Investigating the Potential for Optimising Energy Usage – The Don Valley Intercepting Sewer

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Introduction

AMP5 saw the start of an industry shift towards a TOTEX (total expenditure) approach to asset management and this is set to continue into AMP6 and beyond. In practice this means water companies are looking closely at enhancing the value of existing assets, through maximising the use and minimising the total costs and carbon footprints of operation.

Energy costs are projected to rise significantly over the coming years, as illustrated in Figure 1. Yorkshire Water (YW) is committed to reducing the carbon footprint and overall costs of its operation. Sewer catchment models are a unique tool that can be utilised to investigate sewer optimisation scenarios. This type of modelling can be used for any site and we present here an example focused on the Don Valley Intercepting Sewer and its associated pumping stations at Blackburn Meadows WwTW.

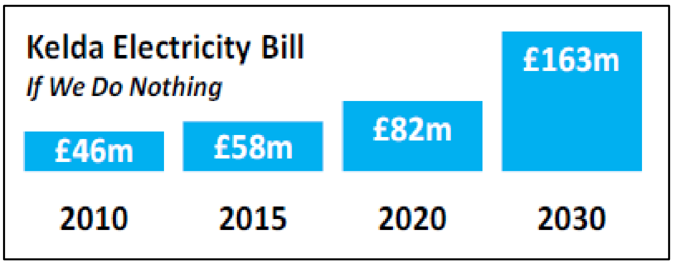

Figure 1 – Projected Kelda Electricity Bill, from Kelda Energy Strategy 2014

The potential for optimisation of the Don Valley Intercepting Sewer (DVIS) and its associated pumping stations was highlighted during AMP5 WFD and DAP studies. Further discussion led to a collaborative investigation between Clear and YW, utilising the Upper Don WFD model, looking into potential methods of reducing energy usage and pumping costs at Blackburn Meadows WwTW.

Blackburn Meadows Wastewater Treatment Works

Blackburn Meadows WwTW is a large facility located in Sheffield, serving the Upper Don catchment. The Upper Don catchment has a population of around 430,000 and an area of approximately 25,000ha. A high level sewer network enters Blackburn Meadows through four high level inlets and this system historically carried all DWF (dry weather flow) to the works. BLACKBURN MEADOWS 2/SPS (BBM 2/SPS) lifts the high level flow approximately 5.6m into the inlet works by means of three screw pumps. In the late 1980's the Don Valley Intercepting Sewer (DVIS), a low level system, was developed in order to intercept spill flows from numerous CSOs (Combined Sewer Overflows) along the River Don in an effort to improve water quality. The DVIS is approximately 10km in length with a maximum pipe size of 5.1m diameter at its downstream end; it is approximately 25m deep at its deepest. Flow is able to enter the DVIS via 34 transfer chambers located on the high level system. The DVIS was originally designed to carry storm flows and provide storm storage but it now carries a significant proportion of DWF, as much as 1500l/s or 99500m^3/day, down to Blackburn Meadows WwTW, where it passes through the 6xDWF overflow before it is pumped approximately 20.5m up to the inlet works by BLACKBURN MEADOWS/1 SPS (BBM 1/SPS) pumping station. The current estimated energy usage of BBM 1/SPS is approximately 3,095,000KWh per annum.

Transfer Chamber	Min DWF flow (l/s)	Max DWF flow (l/s)	Daily volume (m^3)
A5a	279	415	29,945
H1a	54	419	21,513
E1a	100	208	13,799
A16a	77	203	13,249
B3a	91	151	10,741
A27a	0	85	3,627
A15a	16	29	1,988
L1a	10	19	1,245
B1a	8	17	1,149
C1a	3	9	492

Table 1 – Predicted DWF transfer flow values for the 10 chambers.

An Upper Don catchment sewer model, with detail focused on and around the DVIS and Blackburn Meadows WwTW, was developed by Clear for Yorkshire Water in AMP5 as part of a WFD study of the River Don. During the initial model build and verification process, flows to the DVIS during dry weather conditions were identified at 10 of the 34 transfer chambers. These transfer flows were considered to be caused by a variety of factors; including catchment growth, sediment build-up in the high level system and transfer chamber design. As shown in Table 1, verified model simulations predict a range of flow volumes from the transfer chambers, with the two largest flow transfers chambers, A5a and H1a, producing a larger volume than the rest put together. Transfer flows into the DVIS during dry weather are, in general, considered unnecessary for acceptable operation of the high level system and are a source of significant additional energy usage and pumping costs at Blackburn Meadows WwTW.

Yorkshire Water requested Clear utilise the Upper Don WFD model to investigate the feasibility of reducing dry weather transfer flows to the DVIS and to quantify the associated energy and cost savings.

BBM/1 SPS is a complex asset with six pumps installed; the pump capacities vary and the pumps operate at variable speeds and in a range of combinations depending on wet well depth and whether the level is rising or falling. Table 2 illustrates the range of pumps installed at the site. After the WFD model had been verified (against flow survey and telemetry data from 2011), BBM/1 SPS was upgraded as part of the major redevelopment and refurbishment program at Blackburn Meadows WwTW. As part of this upgrade the pumps were replaced and a new control regime implemented. Given the complex and wide range of power, pump speed, pump combination and head, (as demonstrated in Table 2) it is clearly important to have a detailed representation of the control regime in order to determine the length of time each pump is operational and at what power requirement. The verified WFD model was upgraded with the new pumps and the control regime replicated using Real-Time-Control (RTC), verified against the available telemetry data from September to December 2013.

Pump	Control description	Discharge range (l/s)	Maximum power required (KW)
Pump No 1	Large Flow Pump	1400 – 2000	640
Pump No 2	Small Flow Pump	400 - 850	300
Pump No 3	Medium Flow Pump	550 – 1111	505
Pump No 4	Large Flow Pump	1400 - 2000	640
Pump No 5	Small Flow Pump	400 - 850	300
Pump No 6	Medium Flow Pump	500 - 1111	505

Table 2 – Details of the new pumps installed in the BBM

Using the predicted head and flow rates for each pump it was possible to calculate the power required to transfer the incoming flow from BBM/1 SPS to the inlet works, for each time-step. Calculations using pump performance curves provided by the manufacturer and the model predicted head/flow for each pump, were completed in order to determine the efficiency of each pump at each time step and therefore the power used. The efficiency of the drive chain (estimated at a typical value of 95%) was also taken into account. Additional pipe losses along the rising mains were calculated using the maximum flow for each pump and applied to the predicted head values. Energy usage was then calculated for a typical period of dry and wet weather, using continuous simulation of the model. The derived annual values are shown in Table 3.

BBM 2/SPS comprises three screw pumps operating on a Duty/Assist/Assist control regime. The screw pump efficiencies vary by just 1% from touch point to fill point hence an average efficiency value was utilised, along with the manufacturer-provided absorbed power usage estimates for the pumps and predicted flow per time-step, in order to calculate the annual energy usage, for the predicted pumping times.

Reducing the amount of DWF in the DVIS would result in a reduced flow load to BBM 1/SPS but an increased flow load to BBM 2/SPS. Due to the difference in lift and pump efficiencies BBM 2/SPS uses less energy per m^3 than BBM 1/SPS, using on average 0.02kWh/m^3 and 0.07kWh/m^3 of flow respectively, and therefore both pumping stations need to be taken into account in estimated power and cost calculations. DWF conditions are prevalent approximately two thirds of the time and this could therefore lead to substantial reductions in pumping costs.

Energy costs for both pumping stations vary throughout the day and this has been factored into the energy cost calculations using values provided by YW.

	BBM 1/SPS (MWh)		BBM 1/SPS Cost		BBM 2/SPS (MWh)		BBM 2/SPS Cost		Total	
	Day	Night	Day	Night	Day	Night	Day	Night	MWh	Cost
Annual	1,942.3	745.4	£105,048	£59,652	291.0	117.2	£16,704	£9,348	3,095.9	£319,756

Table 3 – Baseline predicted energy use and typical cost.

Scenario Testing

Four different potential energy and cost rationalisation scenarios were identified:

1. Sediment removal from the high level system – reducing volume of DWF transfer to the DVIS.
2. Raising of weirs in the transfer chambers (weir optimisation) – reducing volume of DWF transfer to the DVIS.
3. A combination of scenarios 1 and 2 above.
4. Upwards adjustment of the dry weather operating level at BLACKBURN MEADOWS/1 SPS in order to reduce hydraulic head.

Impacts on model predicted flooding and CSO spills were investigated for all four scenarios by running a selection of design storms to ensure no detriment in performance was caused.

Scenario 1 - Sediment Removal

During the model build and verification process, significantly high levels of sediment were identified downstream of several of the transfer chambers, contributing to flow transfers to the DVIS during dry weather. Initial tests showed that removal of the sediment resulted in reduced predicted flow transfers to the DVIS. The practicality of permanently removing *all* of the existing sediment is questionable however. In order to determine the likely influence of an achievable reduction of this sediment, upon the transfer chamber flows, initial runs were undertaken with sediment limited to 0%, 5% and 10% respectively of pipe height in all of the high level sewers.

The impact of sediment removal however is not even across the high level network, initial modelling results suggested that sediment removal would significantly reduce transfer of flows at chambers A5a, H1a and A16a but would increase transfer flows at chambers B3a and B1a, as a result of increased pass forward flows from the upstream network. Smaller changes in transfer flow volume to the DVIS were predicted for the remaining transfer chambers and no transfer flow was predicted for any chambers which had not previously been discharging to the DVIS in dry weather. Further trials were then undertaken to target the removal of sediment at the most effective locations. Targeted sediment removal was therefore investigated at three sites; transfer chambers H1a, E1a and A16a were selected on the basis of ease of access, what is known about the sediment composition and the high volumes of transfer flows at these locations, again limiting the sediment depth to 0%, 5% and 10% respectively of pipe height.

Estimated cost savings for each sediment removal strategy are displayed in Tables 4a and 4b.

Scenario	Annualised transfer flows to DVIS (m^3)		Annualised BBM 1/SPS Pumped Flow (m^3)		Annualised BBM 2/SPS Pumped Flow (m^3)	
	Total Vol (000s)	Change*	Total Vol (000s)	Change*	Total Vol (000s)	Change*
Baseline (existing)	45,143	-	45,301	-	18,256	-
0% silt – all	26,376	-41.6%	26,557	-41.4%	37,020	+102.8%
5% silt – all	29,949	-33.7%	30,119	-33.5%	33,443	+83.2%
10% silt – all	32,729	-27.5%	32,896	-27.4%	30,691	+68.1%
0% - targeted	40,221	-10.9%	40,404	-10.8%	23,186	+27.0%
5% - targeted	40,554	-10.2%	40,733	-10.1%	22,861	+25.2%
10% - targeted	41,031	-9.1%	41,212	-9.0%	22,314	+22.2%

Scenario	Annualised BBM 1/SPS Cost		Annualised BBM 2/SPS Cost		Total Annualised Cost		Projected 2030 Annualised Cost	Annual tonnes CO_2	
	Total Cost	Change*	Total Cost	Change*	Total	Total		Total	% change
Baseline (existing)	£164,713	-	£26,063	-	£190,776	-	£373,920	1,379	-
0% silt – all	£108,531	-34.1%	£49,836	+91.2%	£158,368	-17.0%	£310,401	1,108	-19.6%
5% silt – all	£116,855	-29.1%	£45,194	+73.4%	£162,050	-15.1%	£317,618	1,133	-17.8%
10% silt – all	£126591	-23.1%	£41,872	+60.7%	£168,463	-11.7%	£330,187	1,175	-14.7%
0% - targeted	£152,393	-7.5%	£32,330	+24.1%	£184,723	-3.2%	£362,057	1,296	-5.9%
5% - targeted	£153,563	-6.8%	£31,880	+22.3%	£185,444	-2.8%	£363,470	1,302	-5.6%
10% - targeted	£156,405	-5.0%	£31,199	+19.7%	£187,605	-1.7%	£367,705	1,310	-4.9%

Table 4a and 4b - Initial estimated volume and cost savings for sediment removal
*** % change relative to Baseline.**

The total 0-10% sediment removal scenarios result in a significant reduction in annualised transfer of flows to the DVIS, which is reflected in the increased pumping costs at BBM 2/SPS and the reduced costs at BBM 1/SPS. Total removal of sediment could generate an 11% cost saving at current values and a carbon saving of 204 tonnes of carbon dioxide at the 10% silt scenario.

Significantly lower savings are predicted for the targeted scenarios, with total cost savings of 1.7-3.2% and total carbon savings of 4.9 – 5.9%.

Other issues to be considered in a detailed cost-benefit analysis to be conducted at a later stage include the following:

- Cost and ease, including site access, of sediment removal and disposal – Initial estimates of £500,000 for the targeted locations appear to be probative.
- Likelihood and predicted timescale of potential sediment return.
- Pump wear and tear.

Scenario 2 - Weir Optimisation

A review of the causes of dry weather transfers to the DVIS highlighted low weirs compared to the DWF level as a significant factor at a number of sites. By raising the transfer weir levels, it may be possible to significantly reduce transfer flows to the DVIS, dramatically reducing pumping costs. Some DWF in the DVIS would still be expected as a result of some direct connections and infiltration however the remaining flow would be minimal.

An option model was created in which the weirs in the 10 transfer chambers, where dry weather transfer flows are predicted, were raised to prevent significant transfer flows to the DVIS (Total Weir Optimisation Scenario). However it was considered that the initial cost of weir optimisation may be prohibitive, given the low level of transfer flows from some of the transfer chambers, (for example the 492m3/day transfer flow at chamber C1a), and it may not ultimately be cost effective to raise all of the weirs.

A preliminary review of the transfer chambers was also conducted and five chambers were selected for modification to give the most cost-effective results, namely B3a, A27a, E1a, A5a and B1a, selected on the basis of a combination of factors including ease of access, the presence of particularly low weirs in relation to the DWF level and large predicted flow transfer volumes (Targeted Weir Optimisation Scenario). Model results are summarised in Tables 5a and 5b.

Scenario	Annualised flow transfer to DVIS (m^3)		Annualised BBM 1/SPS Pumped Flow (m^3)		Annualised BBM 2/SPS Pumped Flow (m^3)	
	Total Vol (000s)	Change*	Total Vol (000s)	Change*	Total Vol (000s)	Change*
Baseline	45,143	-	45,301	-	18,256	-
Total Weir Optimisation	12,052	-73.3%	12,337	-72.8%	53,177	+191.3%
Targeted Weir Optimisation	24,644	-45.4%	24,815	-45.2%	38,733	+112.2%

Scenario	Annualised BBM 1/SPS Cost		Annualised BBM 2/SPS Cost		Total Annualised Cost		Projected 2030 Annualised Cost	Annual tonnes CO_2	
	Total Cost	Change*	Total Cost	Change*	Total Cost	Change*		Total	Change*
Baseline	£164,713	-	£26,063	-	£190,776	-	£373,920	1,379	-
Total Weir Optimisation	£52,695	-68.0%	£63,724	+144.5%	£116,420	-38.9%	£228,183	808	-41.4%
Targeted Weir Optimisation	£104,342	-36.7%	£51,322	+96.9%	£155,665	-18.4%	£305,103	1,089	-21.0%

Table 5a and 5b - Initial estimated volume and cost savings for weir optimisation
*** % change relative to Baseline.**

The most significant reduction in cost and energy usage comes from the Total Weir Optimisation scenario, as expected, however significant additional height is needed in places (above 0.5m) and initial model runs suggest this scenario may be leading to an increase in high level CSO spills. Targeted weir optimisation predicts more modest savings and is consent compliant and predicts there to be no overall detriment.

Other issues to be considered in a detailed cost-benefit analysis to be conducted at a later stage include the following:

- Cost and ease of access for weir optimisation.
- The impact on sedimentation levels in the high level following weir optimisation.

* Changes to pump wear and tear due to the redirection of flows between the high level and DVIS.
* Further assessment as to the impact on the level of service with regard to flood risk and CSO performance.

Scenario 3 - Combined Targeted Weir Optimisation and Sediment Removal

Scenarios 1 and 2 suggest that significant energy and cost savings would be achieved by combining the targeted removal of sediment with the raising of weir levels. A further investigation was conducted to quantify possible savings by combining the two approaches. It was decided to run the targeted weir optimisation scenario described above with the targeted sediment removal scenario (0%, 5% and 10% limits, respectively). Results are summarised in Tables 6a and 6b below:

Scenario	Annualised transfer flows to DVIS (m^3)		Annualised BBM 1/SPS Pumped Flow (m^3)		Annualised BBM 2/SPS Pumped Flow (m^3)	
	Total Vol (000s)	Change*	Total Vol (000s)	Change*	Total Vol (000s)	Change*
Baseline	45,132	-	45,301	-	18,256	-
Combined - 0% silt	23,275	-48.4%	23,466	-48.2%	40,100	+119.7%
Combined - 5% silt	23,636	-47.6%	23,819	-47.4%	39,801	+118.0%
Combined - 10% silt	24,496	-45.7%	24,674	-45.5%	38,864	+112.9%

Scenario	Annualised BBM 1/SPS Cost		Annualised BBM 2/SPS Cost		Total Annualised Cost		Projected 2030 Annualised Cost	Annual tonnes CO_2	
	Total Cost	Change*	Total Cost	Change*	Total Cost	Change*		Total	% change
Baseline	£164,713	-	£26,063	-	£190,776	-	£373,920	1,379	-
Combined - 0% silt	£100,111	-39.2%	£52,247	+100.5%	£152,359	-20.1%	£298,623	1,067	-22.6%
Combined - 5% silt	£101,255	-38.5%	£52,035	+99.7%	£153,291	-19.7%	£300,450	1,073	-22.2%
Combined - 10% silt	£103,847	-36.9%	£51,068	+51.1%	£154,916	-18.8%	£303,635	1,084	-21.4%

Table 6a and 6b - Initial estimated volume and cost savings for scenarios

*** % change relative to Baseline**

Larger energy usage savings are achieved by taking a combined approach, although the 10% sediment scenario is not significantly better than targeted weir optimisation alone. The areas of consideration, discussed in scenarios 1 and 2, would still apply to this scenario.

Scenario 4 – Adjustment of Dry Weather Operating Level at BBM 1/SPS

An alternative approach was suggested during the initial stages of the investigation and some preliminary model trials were run to determine the feasibility.

During current operation Blackburn Meadows 1 maintains a low operating level to enable maximum storm storage capacity, should a significant event occur within the catchment. With the advent of radar rainfall and improved rainfall forecasting, this has the potential to enable the DVIS to be operated in a "Real Time Controlled" basis, as follows:

If the DVIS (existing system – no modifications) could be allowed to fill during dry weather this would reduce the hydraulic head against which BBM 1/SPS operates and therefore reduce the required energy and associated carbon footprint and pumping costs during dry weather. A major advantage of this scenario over scenarios 1, 2 and 3 is that it would not require a significant initial outlay and there would not be any on-going maintenance costs. The DVIS provides approximately 90,000m^3 storage before the 6xDWF overflow spills and this storage volume forms part of the consent at the works. As such, the maximum storage volume must be made available in the event of a storm.

In order to investigate this scenario, adjustments were made to the RTC control to enable two distinct control regimes to be employed dependent on weather conditions. A new, high operating level would be maintained during dry weather and a low operating level (the same as the existing system) would be targeted and maintained in the event of a rainfall warning. Several different high operating levels were tested to check the cost-savings vs drain-down times and associated risks for each level. Model results are summarised in Table 7.

Dry weather operating Level (mAOD)	Temporary reduction in available storage volume in DVIS (m^3)	Minimum drain down time to baseline (hours)	Annualised energy cost		Projected 2030 energy cost	Annual tonnes CO_2	
			Total Cost	Change*		Total	% change
25	78,688	12.0	£174,436	-8.5%	£341,894	1,223	-11.3%
22	68,123	10.5	£176,930	-7.3%	£346,782	1,243	-9.8%
19	55,742	8.5	£181,112	-5.1%	£354,979	1,273	-7.7%
16	31,475	4.5	£187,825	-1.6%	£368,137	1,313	-4.7%
13 – Baseline	0	0.0	£190,776	-	£373,921	1,379	-

Table 7 – Estimated cost saving at different DWF levels
*** % change relative to Baseline**

The most significant energy usage savings were achieved by maintaining the dry weather level at 25mAOD; however the accompanying high drain downtime and reduction in available storm storage make this the most high risk scenario. There is a benefit to be achieved between energy efficiency and risk to the level of service provided to the catchment.

It should be noted that these are conservative estimates of cost savings; a more sophisticated real time control philosophy has the potential to generate increased energy savings.

Simulation results suggested that, although the most significant savings could be made by maintaining the DVIS at higher operating levels, this approach would not be feasible due to the lengthy drain-down times.

Whilst model predictions are encouraging, there are several issues which would require further assessment should this scenario be taken forward:

- Septicity – This is a common problem in sewers with a long retention time and there is potential for this to occur given the greater volume of flow stored in the DVIS.
- Sedimentation – There is a potential risk that increasing the operating dry weather level in the DVIS would lead to increased sediment deposition, which would increase maintenance costs.
- The increased risk of spilling prematurely from the 6xDWF overflow at Blackburn Meadows would have to be carefully assessed and discussed with the EA in order to ensure the works remained within consent. This risk is dependent on the accuracy of the rainfall forecast data.
- Radar rainfall forecasting is not currently considered reliable beyond 3 hours. Radar rainfall forecasting is currently limited in reliability and lead-times however this is a developing field and advances in technology may make this concept more feasible in the future.
- Assessment of any potential change in the composition and resultant quality of flows being conveyed to the inlet works.

Conclusions

Due to the complex pumping arrangement and the nature of flows being transferred from the high level system to the DVIS, these scenarios could not have been accurately assessed without the use of the hydraulic model. From the assessments undertaken to date, it appears as though the weir optimisation scenario is the most promising, given the lower initial outlay costs compared to the benefits in operational energy, carbon and cost reduction.

Due to the nature of this pre-feasibility study there are a number of areas which require further investigation before any of the options can be progressed further, which have been discussed in the individual scenarios.

The results of this pre-feasibility study demonstrate that catchment models provide not only a good representation of the hydraulics and holistic system understanding of network performance, but can also provide outputs that can be adapted to calculate the energy and carbon usage of key assets and enable operational cost optimisation for current and future scenarios. This provides a useful tool for water companies in the forthcoming AMP6 TOTEX environment, especially given the projected rise in future energy costs and pressures on carbon footprint reduction.