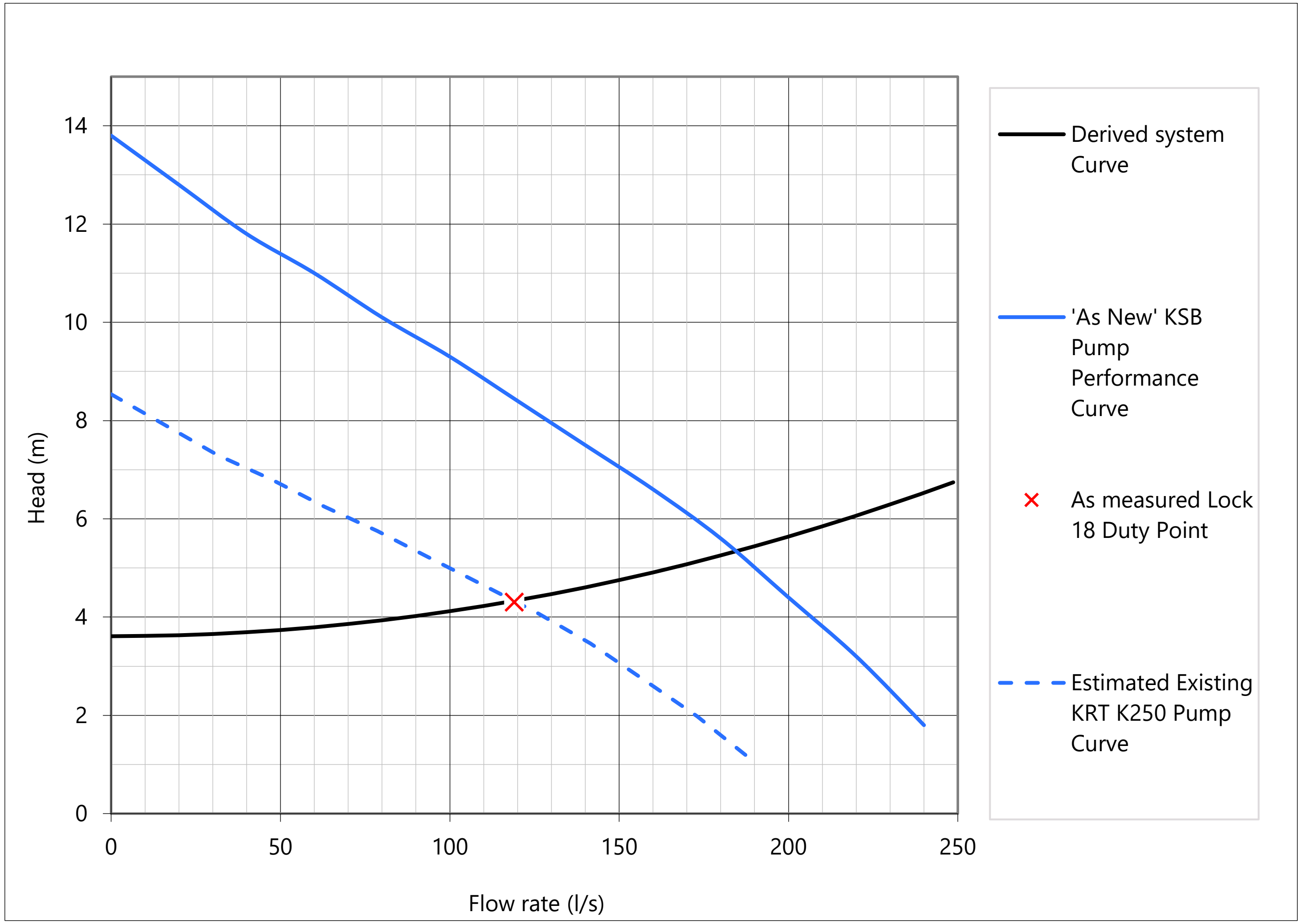


Figure no. 24: Lock 18 PS Derived System Curve

The key observations from the derived system curves are as follows:

a) The pumps at Lock 16 and Lock 18 are significantly operating below the "as new" pump curves provided by KSB. The Lock 17 pump performance is effectively "as new".
b) There could be several reasons for the lower pump performance at Locks 16 and 18, with possibilities including:-
    - Impeller wear or damage.
    - Debris impinging on the impeller or delivery connection (floating vegetation/reeds in the canal were significant). Piles of reeds/vegetation were noticed on the bank at each of the intake screens, which indicates that they are regularly cleared, and that debris is a known issue.
c) During the site audit at Lock 17, there was significant over topping of the upstream lock gate - this was noted as a common occurrence (Figure no. 25). In addition, significant leakage through the lock gate was observed.
d) The measured head for Lock 18 was significantly fluctuating due to a possible issue with the pump. Although averaged over a 20-minute period this fluctuation may be skewing the averaged pressure results and not giving a true representation of the operating pressure of the system.
e) During the site audit at Lock 18, the pump was vibrating significantly.
f) During the site audit at Lock 16, the handrailing to the inlet screens was found to insecure, this was then taped off during the site visit to prevent unsafe access. As such the inlet screens at Lock 16 could not be investigated.

Figure no. 25: Over topping of lock gate at Lock 17

From the measured power, flow recorded, and estimated head based on system curve, an analysis of pumping efficiency and the amount of energy needed to pump flows has been undertaken. Table no. 14 summarises the specific energy findings.

Pumping Station	Measured Flow Rate (l/s)	Measured Power (kW)	Measured Specific Energy (kWh/Ml)	"As new" Specific Energy (kWh/Ml)	Difference (kWh/Ml)
Lock 16	160.6	14.6	25.3	25.1	+0.2
Lock 17	185.2	15.7	23.6	24	-0.4
Lock 18	123.2	13.8	31	24.3	+6.7

Table no. 14: Lock 16, 17 and 18 PS Specific Energy Review

3.2.3 Possible Improvements

A summary of potential solutions/considerations for improvement provided in Table no. 15.

Item or Issue	Potential Improvement Action	Potential Impact on Energy/CO_2
Pump Performance Uncertainty	Investigate the pumps at Lock 16 and 18 for loss of efficiency, potential debris in pump/ motor deficiencies/ etc. A more efficient option of pumping is available by examining the market for alternative pumps. For example, utilising a Xylem NP3171 LT612 may save 3.7 kWh/Ml on paper. At this stage it is suggested that pump replacement is not an immediate priority.	-8%
Instrumentation and Controls	Install level sensors on discharge canal flight. Install magnetic flowmeters on all three pump delivery lines Install threaded process connection on all three pump delivery lines Install a 'smart' pump controller including power metering that can automatically control the pumps using inputs from above instrumentation measurements together with optimised efficient running and callouts.	-5% to -10%
SCADA / Telemetry	Install 'smart' controller (as above) with communication capability and remote data access via GPRS/GSM signal in lieu of more expensive SCADA and telemetry at PS.	
Lock Gates	Investigate the lock gates at Lock 17 for leakage and possible refurbishment.	-2.5 %
Handrails	Rectify the loose handrailing on the inlet screens at Lock 16	N/A

Table no. 15: Lock 16,17 & 18 Grand Canal Potential Solutions

3.3 Shannon Harbour Locks 35 and 36

3.3.1 Description

Two pumping stations are used in a chain to supply water to the Grand Canal from the River Shannon/River Bresna confluence during dry periods to maintain navigable levels.

Figure no. 26: Lock 36 PS on the Grand Canal (Left); Inside Lock 36 PS wet well (Right)

The audit assessment was based upon the following inputs:

- Initial Technical Assessment paper by WI.
- Existing pump datasheet.
- A site audit investigation and pump performance testing by Arcadis and Samatrix in September 2019.

At the site audit, the following parameters were measured in order to derive the system performance for both Lock 35 and Lock 36 pumping stations:

- Power (using Fluke power meter).
- Flow rate (using Panametrics PT878 ultrasonic flow meter).
- Levels and dimensions (laser/tape measure).

No pressure measurement point could be found therefore not undertaken.

Both pumping stations are very similar in layout and construction, and are essentially identical, from a pump hydraulic perspective. Each pumping station comprises one ABS fixed-speed submersible pump. The pumping station intakes are fully submerged and is protected with a 50 mm spaced bar screen within the wet well. A manually operated penstock (sluice gate) is located on the inlet to the chamber as a means of isolation.

The pump discharge pipework is 150 mm nominal diameter (DN150) flanged DI pipe. The DI pipework connects to a 250 mm diameter rising main of unknown material, suspected to be asbestos cement. The discharge points are concealed and not accessible from the surface.

There are no isolation or check valve contained within the pump station. An ultrasonic level probe is located within the wet well and for purposes of pump suction protection. No sustained reverse flow was observed following cessation of pumping.

Figure no. 27: Lock 35 PS on the Grand Canal (Left); Inside Lock 35 PS wet well (Right)

Figure no. 28: Lock 35 PS Outfall

Parameter	Description
Pumps & Motors	ABS AFP 1521 M150 4-32
No. & Configuration	1 - Duty Only
Drives	Fixed Speed Star Delta
Local Pipework	150 mm diameter ductile iron in wet well
Rising Main Length	30 m
Elevation Rise	Measured at 1.8 m between locks
Rising Main	250 mm diameter unknown (possibly AC)
Controls	Manual only Pump Protection - Low level suction protection and electrical overloads
Communications	N/A

Table no. 16: Lock 35 and Lock 36 PS Summary Technical Details

Both pumping stations operate under manual control and run continuously where possible. This is reportedly because of the pumping system being unable to quickly recover levels should the upstream level drop significantly, especially if the boat repair dry dock is in operation.

There are no operational telemetry or SCADA facilities associated with the two pumping stations.

Waterways Ireland are considering a new additional pump station at Lock 34. There are reports of substantial leaks in the system between Lock 31 and Lock 34, therefore increasing pump capacity to 150 l/s is preferred from Lock 36, and in turn Lock 35 if feasible.

3.3.2 Key Observations

Based on the site pump performance test data, system curves have been derived for the single pump operation as there is no common main within this system. As no pressure data or drawings are available the losses have been estimated.

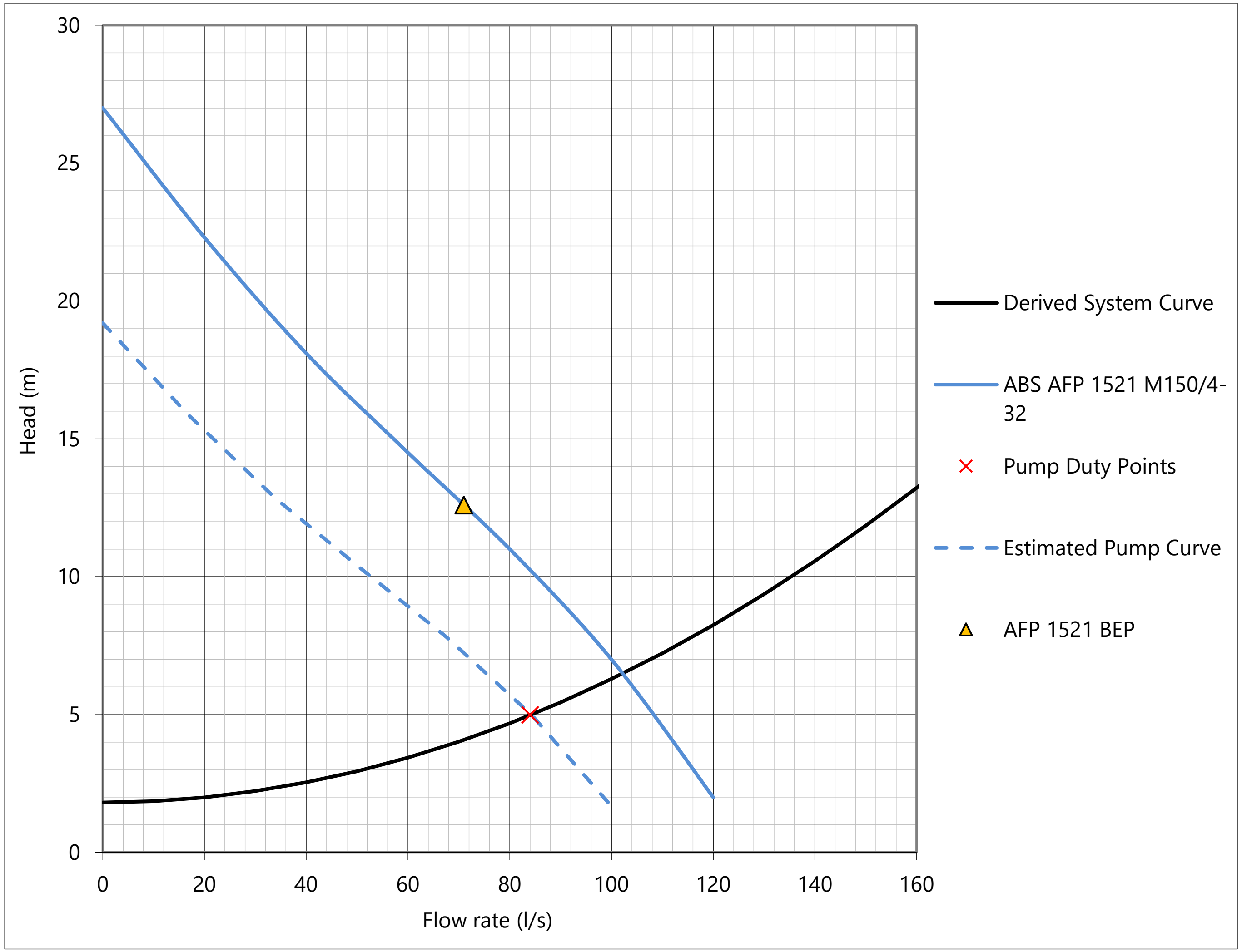


Figure no. 29: Derived System and Pump Curves for Lock 35 Pumping Station

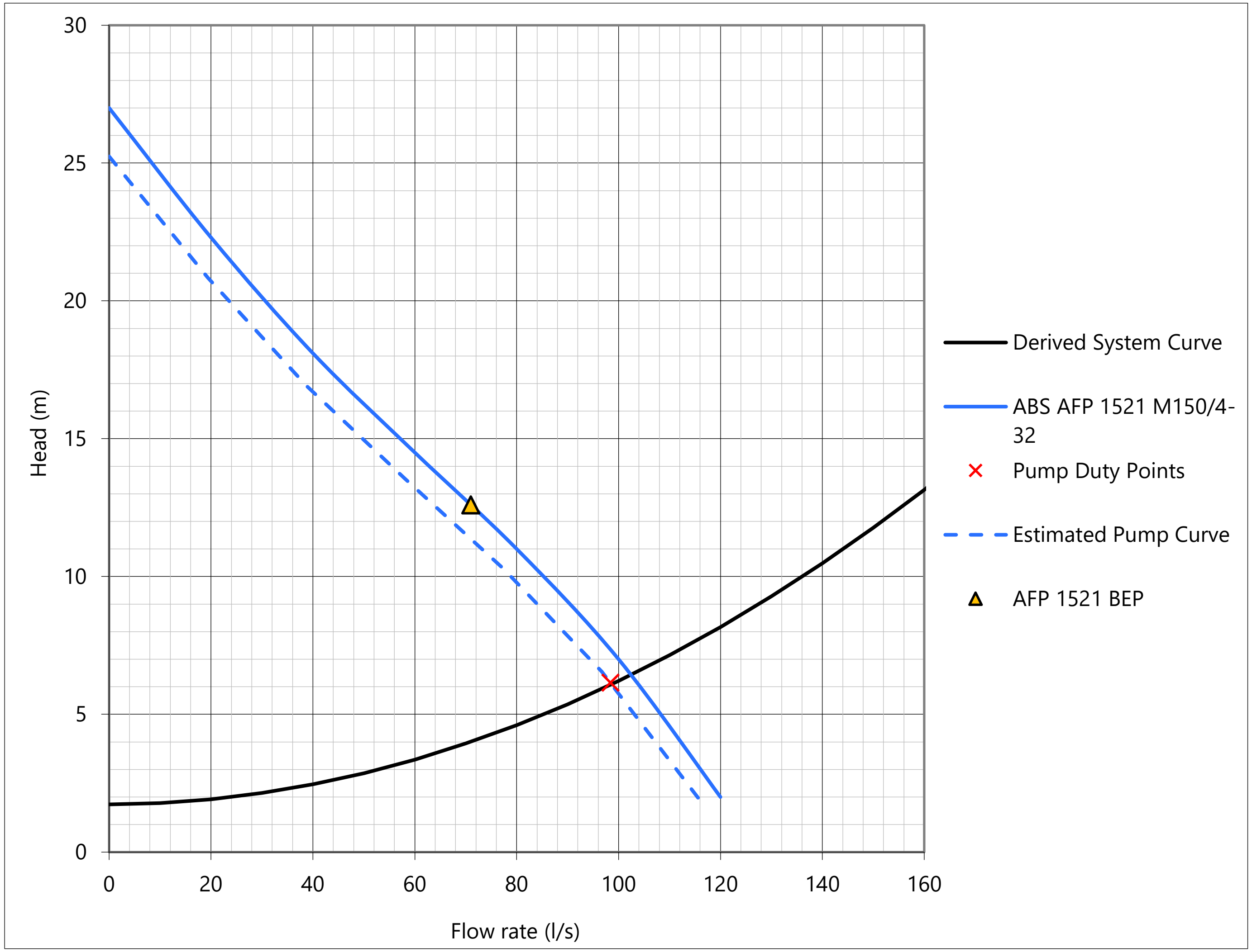


Figure no. 30: Derived System and Pump Curves for Lock 36 Pumping Stations

The key observations from the derived system curves are as follows:

a) Rising Main losses –The pipe roughness was assumed as no pressure data was able to be taken at the pump audit.
b) The ABS 1521 pumps at Lock 35 & 36 are operating well to the right of the BEP (Best Efficiency Point), and outside the recommended preferred operating region. This could lead to a reduced operational life and mechanical issues over time.
c) The performance of the pumps at Lock 35 and Lock 36 appear to be operating below the "as new" system curves provided by ABS. The performance degradation in Lock 36 pump is slight/reasonable. The performance drop-off in the Lock 35 pump. Is more significant.
d) During time of audit, the water level at both Lock 36 and Lock 35 was being maintained above the lock gate, as such there was significant over topping at both gates.

Figure no. 31: Flow overtopping lock gate at Lock 35

At Lock 36 there are reports of pump trip from excessive current. It was reported that the overload relay setting was adjusted to stop this from happening, and it was observed that the ammeter on Lock 36 reads 22 A instead of 27 A as measured by the temporary power meter.

During the site audit at Lock 36, the pipework at ground level could be felt vibrating through the earth during operation. This could be due to the high velocities within the 150 mm sections (4.75 m/s) creating turbulence within the pipework. Alternatively, this could be early indication of something more significant, possibly the beginning of a bearing or seal failure. The high velocities within the 150 mm sections of both Lock 35 & 36 created approximately 2.5 m of losses.

From the audit derived data, the calculated specific energy of the existing pumps has 45 kWh/Ml and 50.6 kWh/Ml for Locks 36 and 35 respectively. Both calculated values are significantly higher than 38.4 kWh/Ml for an "as new" pump.

Based on the 2017 power consumption of 286,748 kWh (costing €39,908), an estimated pumped volume of 2,750 Ml has been derived, equivalent to approximately 11-months continual pumping. This is consistent with site reported account from the Lock keeper.

3.3.3 Possible Improvements

To achieve 150 l/s, pump selections using a 250 mm diameter (DN250) outlet connection and wet well riser pipework have been investigated. Both Xylem and Sulzer (ABS) manufacturer options have been considered for the purposes of the investigation and their predicted performance is shown in Table no. 17.

Selection	**Flow Rate (l/s)**	**Pressure (m)**	**Input Power (kW)**	**Pump and Motor Efficiency (%)**	**Estimated Specific Energy (kWh/Ml)**
Sulzer (ABS) XFP 250J-CB2	142	3.77	8.1	64.5	15.9
Xylem NP3153 LT 321 252mm	151.6	4.05	9	67.2	16.4

Table no. 17: Alternative pump selections for Lock 35 and Lock 36 Pumping Stations

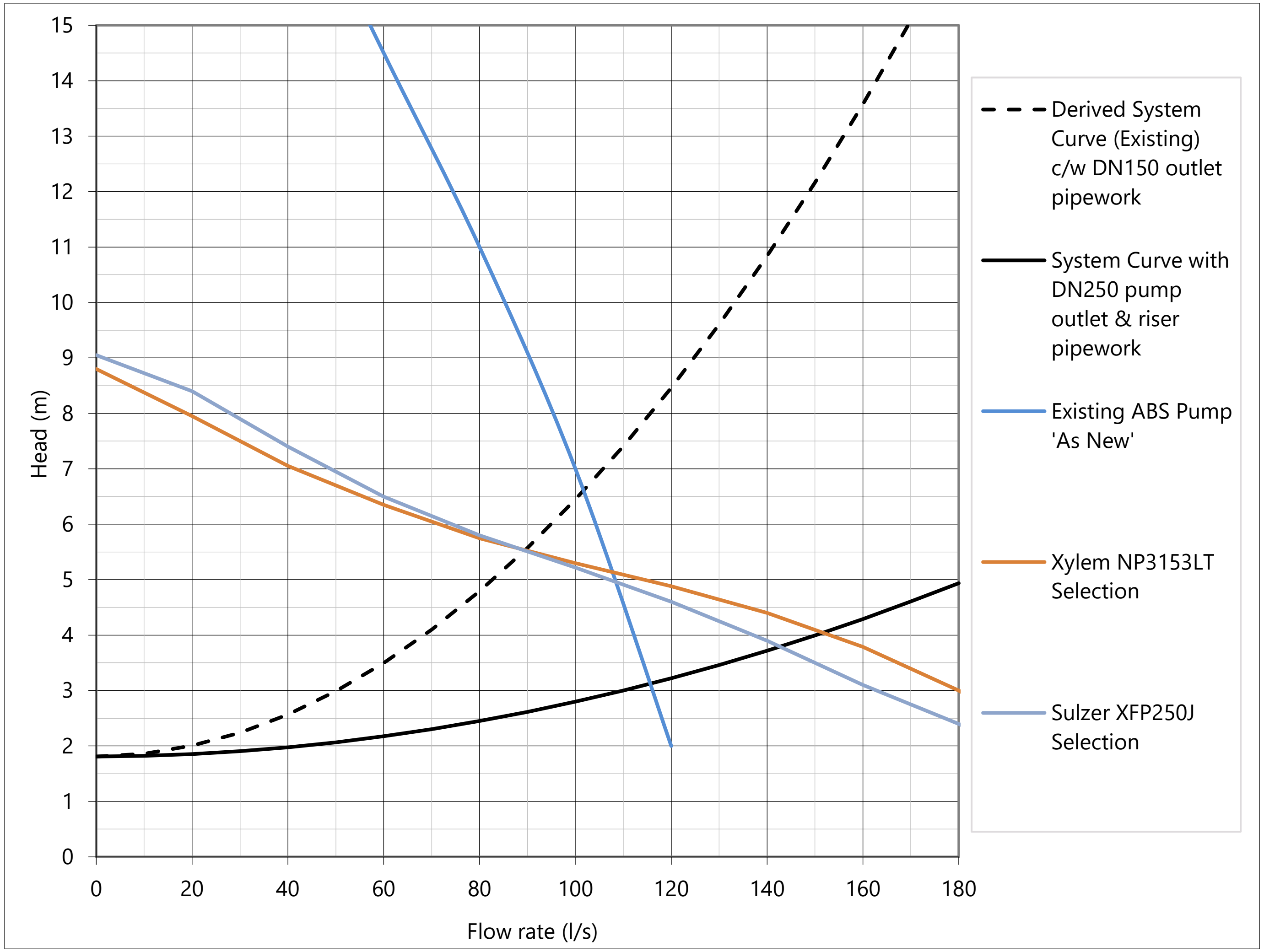


Figure no. 32: Amended system curve and pump selection based on new DN250 outlet and riser pipework (replacing existing DN150) – Lock 35/36 PS

A summary of potential solutions/considerations for improvement provided in Table no. 18.

Item or Issue	Potential Improvement Action	Potential Impact on Energy/CO_2
Pump Performance	SHORT TERM - Check the existing pumps, notably Lock 35, for signs of blockage, impeller damage, and impeller to bottom plate gap, adjusting as necessary. Temporary testing an alternative pump with a known performance curve would help ascertain the system requirements so that a permanent pump selection can be made with further confidence. Replace pumps with DN250 outlet alternative as per highlighted Xylem / Sulzer performance and non-clog impellers and sized for 150 l/s duty flow rate. Replace existing DN150 pipework with DN250 pipework to reduce piping pressure losses	-40 %
Instrumentation and Controls	Install level sensors on discharge canal flight. Install magnetic flowmeter on pump delivery lines Install threaded process connection on pump delivery lines Install a 'smart' pump controller including power metering that can automatically control the pumps using inputs from above instrumentation measurements together with optimised efficient running and callouts.	-30 %
SCADA / Telemetry	Install 'smart' controller (as above) with communication capability and remote data access via GPRS/GSM signal in lieu of more expensive SCADA and telemetry at PS.	
Lock Gates	Investigate the lock gates at Lock 17 for leakage and possible refurbishment.	-2.5 %
Asset Data Information	Conduct a design survey, possibly point cloud survey, and outline design of the existing wet well to confirm the feasibility of accommodating larger DN250 pipework and pumps.	

Table no. 18: Shannon Harbour Potential Solutions

3.4 Richmond Harbour Pumping Station

3.4.1 Description

Richmond Harbour is located near Cloondara, County Clondra. The pump house is the first in a chain of pumping stations along the Royal Canal designed to maintain an upstream level within the canal from the River Camlin.

The energy consumed in 2016 was 78,554 kWh.

Figure no. 33: Richmond Harbour PS (Left); Richmond Harbour PS Outfall (Right)

There is no historic performance data or drawings available for Richmond Harbour. A site visit and was undertaken in September 2019.

The following parameters measured at the site visit:

- Power (using Fluke power meter).
- Levels and dimensions (laser/tape measure).
- Due to the constraints of site, the flow rate and pressure were unable to be measured at the time of audit.

Richmond Harbour comprises one KSB PLZ300, fixed-speed axial flow pump which was installed in 1968. The pump station intake is direct from the River Camlin via a concrete intake culvert. The intake is fully submerged and is protected with a 100 mm spaced bar screen. Electrode level probes are located within the wet well and operate for low level protection.

The pump discharge pipework is PN16 DN300 cast iron and includes a gate isolation valve complete with pedestal. The pipework is located below ground level and can be accessed by a 500 mm x 1000 mm inspection hatch located on the pump house floor.

The rising main discharges directly into Richmond Harbour; the exact nature of the discharge could not be ascertained as it was submerged, but it is reported to have a flap valve on the exit.

Figure no. 34: Richmond Harbour Existing Pump Nameplates

Parameter	**Description**
Pumps & Motors	KSB PLZ300 – 290 mm impeller
No. & Configuration	1 - Duty Only
Drives	15 kW Fixed Speed Star Delta
Local Pipework	300 mm diameter ductile iron in wet well
Rising Main Length	Estimated at 8 m
Elevation Rise	Measured at 1.7 m between locks
Rising Main	300 mm diameter cast iron
Controls	Manual only Pump Protection - Low level suction protection by electrode type level switch
Communications	N/A

Table no. 19: Richmond Harbour PS Technical Summary

The rising main runs from the pump house to Richmond Harbour and discharges fully submersed via a flap valve. It is reported that there are no other isolation or check valves present on the rising main. The pipeline condition is unknown but there are no reports of bursts arising since construction.

3.4.2 Key Observations

The system curve has been estimated based upon the measurements taken at the site visit and the manufacturers provided pump curve. Due to site constraints the actual flow performance for the existing pump could not be determined.

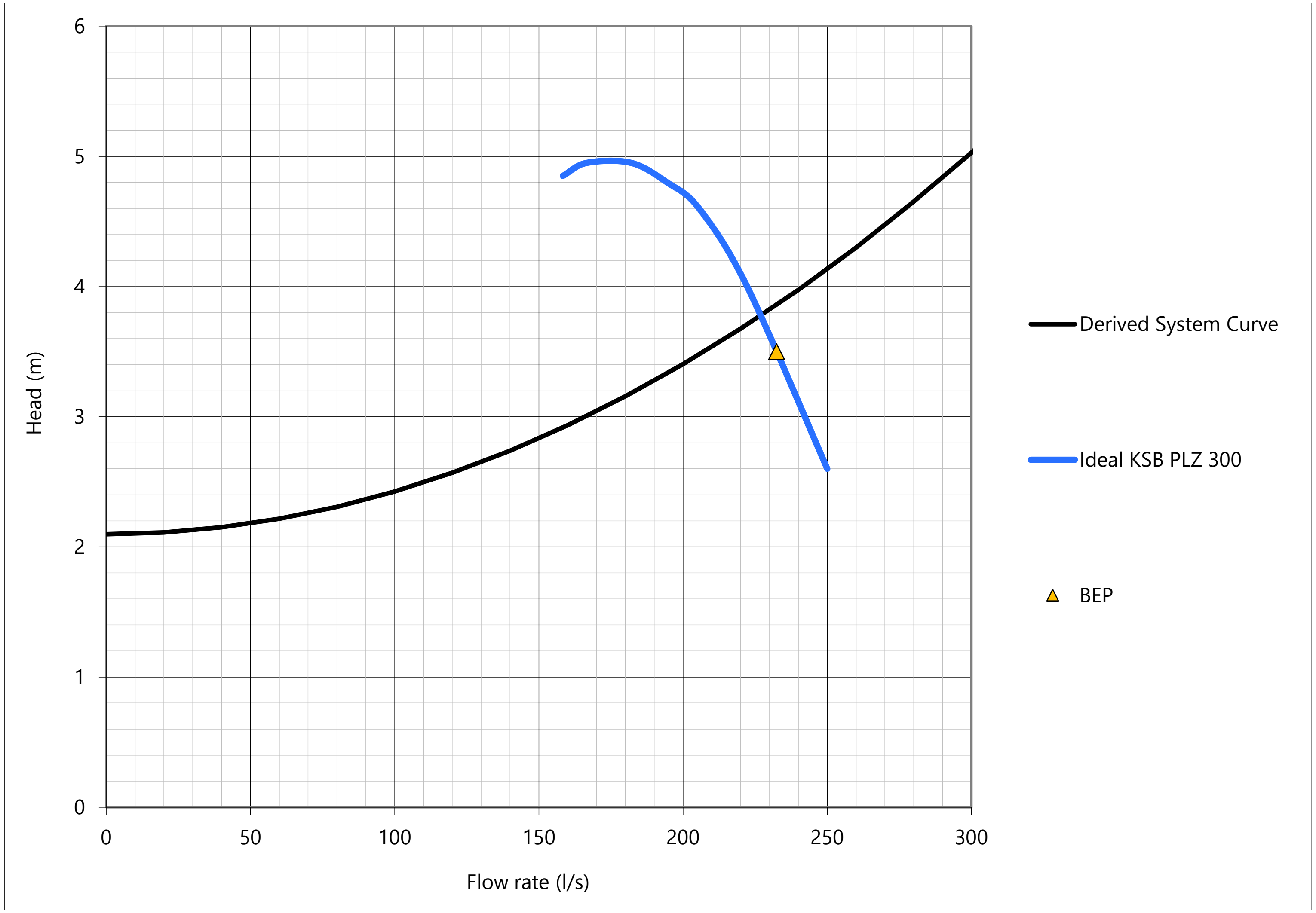


Figure no. 35: Derived System and Pump Curves for Richmond Harbour PS (KSB PLZ300 Pump in Ideal Condition)

The key observations from the visit and derived system curves are as follows:

a) The flow and pressures could not be ascertained on site, but pump "as new" condition is estimated to be capable of delivering a flow rate of 227 l/s with a pump hydraulic efficiency of approximately 74 %.
b) There was a noticeable leak through the stuffing box packing.
c) It was observed that the auto degreasing system had been removed due to repeated failure and the grease was being applied manually.
d) The pump house in its current guise could not accommodate a second pump. It would require substantial civil and structural works to both open the inlet bay to accommodate the additional pump and the pump house would likely need to be extended to maintain good access.

During the pump audit visit by Samatrix Ltd, a temporary "Fluke" power meter was connected at the pump starter compartment to record power into the drive.

Although the power readings were taken at the time, with no flow or pressure measurements it is impossible to ascertain the current performance of the pump. The energy analysis has been made based on the pump matching the factory curve. Given the age and condition of the existing pump, the actual specific energy is likely to be higher.

Pump Configuration	Estimated Flow rate (l/s)	Calculated Head (m)	Measured Power Factor	Required power (kW)	Pump Efficiency (%)	Specific energy (kWh/Ml)
"Al New" PLZ 300 Unit	229	3.8	0.85	13.7	74	16.4

Table no. 20: Richmond Harbour PS Input power, Efficiency and Specific Energy based on manufacturers curve

3.4.3 Possible Improvements

A summary of potential solutions/considerations for improvement provided in Table no. 21.

Item or Issue	Potential Improvement Action	Potential Impact on Energy/CO_2
Pump Performance	Consider like for like replacement with new vertical pump and premium efficiency motor	-11 %
Pumping Station Resilience	Consider design and construction of new wet well pumping station off-line c/w 2no. submersible pumps.	-
Instrumentation and Controls	Install level sensor on discharge canal flight. Install magnetic flowmeter on pump delivery line Install threaded process connection on pump delivery line Install a 'smart' pump controller including power metering that can automatically control the pumps using inputs from above instrumentation measurements together with optimised efficient running and callouts.	TBC (-50 %)
SCADA / Telemetry	Install 'smart' controller (as above) with communication capability and remote data access via GPRS/GSM signal in lieu of more expensive SCADA and telemetry at PS.	
Asset Data Information	Conduct a design survey, possibly point cloud survey of the inlet culvert should be undertaken to determine dimensions and facilitate future works	

Table no. 21: Richmond Harbour Potential Solutions

3.5 Drumleague Pumping Station

3.5.1 Description

Drumleague PS is situated on the Lough Allen Canal, between Deffier and Lustia, Carrick-on-Shannon, County Leitrim. The pumping station is supplementary to Drumshanbo and was made operational as Drumshanbo PS is unable to maintain the level in the Lough Allen canal system. Drumleague PS has only been operating for approximately 12-months and had been out of commission for a period.

A site visit was undertaken in September 2019 and the following parameters measured:

- Power (using Fluke power meter).
- Flow rate (using Panametrics PT878 ultrasonic flow meter).
- Levels and dimensions (laser/tape measure).

Figure no. 36: Drumleague PS

Drumleague PS comprises one Xylem 15 kW, fixed-speed, submersible pump (Model: NP3171.181). The pump is situated at the bottom of a circa 3.5 m deep wet well. No record drawings could be obtained for Drumleague PS and the wet well depth is based upon site measurements of the building and the water level.

The wet well is reported to have a low-level contact probe, but this could not be confirmed at the time of the audit visit. A stilling tube was found within the outfall chamber, but it could not be confirmed whether any instrumentation was present.

Figure no. 37: Drumleague PS Outfall viewed from the Lock (left); Rising Main outfall Farrer 12" flap valve on outlet (Right)

The pump is operated manually in 'hand', with no other instrumentation present (flow meter, pressure transducer, etc.) on the system. It was reported that the pump currently operating at Drumleague had been sat in dry dock for several years before and its condition was unknown.

Parameter	**Description**
Pumps & Motors	Xylem N3171.181– 304 mm impeller
No. & Configuration	1 - Duty Only
Drives	15 kW Fixed Speed Star Delta
Local Pipework	250 mm diameter ductile iron in wet well
Rising Main Length	Estimated at 35 m
Elevation Rise	Measured at 3.25 m between locks
Rising Main	355 mm outside diameter PVC-U
Controls	Manual only Pump Protection - Contact probes for low level protection (unconfirmed)
Communications	N/A

Table no. 22: Drumleague PS Technical Summary

The pump discharge pipework is DN250 ductile iron up to the pump house and connects into a 355 mm OD brown PVC-U rising main. The rising main discharges via a 12" Farrer flap valve into a concrete outfall chamber upstream of the lower Lough Allen Lock. No other isolation valves or check valves could be validated at the time of audit, but reportedly there are none on the system. There are no reports of bursts on this rising main.

3.5.2 Key Observations

3.5.2.1 System Curves

System curves have been derived for the single pump operation. The suction and delivery elevations, pipe roughness values have been based on the site recorded measurements as there is no SCADA system present.

The derived system curve has been estimated based on the manufacturers published pump curve and the power data, as no pressure measurements could be taken at the time of the audit.

The power data obtained from the on-site measurements were recorded as 13 kW during operation, which align with the manufacturer's performance data. However, it is possible that there may be a different pump operating at Drumleague PS creating an alternative system curve, as the nameplate could not be confirmed at the time of the audit.

The derived system curve has a very high loss coefficient to align with the pump curve. (Figure no. 38). This gives the required head for the N3171.181 pump to operate at 50 l/s and at 13 kW.

The key observations from the derived system curves are as follows:

a) Although no pressure data was recorded to definitively confirm, the data would indicate that there is some form of restriction on the line creating a high head loss within the system. The reason for this loss cannot be fully explained with the information known. It is suspected that there is a restriction (equivalent to a 97 mm orifice plate) within the system resulting in a lowering the flow rate from the expected 185 l/s to the recorded 50 l/s.
b) At present, an unknown restriction seems like the most likely scenario but there could be a variety of reasons for this discrepancy/head loss:-
   - Blockage in the rising main caused by debris or a partially collapsed pipe.
   - Unknown partially closed valve on the system that could not be seen during the audit.
   - 12" Flap valve on the outlet could have limited movement creating a restriction.
   - Debris within the pump casing.
   - Pump impeller damage or excessive wear.
   - Alternative pump operating a lower head but drawing a similar power to the 15 kW N3171.181.

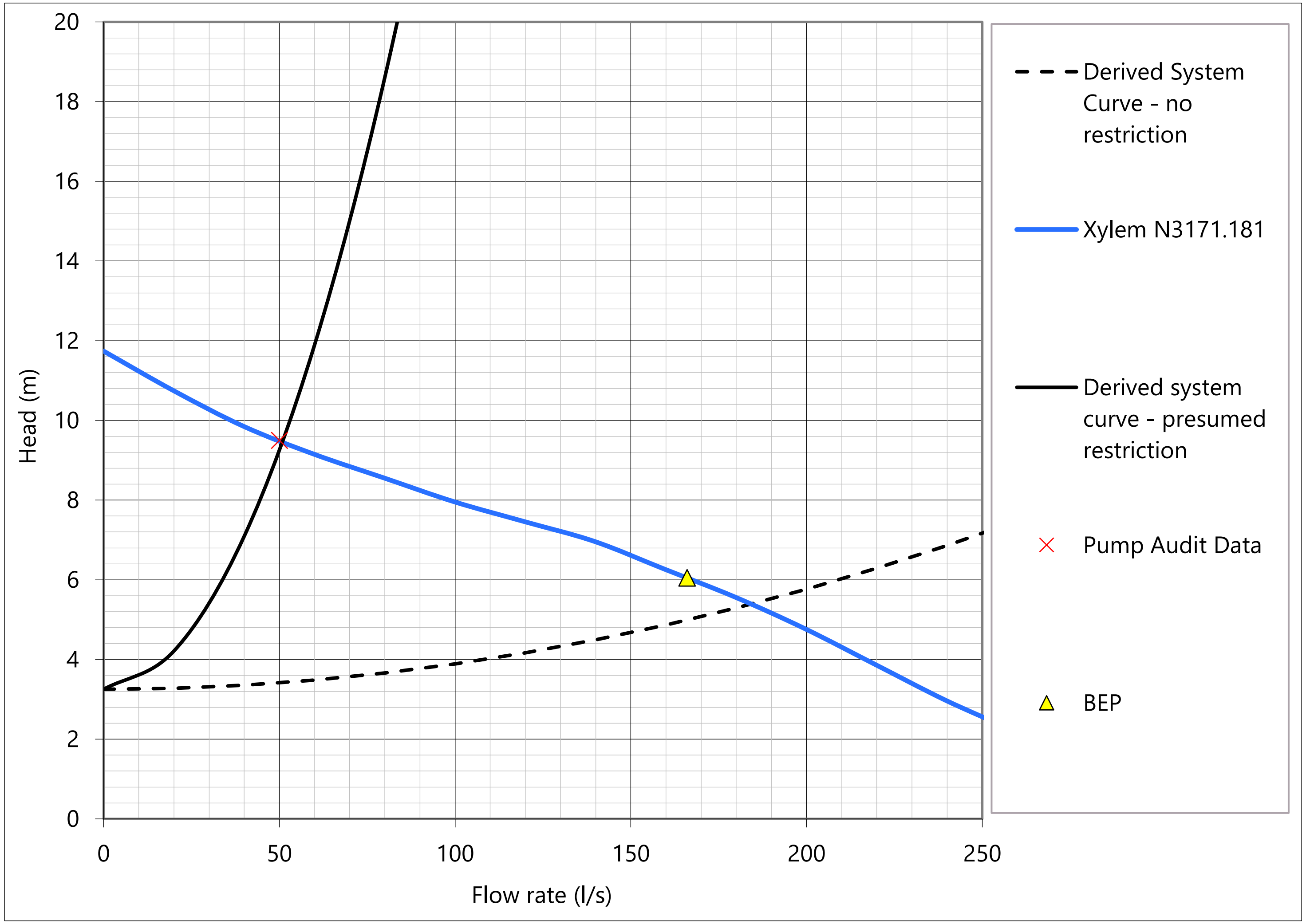


Figure no. 38: Derived System Curves – Drumleague PS

Given the wide discrepancy between estimated (no restriction) and derived head outlined above it is difficult to confirm the actual performance of the pump with confidence. It is possible that the pump is under performing and the head is reduced at the observed flow rate.

From the measured power, flow recorded, and estimated head based on system curve, an analysis of pumping efficiency and the amount of energy needed to pump flows has been undertaken.

Table no. 23 summarises the measured input power, and derived efficiency and specific energy findings.

Pump Configuration	Flow rate (l/s)	Calculated Head (m)	Measured Power Factor	Measured power (kW)	Pump Efficiency (%)	Specific energy (kWh/Ml)
"As New" Unit (c/w Assumed Restriction)	50 (as measured)	9.51	0.79	13.2	35	73.1
"As New" Unit (No Restriction)	185	5.6	0.85	13.2	78.7	19.7

Table no. 23: Input power, Efficiency and Specific Energy

This shows that the pump is currently operating poorly from an efficiency point of view as the duty point lies well to the left of the BEP of the pump and outside the preferred operating region which could reduce the life of the pump and its reliability.

If the head loss can be determined and resolved the current pump would produce approximately 3 times the flow at a significantly lower head. As such, the pump would have a specific energy reduction of approximately 66 %.

As no previous data has been acquired for this site in terms of power and operation, it will difficult to ascertain a precise energy saving potential can be gained without further long-term study.

At present the pump is effectively run manually in "hand" and it is unconfirmed whether there is any form of control, such as an automatic stop from the low-level probes contained within the wet well. This means that the pump is likely to be pumping for periods of time where flow may not be required, and therefore wasting energy.

3.5.3 Possible Improvements

A summary of potential solutions/considerations for improvement provided in Table no. 24.

Item or Issue	Potential Improvement Action	Potential Impact on Energy/CO_2
Pump Performance	Inspect existing pump for any blockage or damage to the impeller. Photograph and record nameplate on pump and motor to confirm pump model. Temporary testing an alternative pump with a known performance curve would help ascertain the system requirements so that a permanent pump selection can be made with further confidence. Review required flow rate in conjunction with Drumshanbo PS and change pump to suit if required.	TBC (-50%)
Rising Main	Inspect the rising main for any potential issues with a camera survey, such as blockage, collapse or partially closed valves. It is also recommended that the Ferrer flap valve is inspected to ensure free movement over the full range of opening.	
Instrumentation and Controls	Install level sensor on discharge canal flight. Install magnetic flowmeter on pump delivery line Install threaded process connection on pump delivery line Install a 'smart' pump controller including power metering that can automatically control the pumps using inputs from above instrumentation measurements together with optimised efficient running and callouts.	TBC (-50 %)
SCADA / Telemetry	Install 'smart' controller (as above) with communication capability and remote data access via GPRS/GSM signal in lieu of more expensive SCADA and telemetry at PS.	
Asset Data Information	Conduct a design survey, possibly point cloud survey of the inlet culvert should be undertaken to determine dimensions and facilitate future works	N/A

Table no. 24: Drumleague PS Potential Solutions

3.6 Drumshanbo Pumping Station

3.6.1 Description

Drumshanbo PS is located just outside Drumshanbo, County Leitrim. The pumping station lifts water from Lough Allen into the Lough Allen canal system to replenish the system during the summer months. Drumshanbo PS is part of a dual lock system. A dual lock allows for the variations in upstream water levels in Lough Allen, as during the winter months the Lough level exceeds the canal level and the lock works in the other direction.

Figure no. 39: Drumshanbo Dual Lock Station

There are no known drawing records. A site audit visit undertaken in September 2019 and the following parameters were measured:

- Power (using Fluke power meter).
- Flow rate (using Panametrics PT878 ultrasonic flow meter).
- Levels and dimensions (laser/tape measure).

Drumshanbo pump station is comprised of one 15 kW, fixed-speed, submersible pump (Model: Xylem NP3171.181) located within a wet well. Drumshanbo does not currently have an ABS HUP 302 pump as reported in the initial pump audit assessment which was recently replaced due to repeated failure. The wet well has a submerged inlet, reportedly with a 50 mm trash screen (unconfirmed at the audit). The low-level protection within the wet well could also not be confirmed.

The pump is operated manually in 'hand', with no other instrumentation present (flow meter, pressure transducer, etc.). Currently, Drumshanbo cannot maintain a sufficient level within the Lough Allen canal system and additional flow is topped up from Drumleague PS.

The pump discharge pipework is DN300 ductile iron up to the pump house and connects into a 315 mm OD PE rising mains encased in concrete. It should be noted that the PE rising main diameter has been estimated as the pipework could not be fully exposed for the pump audit.

Figure no. 40: Drumshanbo PS Wet well– Concrete top covers

Parameter	**Description**
Pumps & Motors	Xylem N3171.181– 304mm impeller
No. & Configuration	1 - Duty Only
Drives	15 kW Fixed Speed Star Delta
Local Pipework	300 mm diameter ductile iron in wet well
Rising Main Length	Estimated at 15 m
Elevation Rise	-0.3 m at time of audit
Rising Main	355 mm outside diameter (PVC-U/HPPE)
Controls	Manual only Pump Protection - unconfirmed
Communications	N/A

Table no. 25: Dumshanbo PS Technical Summary

The 315 mm OD PE rising main is approximately 15 m in length and has a submerged discharge into the canal. The main consists of one Gate valve (cap top) for isolation and a flap valve on the outlet into the Lough Allen canal system to prevent backflow. No other check valves are present within the system.

There are no reports of bursts arising since construction, and no instrumentation could be found at the time of audit relating to the pump station but the wet well itself was not inspected during this audit.

3.6.2 Key Observations

A system curve has been derived from the site measured parameters (Figure no. 41).

The key observations from the derived system curves are as follows:

a) Flow rate – the flow rate is ascertained from the temporary Panametrics flowmeter which requires the exact diameter of the pipework which could not be measured as the pipework was half encased in concrete. In addition, the flowmeter requires a fixed distance between the sensing equipment which due to the constraints of the exposed pipework could not be met. The measured instantaneous flow rate was consistent for the duration of the test.

b) In order to align the site results with the information obtained on the pump curve from Xylem, the performance of the pump curves has been lowered from the manufacturers published performance curves using the affinity laws. Based on the pump audit data, the pump is currently underperforming by approximately 17 %. There could be several reasons for this, with possibilities including:-
   - Increased rising main losses over that derived as pressure data could not be ascertained at the time of testing.
   - Physical defects such as wear on the impeller or partial blockage.
   - Measurement or Data inaccuracies taken from on-site data collection.

During the pump audit visit by Samatrix Ltd, a temporary "Fluke" power meter was connected at each individual pump starter compartment to record power into the star delta drives.

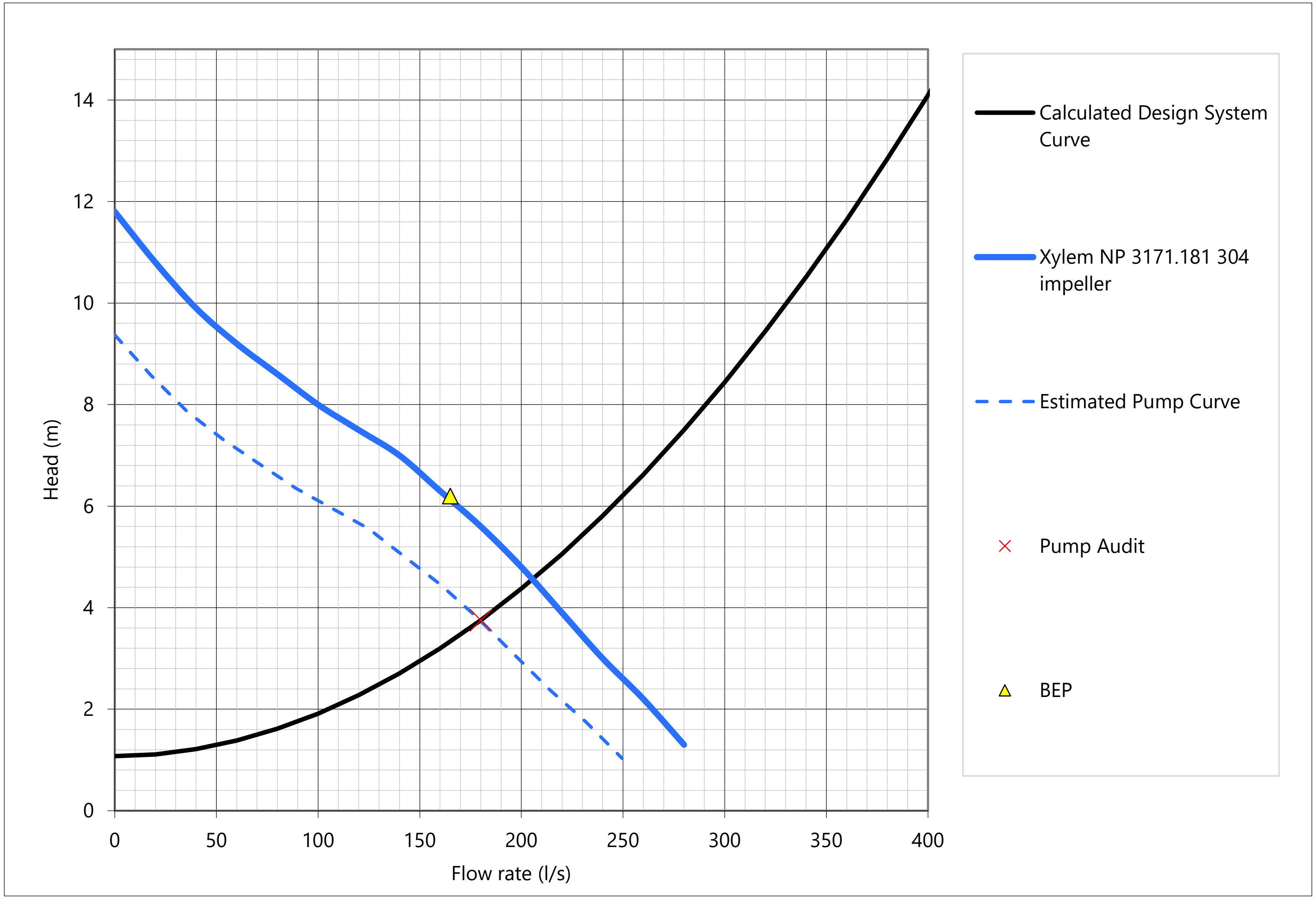


Figure no. 41: Derived System Curve – Drumshanbo PS

From the measured power, flow recorded, and estimated head based on system curve, an analysis of pumping efficiency and the amount of energy needed to pump flows has been undertaken. Table no. 26 summarises the measured input power, and derived efficiency and specific energy findings.

Pump Configuration	Flow rate (l/s)	Calculated Head (m)	Measured Power Factor	Measured power (kW)	Pump Efficiency	Specific energy kWh/ML)
Duty	180	3.7	0.85	17	46	26.3
Ideal unit*	205	4.6	0.86	14	66	18.9
**Ideal unit based on manufacturers published data*						

Table no. 26: Drumshanbo PS Input power, Efficiency and Specific Energy

Table no. 26 indicates that the pump at Drumshanbo is underperforming. There is a difference between the measured power (17 kW) from the fluke meter and the ideal operating power of the pump (14 kW).

As no previous data has been acquired for this site in terms of power and operation, it will difficult to ascertain a precise energy saving potential can be gained without further long-term study.

As the pump shows a drop-in performance when compared to the ideal, it should be investigated to ascertain the reasons behind this. Possible explanations include:

- Debris within the pump casing.
- Damage or wear to impeller.
- Bearing/seal wear within pump unit.

3.6.3 Potential Areas for Improvement

A summary of potential solutions/considerations for improvement provided in Table no. 27.

Item or Issue	Potential Improvement Action	Potential Impact on Energy/CO_2
Pump Performance	Inspect existing pump for any blockage or damage to the impeller. Photograph and record nameplate on pump and motor to confirm pump model. Replace if damaged. Temporary testing an alternative pump with a known performance curve would help ascertain the system requirements so that a permanent pump selection can be made with further confidence. Review required flow rate in conjunction with Drumleague PS and change pump to suit if required.	-26 %
Pump Drives	Provide premium efficiency motor (IE3) if pump replaced	-2 %
Pumping Station Resilience	Survey wet well and consider modification with an additional pump, commencing with feasibility study. Consider box spare pump as lower cost (and less resilient) alternative option.	N/A
Rising Main	Inspect the rising main for any potential issues with a camera survey, such as blockage, collapse or partially closed valves. It is also recommended that the Ferrer flap valve is inspected to ensure free movement over the full range of opening.	TBC
Instrumentation and Controls	Install level sensor on discharge canal flight. Install magnetic flowmeter on pump delivery line Install threaded process connection on pump delivery line Install a 'smart' pump controller including power metering that can automatically control the pumps using inputs from above instrumentation measurements together with optimised efficient running and callouts.	TBC (-50 %)
SCADA / Telemetry	Install 'smart' controller (as above) with communication capability and remote data access via GPRS/GSM signal in lieu of more expensive SCADA and telemetry at PS.	
Asset Data Information	Conduct a design survey, possibly point cloud survey of the inlet culvert should be undertaken to determine dimensions and facilitate future works	N/A

Table no. 27: Drumshanbo PS Potential Solutions

4 Voies Navigables de France Audit Findings

4.1 Crissey Pumping Station

4.1.1 Description

The audit assessment was based upon the following inputs:

- Desktop study review.
- Data provided by Voies Navigables de France (VNF) via the Green WIN intranet site.

Figure no. 42: Crissey Lock Pumping Station

Crissey PS was built in 1960s and is located at the eastern end of the Canal du Center, at the junction with the Saône. The canal is supplied with water by the reserve ponds located around Le Creusot (between Montchanin and Montceau-les-Mines), and by the Dheune (which runs along the Mediterranean side between Chagny and Montchanin).

The pumping station is currently designed to allow water to be raised from the Saône to the forebay (towards Reach 34-34 bis) in order to make river navigation possible, but the pumps are out of service.

Crissey PS comprises two Rateau type ID BV 57 pumps each located on either side of the lock, with Pump 1 positioned on the Chalon side and Pump 2 is positioned on the Crissey side. The pumping system was previously controlled manually using push buttons from control consoles located in the upper room and in the control room.

Pump 1 has a downstream pressure gauge and Pump 2 has both upstream and downstream pressure gauges, but these provide local indication only. An ultrasonic level sensor is also provided to measure the level of the forebay; however, this is not used for pump control.

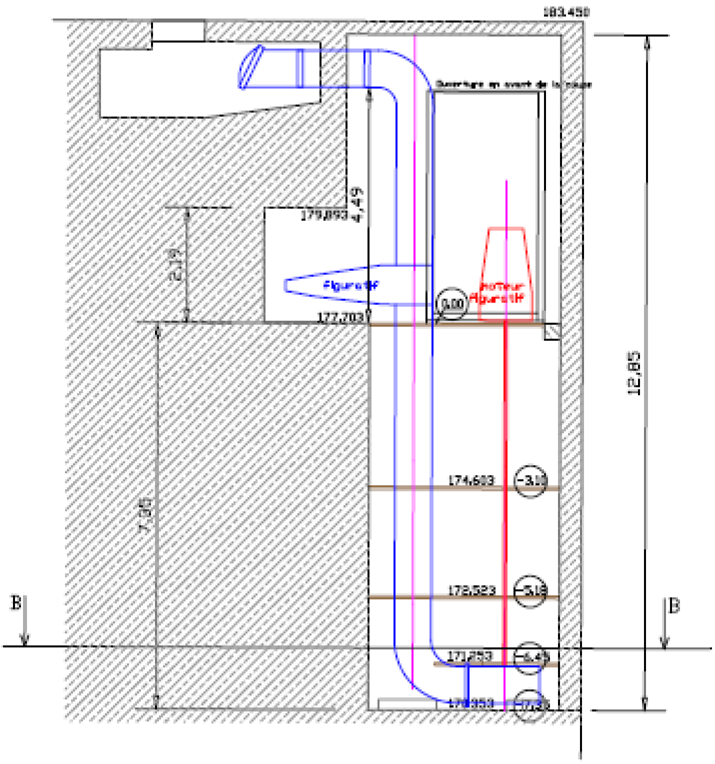


Figure no. 43: Existing Pump Arrangement

Parameter	Description
Pumps & Motors	Rateau ID BV 57 pumps with 162 kW Normacem VBPZ 178 d motors
No. & Configuration	2 (Duty / Standby)
Drives	Star delta
Local Pipework	700 mm
Rising Main Length	13 m (approx.)
Elevation Rise	11.1 m maximum water height
Rising Main	Material unknown (no data) – assumed mild steel
Controls	Manual via pushbuttons on control console
Communications	-

Table no. 28: Crissey PS Summary Technical Details

It is understood that VNF have current proposals for the pumps to be controlled using two upstream level sensors at two separate locations on the canal.

The automation of the pumping system is carried out via the Automate Programmable Industriel (API), i.e. the industrial programmable controller, and the operating range can be adjusted from the HMI. When the level falls below the low-level value (level to be determined), the sectioning valve fully opens.

The operation of the pump continues (and is controlled) until the level passes beyond the high level of the sensor. If the far upstream level measurement is not available, the immediate upstream level measurement is used; if no measurement is available, then automatic control of the pumping system is not possible and a low emergency alarm is sent.

4.1.2 Key Observations

4.1.2.1 Pump/System Curve and Hydraulics

The level of River Saône can vary by up to six metres (Figure no. 44). This impacts on the performance of a fixed speed centrifugal pump, where there is varying relationship for lift and efficiency, against flow rate.

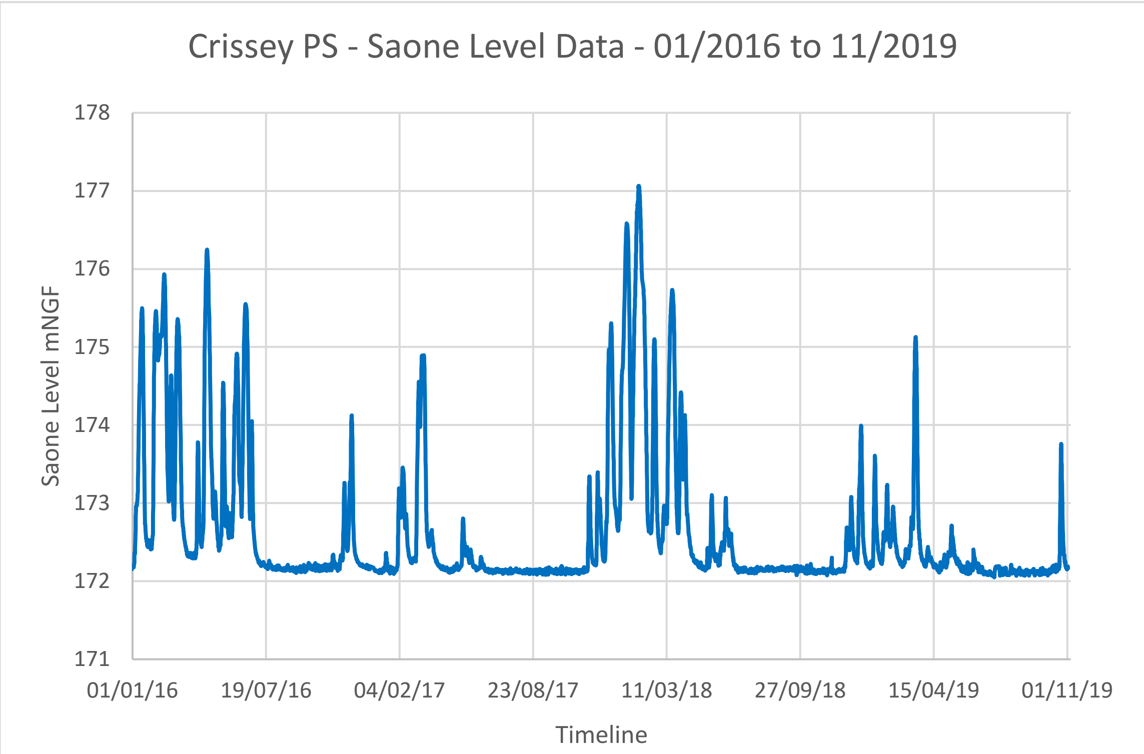


Figure no. 44: River Saône Levels over time (2016 to 2019)

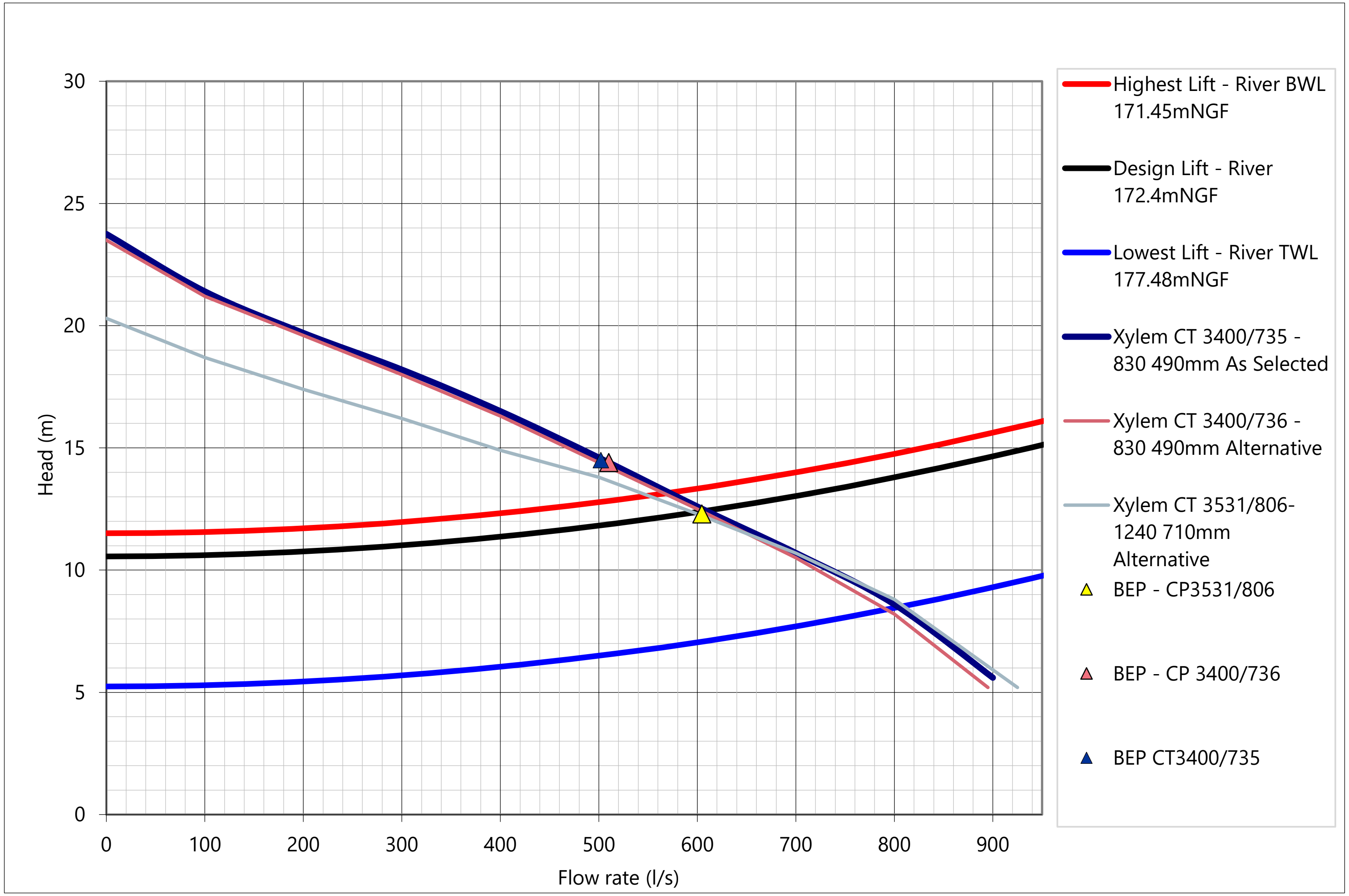


Figure no. 45: Derived System Curves with Tabled and Alternative Xylem Selections at Design Head

Based on the data provided, a system curve has been derived for single pump operation, incorporating the Xylem advised selection of a CT3400/735 ~830 490 mm impeller pump. The results of the Arcadis review indicate that Xylem have further alternative pump selections which achieve similar performance.

From the system curve (Figure no. 45), the pumped flows would reach approximately 800 l/s at minimum lift condition (high river level) under a fixed speed drive arrangement. However, this would not cause any issues with the pump itself.

Although energy savings could be achieved using VSDs at higher River Saône levels, installing a VSD is not essential given the relative infrequency of high river levels and would likely have an excessively long investment return period.

4.1.2.2 Operation and Control

In the future situation, a pump is required with a nominal flow of 0.6 m^3/s and an automated gate valve. The pump and gate valve will need to be controlled from the control desk based upon signals from the upstream level measurement system.

4.1.3 Possible Improvements

- Install the current VNF proposed pump selection, a Xylem CT3400.
- Continue with proposal for fixed speed drives.
- Introduce an automated control system based on downstream (and upstream) level monitoring, including consideration of 'smart' controllers.
- Introduce performance metric reporting and possible smart control adjustment.

4.2 Briare Pumping Station

4.2.1 Description

Briare PS is equipped with six pumps although it operates with only two pumps for most of the time and up to three if necessary.

The project considerations for this pumping station for implementation 2020 are as follows:

- Automation, supervision and telecontrol of pumping operations.
- Optimising of operations time periods.
- Implementing at least one new pump.
- Motor IE3 or IE4 energy performance, VSD.
- Smart water and energy monitoring.

Arcadis' Phase 1 assessment was a desktop study review based upon the data provided by VNF via the Green WIN intranet site.

Parameter	Description
Pump	Xylem (Flygt) CP3231 / 705 with 53-455 performance curve; 435 mm impeller
No. of Pumps	6
Duty Configuration	Duty / Duty / Assist + 3 Standby units assumed
Rated Motor Output	170 kW; IE2 Motor
Drives	Fixed Speed (assumed star-delta)
Pipework in Pumping Station	300 mm diameter branch into 750 mm diameter manifold (3 pumps)
Rising Mains	Twin 900 mm diameter (Unconfirmed Material)
Rising Main Length	2650 m
Elevation Rise	Approx. 43 m

Table no. 29: Briare PS Technical Summary

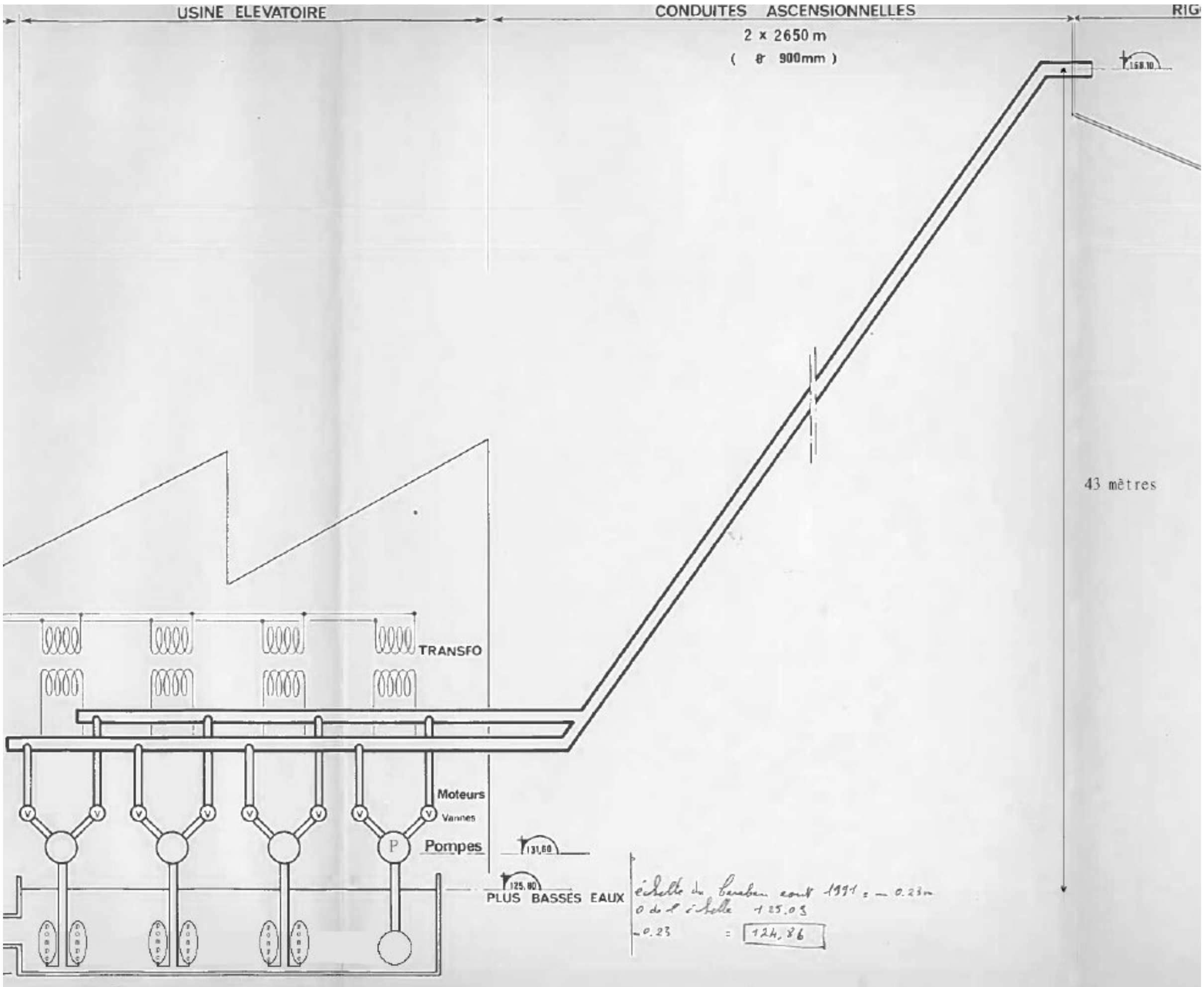


Figure no. 46: Briare PS System Schematic and Elevations

4.2.2 Key Observations

4.2.2.1 System Curve

The derived system curves are shown in Figure no. 47.

The key observations from the derived system curves is that the existing pump selection provides a very good correlation with VNF's own technical assessment. The pump is also available with an IE3 premium efficiency motor option.

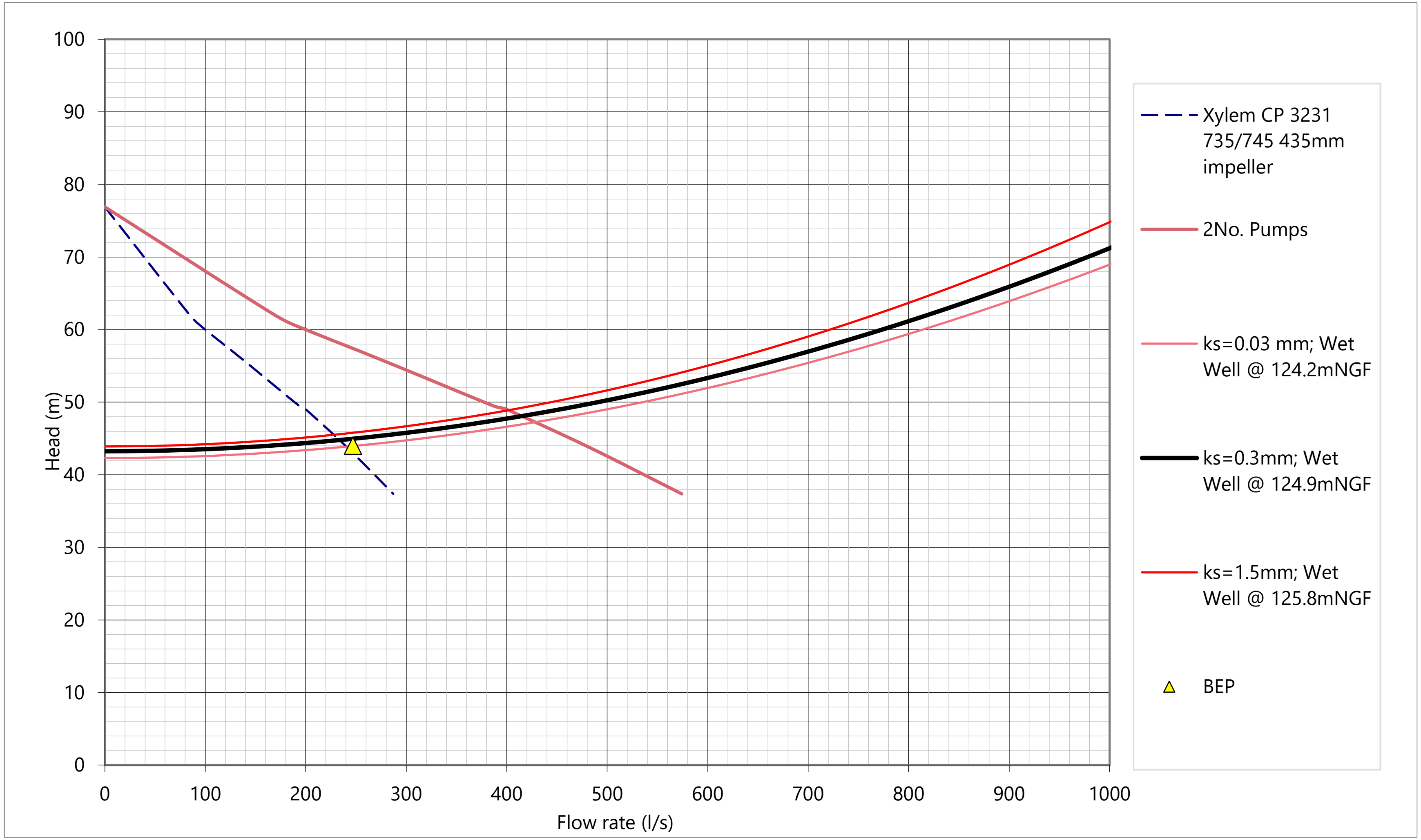


Figure no. 47: Derived System Curves for 2-Pump Operation at Briare PS

4.2.2.2 Energy Assessment

Energy consumption reports from EDF from 2017 and 2018 were reviewed for this study.

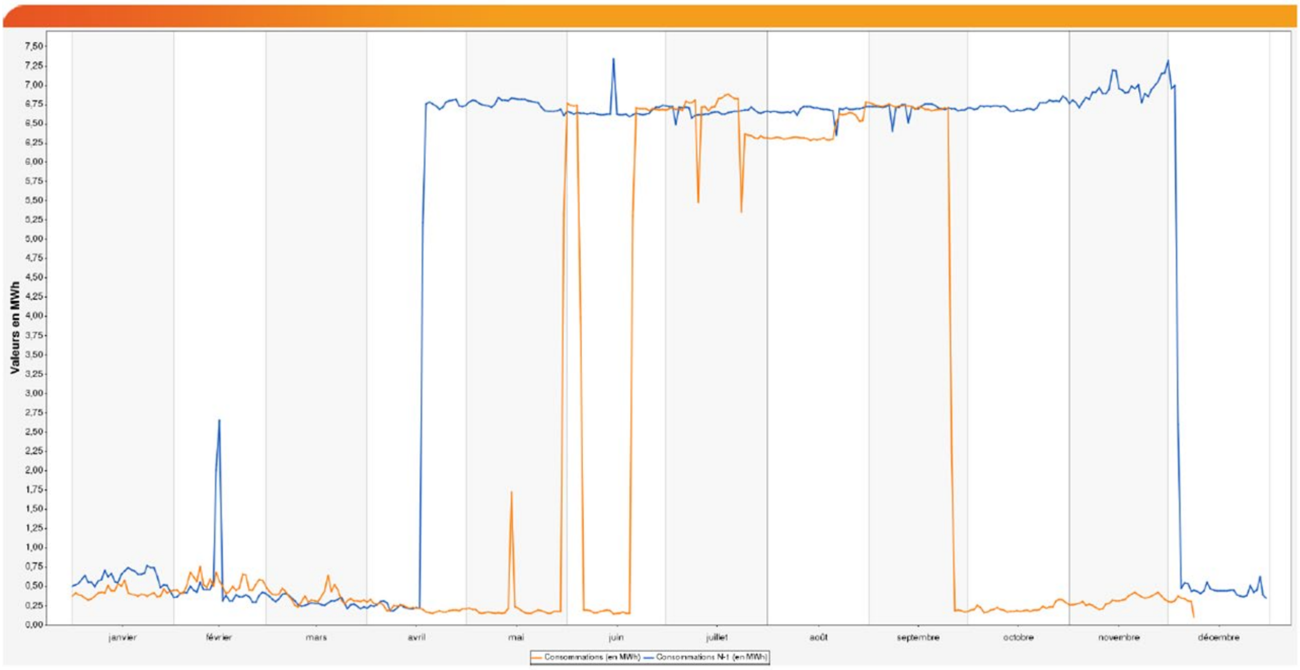


Figure no. 48: Briare PS Energy Consumption 2017 (Blue) and 2018 (Orange)

Based on the EDF reports, Arcadis have estimated a base load of approximately 10 kW during the summer months and 20 kW during the winter months, which is assumed to be from building services for the pumping station (e.g. heating, lighting, panels, etc.).

The typical loads during the summer months reflect a load of approximately 280 kW. Taking off the base load leaves a pumping load of approximately 270 kW. From the system curve and Xylem data review, this aligns with the predicted load for two running pumps of 265 kW and reflects the operational description provided by VNF.

As no flow measurement have been undertaken, VNF have estimated the cost of pumping at 222 kWh/Ml which is based upon pump running time and assigning an arbitrary 200 l/s per pump. It also does not consider any supplementary loads.

From initial calculations, the estimated specific energy of pumping with two or three existing pumps is 174 kWh/Ml. Using an IE3 motor on one pump is anticipated to reduce this to 172 kWh/Ml.

Arcadis has investigated the impact of a variable speed drive. Figure no. 49 shows the anticipated performance for a single pump operation.

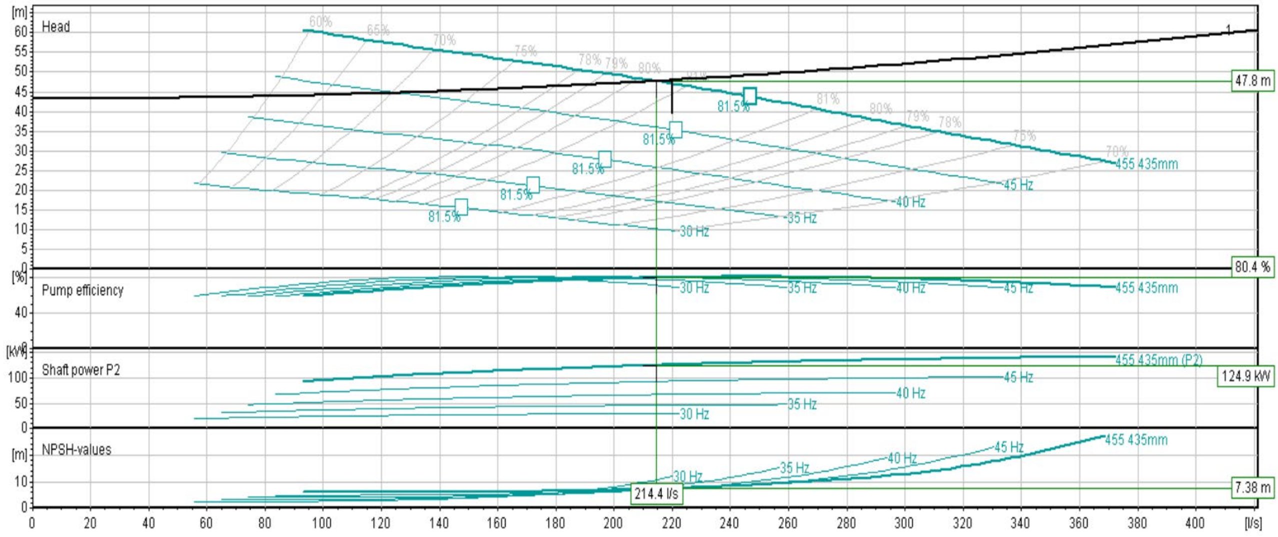


Figure no. 49: Briare PS 1-pump operation performance curves with VSD

As it can be seen from Figure no. 49, the pump efficiency would reduce with speed reduction as its BEP moves further away from duty point. With VSD losses also to consider, the specific energy would increase with operation at a reduced speed.

4.2.3 Possible Improvements

- Undertake on site flow and pressure monitoring assessment to determine actual system characteristics.
- Assuming curves are as expected, select Xylem CP3231 pump model as proposed and consider use of an IE3 motor for new pumps.
- Continue with fixed speed drives.
- Introduce an automated control system based on downstream (and upstream) level monitoring, including consideration of 'smart' controllers.
- Introduce performance metric reporting and possible smart control adjustment.

4.3 Stock Pumping Station

4.3.1 Description

Stock PS is located on the east bank of the Stock Pond and is vital for the water supply of the Marne to the Rhine Canal and the Saar Canal. It is equipped with four pumps and allows the transfer of water to raise the level of the pond towards the canal in order to feed the Vosges sharing bay, and thus the Marne to the Rhine Canal, as well to Strasbourg as to Nancy, and the Saar Canal.

Arcadis have undertaken a desktop study review based upon the data provided by VNF via the Green WIN intranet site.

During 2020/21, VNF intend to carry out the following tasks at Stock PS:

- Renewal/Upgrade of pump station equipment.
- Targeted water flow: 0.6 m^3/s (per pump).
- Motor IE3 or IE4 energy performance.
- Smart water and energy monitoring.
- Automation, supervision and telecontrol of pumping station operations.
- Optimisation of operations time periods.

The pumping station is reported to be able to deliver approximately 171,000 m^3 over 24-hours with three pumps operating simultaneously and 230,000 m^3 with four pumps, although only three can be operated at the same time due to electrical restrictions.

The existing pumps appear to be horizontal, axially split, double suction, centrifugal pumps that are long coupled to 110 kW slip ring motors. It is understood that the motors were refurbished in 2003.

Parameter	Description
Pumps & Configuration	Rateau EPB41 (4no. Duty / Duty / Duty / Standby)
Motor	110 kW; IE1 conforming
Drives	Fixed Speed
Pipework	DN500 suction; DN450 discharge (assumed)
Rising Main	200 m length (Cast Iron and Steel)
Pipe Diameter	900 mm

Table no. 30: Stock PS Technical Summary

Each pump discharge pipe is provided with an actuated guillotine valve for isolation. In addition to acting as an isolation / delivery check valve. Each pump suction incorporates a foot valve for backflow prevention and priming assistance.

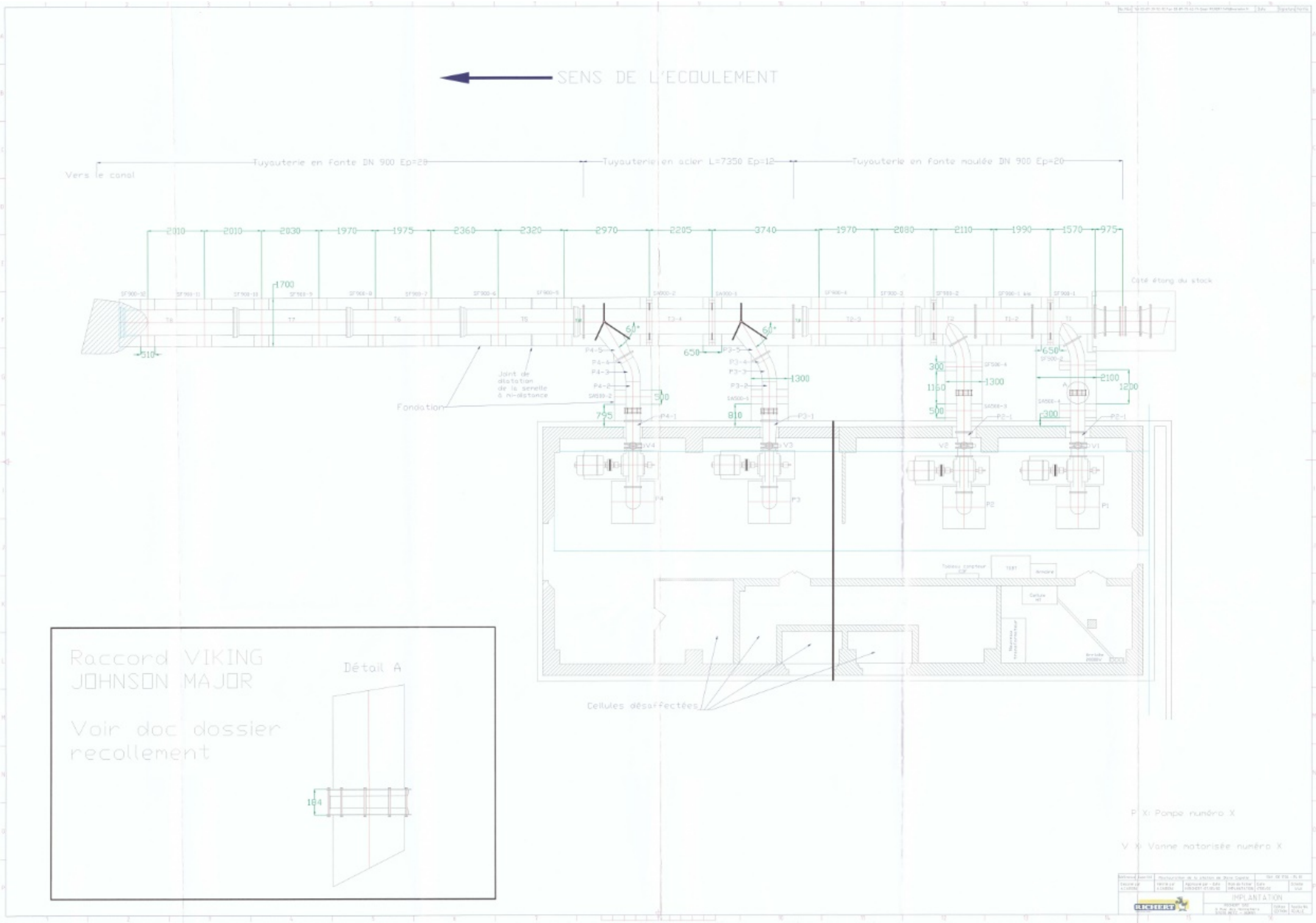


Figure no. 50: Existing Pump Arrangement (Plan) at Stock PS

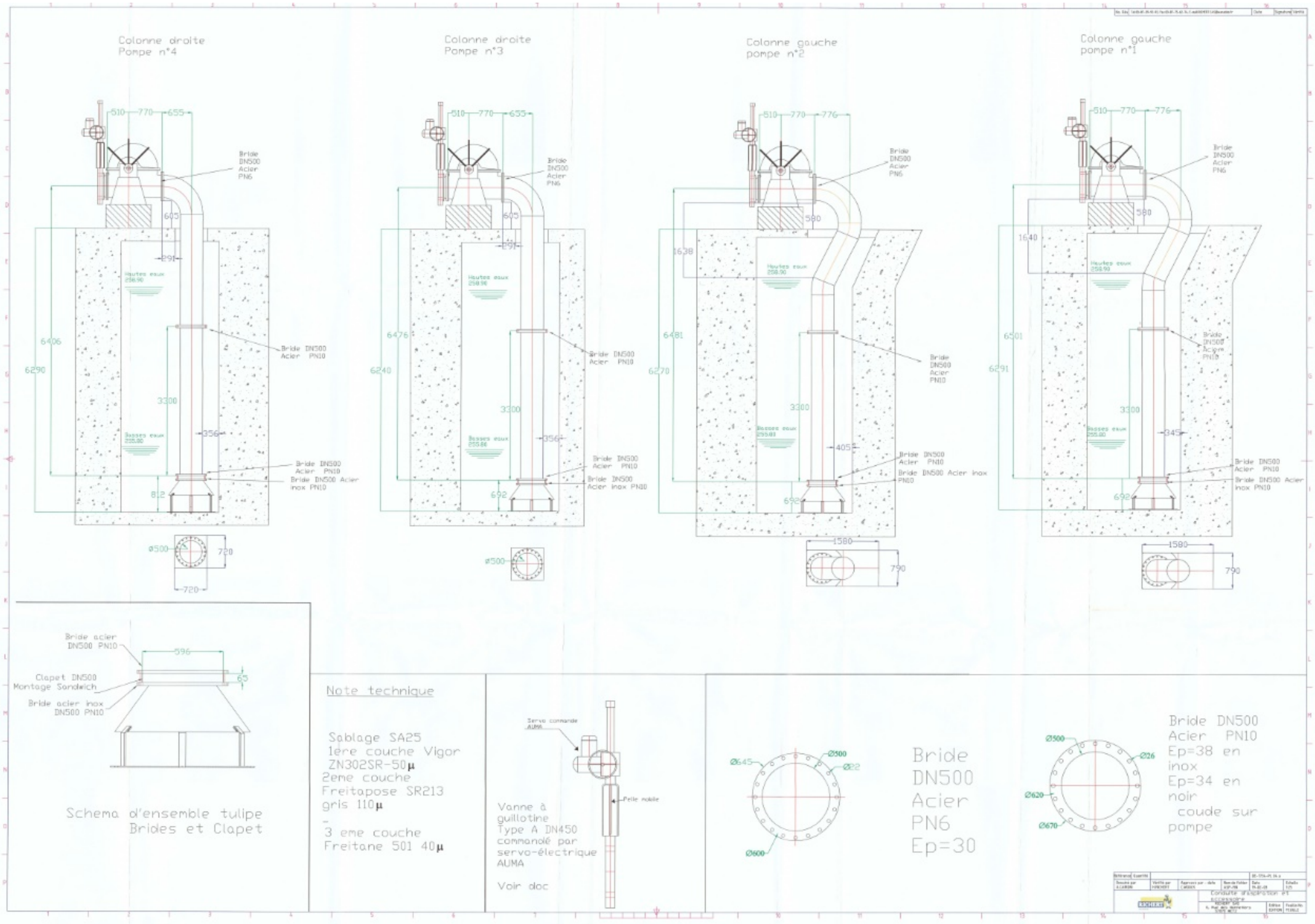


Figure no. 51: Existing Pump Arrangement (Sections) at Stock PS

The pipework is a part-buried, 900 mm diameter cast iron main and allow allows water to both be returned to the canal and to feed the pond. It is provided with a 700 mm diameter guillotine 'percent' valve which regulates the flow of water to the pond, via the opening percentage and the calculated flow. The rising main pipeline is 200 m long of which 120 m is buried.

4.3.2 Key Observations

As no manufacturers or test pump curve data is available, the system and pump curves have been derived by Arcadis from the pumps list and provided reports.

Figure no. 52 indicates that a single pump can deliver a flow rate of between approximately 345 l/s and 430 l/s based on the variation in water levels. With three pumps running in parallel, up to 1170 l/s is possible. At the design lift, a pump duty of approximately 410 l/s at 8.2 m head is suggested. This is less than the required nominal flow rate of 600 l/s.

The arrangement of the existing pumps (pump level above suction well level) requires a means of priming through a dedicated vacuum system.

The regulation of return flows to the pond is achieved via the guillotine 'percent' valve. It may be possible to recover energy using a turbine for this flow regime. There is insufficient information to assess the feasibility.

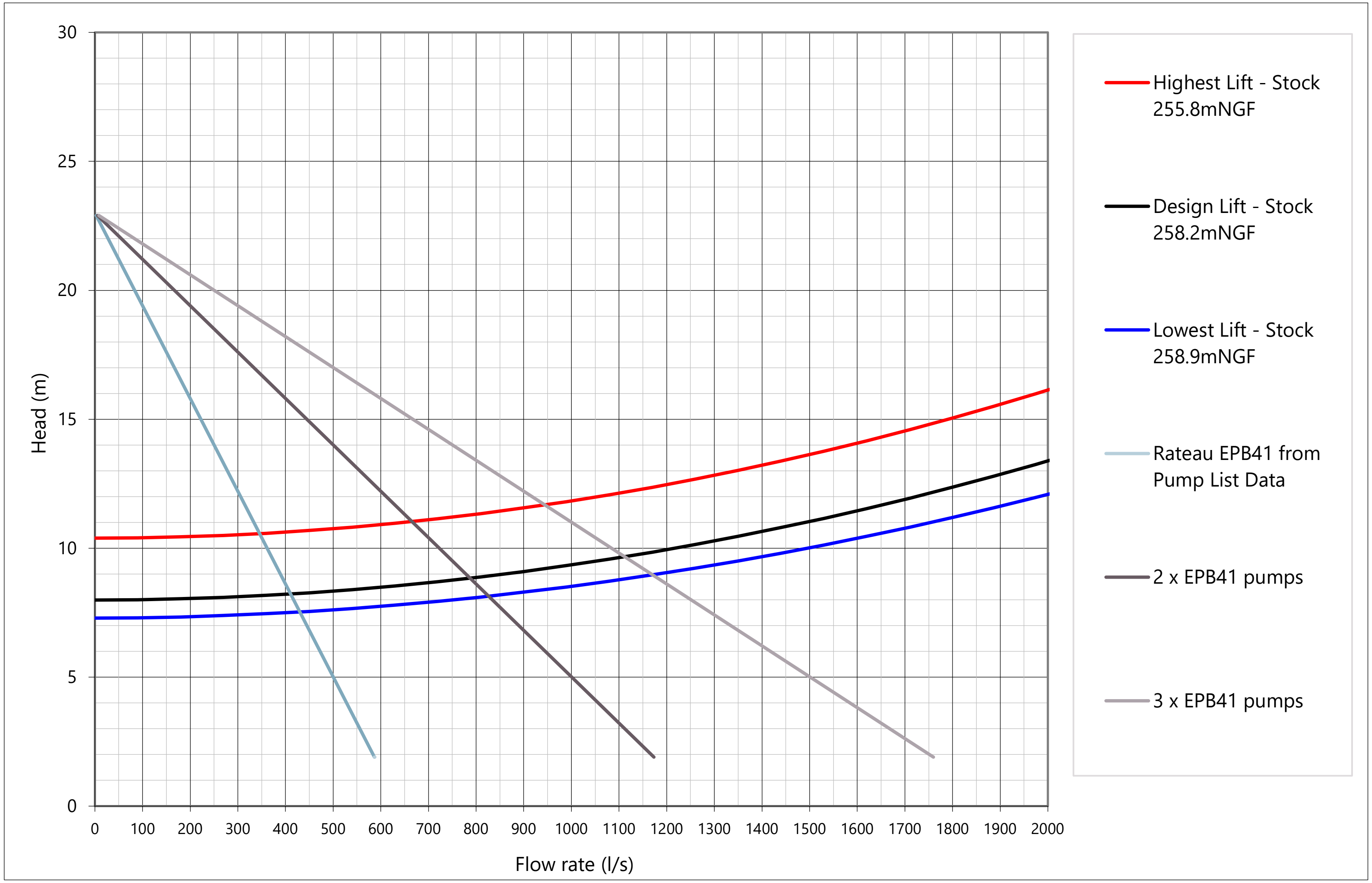


Figure no. 52: Derived System Curves for existing Rateau pumps at Stock PS

4.3.3 Possible Improvements

Consideration of new pumps, similar to the units identified below:

- Bedford SB45.12.06 390 mm impeller - **suspended submersible pump**.
- Xylem 20 x 18 WLS 518 mm impeller - **horizontal split case pump**.

Pump	Duty Point	NPSHr (m)	Motor Rating (kW)	Pump Efficiency at duty point (%)	Motor Efficiency* (%)
Bedford	600 l/s at 11.4 m		90	87.5	95.2
Xylem	600 l/s at 11.0 m	5.5	90	88.9	95.2
**IE3 motor minimum efficiency*					

Table no. 31: Comparison of potential alternative pump selections

The Bedford pump selection can deliver a slightly higher flow rate and would also remove the need for a priming system due to the suspended submersible pump configuration.

The Xylem pump selection would provide a similar suction lift configuration to the existing Rateau pump arrangement and necessitates an automatic priming system.

Other potential improvements include:

- Automation of pumping e.g. use of 'smart' pump controller utilising power, flow, and level measurements.
- Installation of premium efficiency motors to new and/or existing pumps.
- Consideration of variable speed drives.
- Installation of flow meter on common main to provide automation of pump flow control as well as the facility for remote monitoring.
- Investigate energy recovery feasibility for return flows.

5 Pump Summary

5.1 Phase 1 Trial Sites

From the audit assessments of the trial sites, a summary of the installed pump model and its performance is provided, together with the required post-improvement flow rate and head.

Trial Site	Partner	Existing Pump Model	Estimated Existing Flow Rate (l/s)	Estimated Existing Head (m)	Suggested Improvement	Required Flow Rate (l/s)	Required Head (m)	University of Liege Testing
Caen Hill PS	Canal & River Trust	Xylem CT3240	133	84	New Pumps Reduce Main Losses Control Regime	140	82	No
Tinsley PS		Xylem NP3301 HT	109	26	New Hidrostal Pumps VSDs	130	28	No
Seend PS		Xylem NP3301	165	19	New Pumps Control Regime	175	20	Yes
Calcutt PS		KSB KRT200-330 modified	245	14.5	New Pumps New Pipework VSDs	200	9.5	Yes
Leinster Aqueduct	Waterways Ireland	KSB KRT200-401	119	12	Investigate Existing Control Regime	125	12.5	Yes
Locks 16,17,18 Grand Canal		KSB KRT250-400	160	5.3	Investigate Existing Control Regime	180	5.6	Yes
Shannon Harbour		ABS AFP1521 M150 4-32	83 & 98	5 & 6.1	New Pumps Enlarge Pipework Control Regime	150	4	Yes
Richmond Harbour		KSB PLZ300	226	3.8	New Pumps New Well (TBC) Control Regime	225	3.6	No
Drumleague PS		Xylem NP3171	50	9.5	New Pumps Reduce Main Losses Control Regime	185	5.6	Yes
Drumshanbo PS		Xylem NP3171	180	2.7	New Pumps Control Regime	225	3.6	Yes
Crissey PS	Voies Navigables de France	-	-	-	New Pumps Flowmeter	600	12.5	No
Briâre PS		Xylem NP3231	210	48	New Pump Flowmeter	210	48	Yes
Stock PS		Rateau EPB41	410	8.2	New Pumps Controls and VSD	600	11	No

Table no. 32: Trial Site Pump Summary Table

6 Control and Operation Overview

6.1 Overall Appraisal

The trial pumping stations for The Canal and River Trust have SCADA and automatic operation using level monitoring and PLCs. All have permanent flow measurement. The opportunities under Green WIN arise in optimisation and reconfiguration of the control regime to monitor energy performance and obtain specific energy improvements, together with the potential use of variable speed drives at their fixed speed drive sites.

With reference to Table no. 33, the Waterway Irelands' trial site pumping stations have essentially manual operation over long durations with no automatic control except for dry running and overload pump protection. Introducing automatic control is likely to bring significant energy consumption improvements through reduced pumping time.

The trial sites for Voies Navigables de France (VNF) are operated under manual control, mainly on a seasonal basis. None of the VNF sites have permanent flow measurement which would allow more certain energy assessments to be undertaken

For both VNF and Waterways Ireland assets, introducing the capability to remotely monitor the pumping stations would reduce the need for travel to the sites and allow ongoing performance and energy benchmarking to be undertaken. However, SCADA systems are expensive and complex, requiring new specialist personnel to maintain.

'Smart' pumps, controllers and drives are now emerging on the market and offer multi-functional capability, including telemetry, within integrated packages. These products are relatively low-cost and user friendly in comparison to the traditional separated PLC controls, Telemetry, SCADA arrangements. These may an appropriate solution for pumping station assets which have no established SCADA and automatic control infrastructure.

The functionality of smart controller packages may include:

- Combined HMI, PLC, Telemetry unit and pump control in single unit.
- Energy saving functions, including power monitoring, specific energy monitoring, auto reset, pump efficiency monitoring.
- Remote monitoring of levels and flows.
- Blockage detection and pump reversing.
- Automatic speed adjustment to optimise specific energy (VSD).
- Modular expansion capability.
- Local and Remote data trend display.

"Smart" pumps with IE5 permanent magnet motors and integrated VSDs are currently only available in very limited performance duty ranges. No current products are thought to be currently available for the duty ranges at the trial sites. However, the duty ranges are frequently expanding and therefore these technologies should be considered when looking for new or replacement pumps.

In addition to the above measures all partner sites could benefit from improved data collation using GSM or other form of telemetry communications to centralised server hub, SCADA, or cloud-based host site with data analytics and presentation tool (e.g. Microsoft Power BI). Presenting key metrics in a graphical format concerning energy efficiency of a pumping station would enable the organisation to simply monitor asset energy performance in real time without requiring further calculations / derivations.

Trial Site	Partner	Instrument Measurement			Manual / Auto Control (A/M)	Telemetry	SCADA	Variable Speed Drives
		Well Level	Discharge Water Level	Flow Rate				
Caen Hill PS	Canal & River Trust	✓	✓	✓	A	✓	✓	✓
Tinsley PS			✓	✓	A	✓	✓	
Seend PS			✓	✓	A	✓	✓	✓
Calcutt PS			✓	✓	A	✓	✓	
Leinster Aqueduct	Waterways Ireland	✓			M			
Locks 16,17,18 Grand Canal		✓			M			
Shannon Harbour					M			
Richmond Harbour					M			
Drumleague					M			
Drumshanbo					M			
Crissey PS	Voies Navigables de France				M	✓		
Briâre PS					M	✓		
Stock PS					M	✓		

Table no. 33: Trial Site Pumping Station Existing Controls Summary

7 Energy Assessment

7.1 Energy and Carbon Saving Potential

Table no. 34 summarises Arcadis' assessment of the energy improvement potential as a result of implementing the identified improvements. It is recognised that not all recommendations will be achievable, so a range has been established depending on the recommendations adopted.

Trial Site	Partner	Estimated Annual Energy Usage	Suggested Improvement	Potential decrease in Energy Usage		Potential Carbon Emission Reduction (UK values)	Potential Carbon Emission Reduction (Regional values)
		(kWh)		(%)	(kWh)	(kg CO_2)*	(kg CO_2)
Caen Hill PS	Canal & River Trust	1,488,100	Install IE3 motors and new CT4270 pumps, Improve Rising Main head loss and implementing 2-point control	15.2	226,700	57,945	57,945*
Tinsley PS		541,120	Install Hidrostal F06G-EMU1+FEVV4-GSEK1AA Pumps with VSDs	23.2	125,780	32,149	32,149*
Seend PS		223,593	Install IE3 Motors and new fixed speed pumps and implementing 2-point level control	22.4	50,082	12,801	12,801*
Calcutt PS		203,693	Install Hidrostal FE030X4 Duty (single pump)	40.6	82,608	21,115	21,115*
Leinster Aqueduct	Waterways Ireland	133,182	Repair Sluice Gate and implement level control. Investigate and solve pump 2 reduced efficiency	10	13,318	3,005	6,430**
Locks 16,17,18 Grand Canal		201,348	Recondition Lock 16 and 18 pumps and implement level control	14.25	28,692	7,334	13,852**
Shannon Harbour		286,748	Installing 2no. wet well c/w 250 mm outlet pipe and Xylem NP3171.820 with IE3 motors	70.3	201,563	51,520	97,315**
Richmond Harbour		78,554	Installing KSB PNW A4 300 pump	9.0	8,045	2,056	3,884**
Drumleague		49,016	Assuming repair of suspected rising main blockage and utilising new NP3171.181 with flowrate of 185 l/s	73.0	35,806	9,152	17,287**
Drumshanbo		49,891	Install new fixed speed NP3171 MT181 pump with IE3 motor	28.5	14,227	3,636	6,869**
Crissey PS	Voies Navigables de France	46,112	Install new CT3400/736 pumps	17.0	7,832	2,002	458***
Briâre PS		1,011,636	Installing IE3 motors on all 3no. pumps	1.2	11,629	2,972	680***
Stock PS		382,762	Installing 2no. pumps c/w VSDs	42.5	162,726	41,593	9,519***
TOTAL		**4,695,755**		**20.7**	**971,409**	**248,503**	**280,305**

**Assuming average of 1 kWh = 0.2556 kg.CO_2(e), based on 2017 figures (ref.: Department for Business, Energy & Industrial Strategy Methodology Paper for Emission Factors Final Report, 2019 Government Greenhouse Gas Conversion Factors for Company Reporting)*
***Assuming average of 1 kWh = 0.4828 kg CO_2(e), based on 2016 figures (ref.: Sustainable Energy Authority of Ireland 2018 Report, Energy-Related CO_2 Emissions in Ireland 2005-2016)*
****Assuming average of 1 kWh = 0.0585 kg CO_2(e), based on 2016 figures (ref.: European Environment Agency website, Overview of electricity production and use in Europe, Fig. 1: CO_2 emission intensity https://www.eea.europa.eu/data-and-maps/indicators/overview-of-the-electricity-production-2/assessment-4)*

Briare - VNF's assessment of total pumped volume during 2016 is 2,907,360 m^3. Based on this annual volume, the use of an IE3 motor on a single pump (assuming 66 % utilisation) would bring a reduction of 3,873 kWh per annum. If all pumps were changed then the saving would increase to 11,629 kWh per annum.

Table no. 34: Trial Site Energy and Carbon Assessment Summary

8 Key Conclusions

From the Phase 1 audits undertaken for each trial site, system and pump curves have been derived for each site and identified key areas and issues which concern energy efficiency and potential for improvements.

Overall, there is good potential under the Green WIN to improve energy efficiency through variety improvement measures including:

- Inspecting and reconditioning existing pumps.
- Premium efficiency motors.
- Use of VSDs.
- New instrumentation (e.g. level and flow rate).
- Operational regime changes.
- Investigating unexplained high losses and upsizing pipework.
- Improving communication and presentation of energy related data & metrics.

The pumping stations for the Canal and River Trust have an established pump control and monitoring infrastructure. The primary opportunities for energy improvements come from investigating further optimisation of pump control by reducing flow rate in quieter periods, investigating vibration root causes, and reducing pipe losses.

For the Waterway Ireland trial sites, pump operation is generally manual and without remote monitoring. The key opportunities for energy reduction are implementing and trialling automatic control and monitoring, potentially through 'smart' controllers and instrumentation measuring flow and level. Replacing the pumps and pipework at Shannon Harbour sites should also bring significant benefits in terms of energy and CO2 reduction. Testing identical pumps to existing installed at the University of Liege will also provide a good pump performance benchmark and will help establish the system curves at the sites where uncertainty exists.

For the VNF trial site pumping stations, operation is essentially manual although telemetry is present. The pumps at Stock and would benefit from modernisation of pumps and/or premium efficiency motors. VNF's proposed pump selections for Crissey and Briare are considered appropriate and do not require investment on VSDs. The energy monitoring is based on anecdotal flow information and therefore installing flowmeters would provide more accurate data on energy performance. There is potential for automating the pump control from upstream and downstream levels and optimising pumping durations subject to further investigation.

At this stage the estimated net change which Green WIN aims to demonstrate of 778,000 kWh energy saved, and 195-tonnes CO_2 emissions reduced is considered achievable through implementation of key improvement measures as identified in this summary report and the individual site Phase 1 assessment reports.

The estimates include assumptions where poor quality or missing data/ information has not been able to be ascertained in Phase 1.

9 Phase 2 Recommendations

Many of the key recommendations are common to one or more partners organisations and their trial sites

The key recommendations arising from the Phase 1 audits are provided and presented separately at organisation and site/component levels in Table no. 35 and Table no. 36 respectively.

Recommendation	Partner		
	Canal and River Trust	Waterways Ireland	Voies Navigables de France
Review Phase 1 site audit reports and undertake further investigation on issues and missing information / data	✓	✓	✓
Assess feasibility of identified solution options	✓	✓	✓
Review and optimise pumping station operating regimes to further improve overall efficiency and specific energy	✓	✓	✓
Identify and trial pumps for testing at UoL Test Rig	✓	✓	✓
Identify and trial smart pump controller technologies		✓	✓
Identify and trial level sensors		✓	
Trial remote data communication system (e.g. integrated with smart controller)		✓	
Plan and undertake improvements at identified trial sites	✓	✓	✓
Review results and undertake follow up site audits at sites subject to improvement trials	✓	✓	
Improve energy data and metric reporting through improved data analytics software and presentation	✓	✓	✓
Install automatic pump control		✓	✓
Install flow meters on delivery line		✓	✓
Install level sensors on discharge water flight / body		✓	✓
Establish remotely accessible data system		✓	

Table no. 35: Recommendations Summary (Organisation level)

Recommendation	Partner	Canal and River Trust				Waterways Ireland					Voies Navigables de France		
	Pumping Station	**Caen Hill**	**Seend**	**Calcutt**	**Tinsley**	**Leinster Aqueduct**	**Locks 16,17,18 Grand Canal**	**Shannon Harbour Locks 35,36**	**Richmond Harbour**	**Drumleague & Drumshanbo**	**Crissey**	**Briare**	**Stock PS**
Further Investigations	*Investigate cause of pump vibration*	✓ (Priority)	✓										
	Inspect pump and impellers for damage/blockage					✓	✓	✓		✓			
	Recalibrate flow meter		✓										
	Review bar screen spacing / intake design	✓			✓				✓				
	Review sump/well design	✓	✓	✓	✓ (Monitor)			✓	✓	✓			
	Investigate energy saving control functions	✓	✓	✓	✓							✓	✓
	Investigate rising main / rising main condition	✓	✓	✓	✓					✓			
	Investigate existing sluice gate / lock gate					✓	✓	✓					
	Consider site flow and pressure tests								✓			✓	
	Undertake asset design survey			✓				✓	✓	✓			
	Review flow/level trends and peak flow duty	✓	✓		✓					✓			
	Investigate reducing pumped flow rates during quieter lockage periods / level conditions (e.g. multiple set point level control or AI)	✓	✓	✓	✓								
	Investigate power supply			✓									
	Investigate resilience options for 2-pump upgrade or boxed spare								✓	✓			
	Replace pump and/or motors with new	✓	✓	✓	✓			✓	✓		✓		✓
	Consider premium efficiency IE3/IE4 motors for replacement	✓	✓	✓				✓		✓		✓	✓
	Consider VSDs				✓			✓					✓
	Redesign and replace PS pipework	✓		✓				✓	✓		✓		
	Install flow meter on delivery line					✓	✓	✓	✓	✓	✓	✓	✓
	Purchase, test, and trial new pump							✓		✓			
	Purchase, test, and trial new controllers					✓	✓	✓					
	Purchase, test, and trial level sensors					✓	✓	✓					
	Install level sensors on discharge water flight / body					✓	✓	✓	✓	✓			
	Introduce automatic pump level control					✓	✓	✓	✓	✓	✓	✓	✓
	Introduce remote data communication system					✓	✓	✓	✓	✓	✓	✓	✓
	Consider Smart Pump controller for comms in lieu of standard telemetry / SCADA					✓	✓	✓	✓	✓			

Table no. 36: Recommendations Summary (Site and Component level)

Design & Consultancy for natural and built assets

Appendix A

Guide to System Curves and Pump Performance Curves

System Curve

Consider a pump system (Figure no. 53) where water is required to be conveyed from Point A to Point B at a Flow Rate of Q_D.

As the elevation of the water surface at the delivery Point B is higher than at A, it cannot flow under gravity, so pumps are required to lift the water. The elevation difference that the pumps are required to overcome is known as the static head, H_S, where H_S = Surface Elevation @ B – Surface Elevation at A.

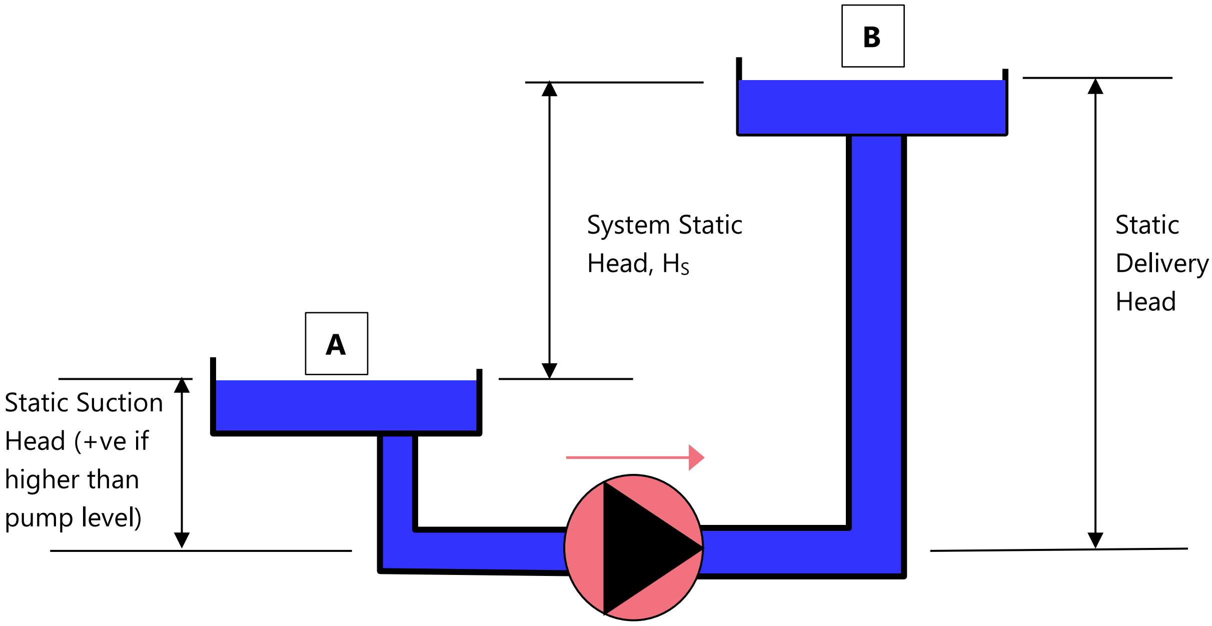
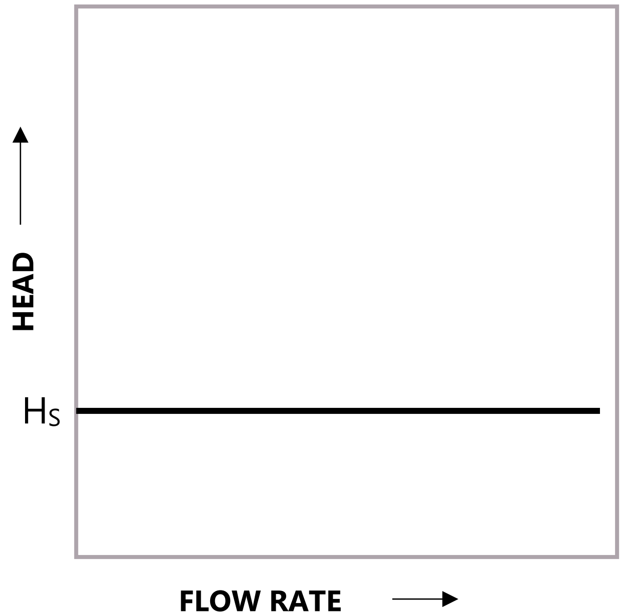


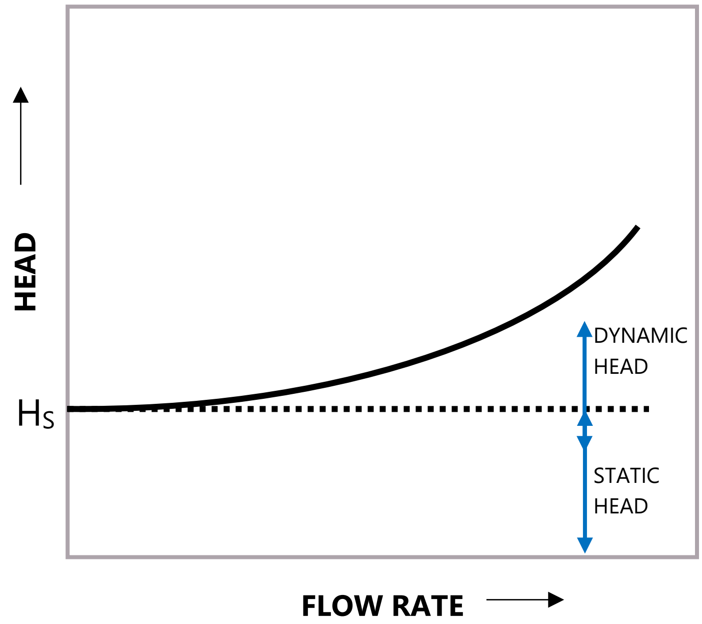
Figure no. 53: Pump System Representation

The calculated static head can be represented on a chart with head on the y-axis and flow rate on the x-axis, as follows:

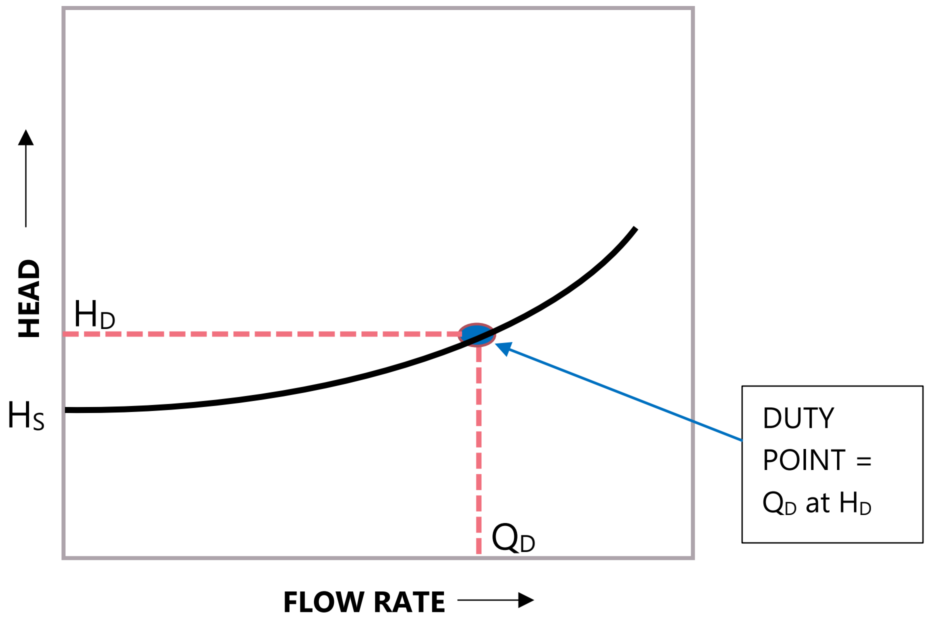


With an increasing flow rate, the flow resistance of the pipe and pipe fittings increases due to friction. So to achieve a higher flow rate, more pressure (or head) is then needed to be generated by the pump. The head losses due to friction increase proportionally to the square of flow velocity and is referred as "Dynamic Head". The Total Head for a given flow rate is the sum of Static Head and Dynamic Head.

Using established equations and loss coefficients the head unique to the pipe system can be calculated at various flow rates and its curve plotted as shown below. This is known as the "SYSTEM CURVE" or "SYSTEM CHARACTERISTIC".

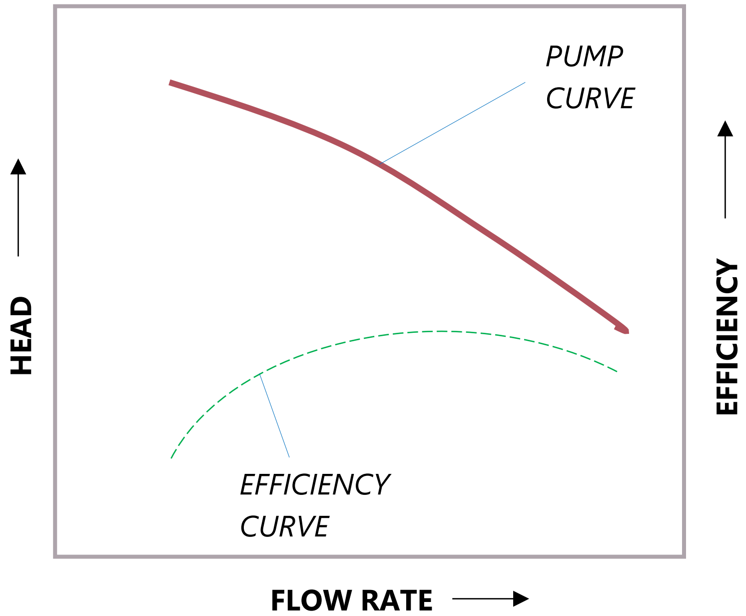


To select a pump for the desired flow rate, Q_D, the intersection point at H_D, is translated from the system curve. This is known as the desired "Duty Point".

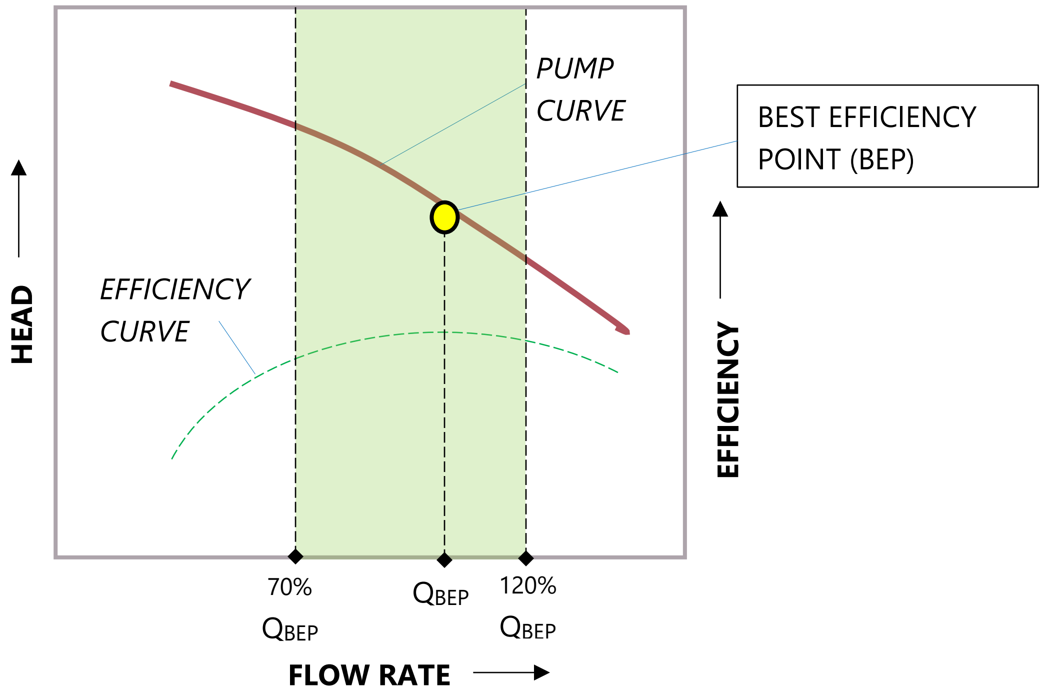


Pump Performance Curves

Centrifugal pumps have a flow-head characteristic known as the “PUMP PERFORMANCE CURVE” or “PUMP CURVE”. This shows the flow rate that can be generated by the pump for a given head. The pump curve will typically fall as flow rate increases. The pump efficiency will typically vary with flow rate, initially rising to a peak and then falling away at higher flow rates. These can be represented by curves aginst flow rate as shown below.

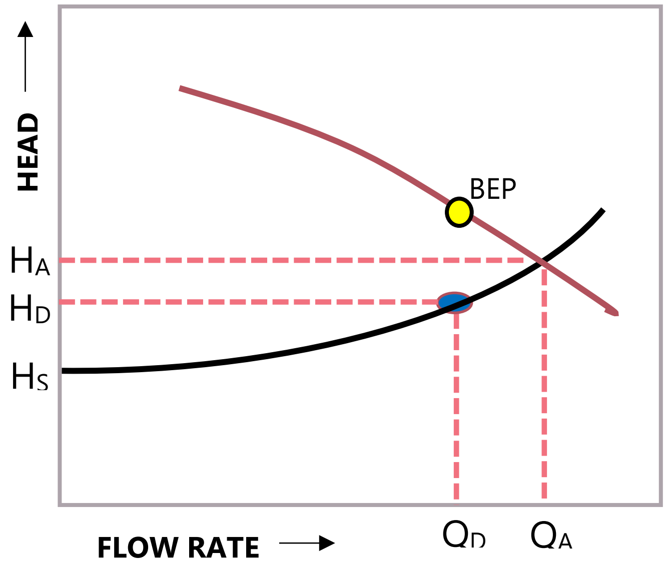


The point on the pump curve where efficiency is highest is known as the “BEST EFFICIENCY POINT”, abbreviated to “BEP”. The flow rate at this point is abbreviated to Q_{BEP}. Well selected pumps generally perform at flow rates within 70%< Q_{BEP} < 120%, in what is known as the “PREFFERRED OPERATING REGION” as highlighted below.



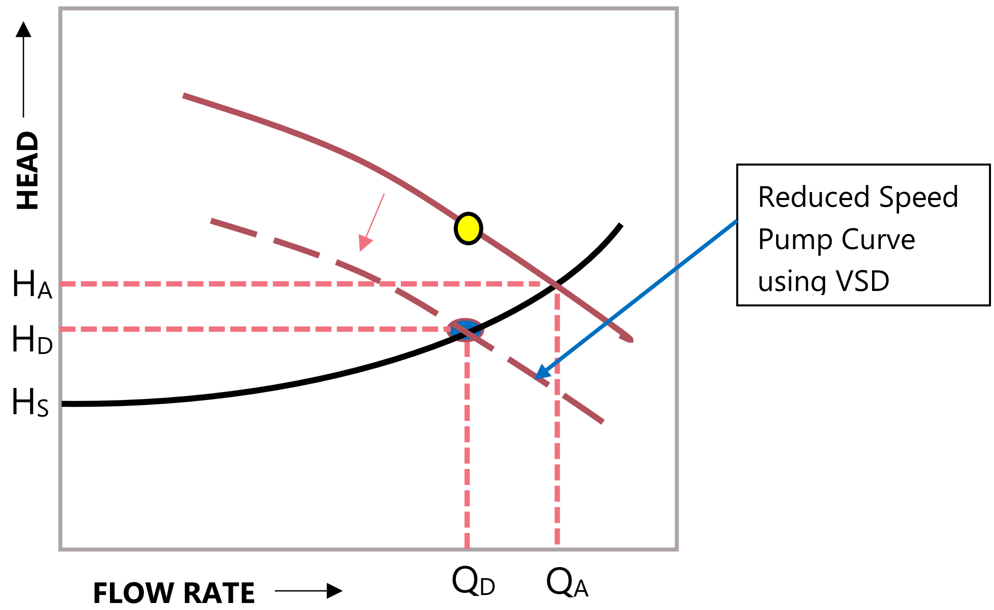
Combining System and Pump Performance Curves

The performance curve for a pump can be overlaid on the system curve. The expected flow rate for a particular pump is indicated where the pump curve intersects the system curve.



In the above example, the pump will pass forward a flow rate, Q_A at a head of H_A (Actual Duty Point) which is higher than the desired duty flow rate, Q_D and higher than (to the right) of its best efficiency flow rate, Q_{BEP}.

Pump Manufacturers can provide a pump curve reflective of a particular model of pump "as new". Sites tests can provide an actual pump performance curve through varying pump speed or adjusting valves and measuring flow rate and pressure.



Using variable speed drives it is possible to change the pump speed by changing the frequency of input power to the pump motor. This varies its performance curve meaning that it can meet a desired flow rate. In this example the speed is reduced to meet the desired duty flow rate, Q_D.

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