

Water for Cambridge: South Level IDB Study – Catchment Conceptualisation and Water Balance Assessment



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Prepared for:
Water Resources East

Date:
3 March

Prepared by:
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Project/File:
331610105/200

Revision Record

Revision	Description	Author	Date	Quality Check	Date	Independent Review	Date
D1	Draft	R Quaglia	20/02/2026	J Murphy	03/03/2026	S Knowles	03/03/2026
1	Final	R Quaglia	26/03/2026	J Murphy	27/03/2026	S Knowles	31/03/2026

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Acronyms / Abbreviations

Acronym / Abbreviation	Full Name
EA	Environment Agency
IDB	Internal Drainage Board
HoF	Hands-off Flow



1 Introduction

This “Catchment Conceptualisation and Water Balance Assessment” report has been prepared by Stantec UK Ltd (‘Stantec’) on behalf of Water Resources East in support of the Water for Cambridge South Levels Study. It has been prepared to undertake an assessment of water availability for abstraction upstream of the Denver Complex within the Ely Ouse and South Level system.

There are three anticipated stages of Water for Cambridge South Levels’ Study

Stage 1: Gap Analysis and Feasibility Assessment

Stage 2: Future Study Phases including potential Modelling

Stage 3: Design and Deliverables

This report is part of a package associated with Stage 1, of which a suite of technical documents is provided, as follows:

- A) Data and Gap Analysis and Feasibility Assessment report
- B) Catchment Conceptualisation and Water Balance Assessment (this report)
- C) Optioneering Report

The Stage 2 and 3 parts of the project are subject to the findings of the Stage 1 works.

1.1 Scope of report

The study area, located east of the Ouse Washes, comprises a heavily managed fenland landscape reliant on pumped drainage, with water levels and flows regulated by Denver Sluice Complex.

The scope of the analysis is to develop an estimate of the volume of water conveyed across the Internal Drainage Board (IDB) catchments and to assess whether a proportion of the pumped discharge could be re-directed for water supply purposes. The assessment is structured in three stages:

- First, a simplified water balance model has been applied to each IDB sub-catchment to evaluate the robustness of simulated pumping flows, considering data availability (Stantec report “331610105-100 Gap Analysis and Feasibility Assessment”) and key modelling assumptions.
- Second, a mass balance has been undertaken at the Denver Complex, linking simulated upstream inflows from the Ely Ouse River and Cut-off Channel to recorded sluice discharges. This provides an improved estimate of winter-period water availability that could potentially be stored and redistributed to support regional supply demand.
- Finally, a series of upstream pumping reduction scenarios were tested to assess the sensitivity of abstraction availability to reduced inflows at the Denver Complex.



1.2 Study area

The Water Balance Analysis covers, only, the flows leading to the Denver Sluice Complex. For a detailed description of the South Levels catchment area, please refer to the Section 1 in Stantec report “331610105-100 Gap Analysis and Feasibility Assessment”.

1.3 Sources of information

This Water Balance Analysis report has been prepared based on numerous sources of information, gathered from a range of Stakeholders and online sources. Specifically, the analysis considers the raw data summarised in Table 1-1. Rainfall and river flow, as well as their quality checks, are described in section 5 of the Stantec report “331610105-100 Gap Analysis and Feasibility Assessment”. Pumping stations, their characteristics and pumping hours dataset are described in section 6 of Stantec report “331610105-100 Gap Analysis and Feasibility Assessment”.

A brief description of the Denver Complex is provided in Section 5 of the Stantec report “331610105-100 Gap Analysis and Feasibility Assessment”, following a site visit undertaken on 4th December 2025. Sluice flow time series data were supplied by the Environment Agency (EA) at 15-minute resolution for the five principal sluices at the complex, namely Denver, Head (A.G. Wright), Diversion, Impounding and Residual. The dataset contained a limited number of missing records across the period of record; the processing approach adopted to address these gaps is described in section 4.2.

Abstraction licence and returns data were provided by the EA for the South Level Fenland system. The dataset comprised licence summary information for both live and lapsed licences, alongside monthly reported abstraction volumes covering the period January 2005 to December 2024. Licence attributes included licence number, type, effective and expiry dates, and licence status (e.g. revoked). Abstraction returns were supplied at licence and Format ID level, with reported quantities reflecting values submitted by licence holders. Data was provided under an EA Conditional Licence and is subject to usage restrictions. In addition, supplementary licence information was obtained from the EA’s public abstraction licensing dataset. This trading dataset provides further details on licence characteristics, including authorised abstraction quantities and annual maximum licensed volumes. The information was used to support interpretation of abstraction licences and to calculate some of the abstraction flow series as explained in the following sections 2.1.4 and 3.1.2.

Potential evapotranspiration (PET) is also considered for the water balance of the IDB sub-catchments. PET data was sourced from the EA gridded PET dataset, available for England and Wales at 1 km spatial resolution. The dataset provides daily PET estimates representing evaporation from well-watered short grass under conditions of unlimited water supply. PET values are derived using the FAO56 methodology and are aligned spatially with Met Office gridded climate datasets, enabling direct integration with rainfall inputs within water balance assessments. For this study, PET values were extracted from a representative EA grid cell located centrally within the IDB catchment area, providing daily evapotranspiration inputs to the water balance model.

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1 Introduction

Table 1-1 Summary of all datasets used to undertake the water balance assessment across the IDB catchment area.

Data	Type of products	Period of records	Data locations	Quality control
Rainfall	Daily totals of rainfall, in mm/d	1999 – 2025	Four rain gauges (Burwell, Denver, Ely, Mildenhall)	Gaps infilled and validated
River flow	Mean daily flow, in m ³ /d	1999 – 2025	Ten gauging stations (Beck, Burnt Mill, Dernford, Lode, Stapleford, Swaffham Bulbeck, Temple, Northwold, Abbey Heath and Whitebridge)	Gaps infilled by seasonal scaling
IDB pumping hours	Monthly pumping hours, in m ³ /month	2012 – 2025	All the pumping stations across IDB catchments	Missing sites identified and scaled from nearby sites.
IDB pump stations' characteristics	Individual capacities, number of pumps	-	All the pumping stations across IDB catchments	Missing capacity data at some sites infilled from Stantec records
Denver sluices flow	15-minute flow series	Mar 2009–Nov 2025	Five sluices (Denver, Head (A.G. Wright), Diversion, Impounding and Residual)	Short gaps interpolated, longer gaps reconstructed via water balance (during the winter months).
Abstraction licence flow	Monthly actual abstraction, in m ³ /month or max annual abstraction flow, in m ³ /year	2005 – 2024	Water abstraction licences (live and lapsed) for the South Level Fenland system	None
PET	Daily PET, in mm/d	2005 – 2024	Whole IDB catchment area	None

1.4 Report structure

The Water Balance Analysis is split into sections, with each section outlining data processing, analytical methods and discussion of outcomes. The report is organised as follows:

- **Section 2 – IDB Water Balance Assessment**
This section develops the water balance for all IDB sub-catchments, supporting model understanding and providing an initial assessment of catchment hydrological behaviour.
- **Section 3 – Water Availability and Catchment Overview**
This section quantifies flows across the South Levels area, focusing on the Lower Ely–Ouse catchment.
- **Section 4 – Denver Sluice Balance Assessment**
This section establishes the mass balance for the Denver Complex, analysing inflows and outflows and linking upstream pumping simulations to downstream discharge.
- **Section 5 –Water Balance Feasibility Assessment**
This section evaluates water availability for abstraction, estimating the volumes potentially available across the assessment period under licensed abstraction conditions.



- Section 6 – Potential Quantity Available
Discussion of yield benefits and practicality constraint discussions on how much water is likely available for the project to use.
- Section 7 – Conclusions
This section summarises the key findings and implications of the study.

2 IDB Water Balance Assessment

2.1 Data input preparation

2.1.1 Rainfall

Preparation of rainfall inputs for the water balance is described in Section 5 of the Stantec report “331610105-100 Gap Analysis and Feasibility Assessment”. Four Environment Agency rain gauges distributed across the South Level area were used: Burwell, Denver, Ely and Mildenhall. For each IDB sub-catchment, the nearest rain gauge was assigned as the representative rainfall source. Point rainfall totals were assumed to be representative of spatially distributed catchment rainfall at this stage, given the relatively small contributing areas (average IDB sub-catchment area of 13.1 km²). Rainfall depths were subsequently converted from mm/d to m³/d using the corresponding sub-catchment areas.

2.1.2 Pump station flow

To derive flow time series for each pump station, the monthly pumping hours provided by the Ely Group IDB were combined with pump station asset data, including individual pump capacities. Pump operation was assumed to respond to rainfall events and, therefore, to follow a similar temporal distribution within each month. All daily pump flow series were computed externally (in R), and the final outputs were compiled in the spreadsheet “IDB Pumping Stations Daily Flows.xlsx”, which is described in Appendix A.

Monthly pumping hours were disaggregated to daily values using rainfall as a temporal weighting factor for each IDB catchment. This was undertaken by first computing non-dimensional daily rainfall ratios, obtained by dividing daily rainfall totals by the corresponding monthly rainfall total. The monthly pumping hours for each station were then distributed across the days of the month in proportion to these rainfall ratios, thereby aligning pumping activity with observed rainfall patterns. To convert pumping hours into flow volumes, total daily operating hours (aggregated across all pumps at each station) were multiplied by the installed pump capacities. This produced daily pumped volumes expressed in m³/d, as defined by the following relationship:

$$Q_{PUMP,i} = 3600 \frac{d_i}{\sum_i d_i} PH PIC \quad (1)$$

where $Q_{PUMP,i}$ represents the daily pumped flow on day i of the month (m³/d); d_i is the rainfall depth recorded on day i ; $\sum_i d_i$ denotes the total rainfall depth accumulated over the corresponding month; PH is total pumped hours in the month (hour); PIC is the installed pump capacity (m³/s); and 3600 is the unit conversion factor (from hours to days) applied to ensure consistency of units.

Some pump stations are equipped with multiple pumps of differing capacities, which are not operated simultaneously under normal conditions but are brought into operation progressively during more intense rainfall events. This operational configuration applies to stations such as Lark, Cawdle Fen, Cam, Upware, Queensholme and Hundred Foot. For these stations, based on the IDB Ely group feedback, bespoke rules were implemented to estimate the effective PIC as a weighted average of the individual pump capacities assumed to be operating on a given day. Pumping regimes were defined using threshold values of daily rainfall totals, which were used as proxies to determine the number of pumps likely to have been active. The pump flow series sensitivity towards the thresholds selection is investigated later in this

study. This is not an accurate representation of the pumping on the given days as there is storage in the IDB drainage network and the pumps would draw the water levels down over time, however this was considered the most accurate manner of apportioning the pump data to estimate the usage of the larger pumps with the data available at the time. The corresponding formulations used to derive the effective *PIC* for these stations are presented below, where each pump individual capacity is reported in the Table 2-1.

- Lark:

$$PIC = 0.867 \frac{m^3}{s} \quad \text{if } d_i < 15 \text{ mm}$$

$$PIC = (0.75 \cdot 0.867 + 0.25 \cdot 1.7) \frac{m^3}{s} = 1.075 \frac{m^3}{s} \quad \text{if } d_i \geq 15 \text{ mm}$$

- Cawdle Fen:

$$PIC = 0.174 \frac{m^3}{s} \quad \text{if } d_i < 10 \text{ mm}$$

$$PIC = (0.5 \cdot 0.174 + 0.5 \cdot 0.365) \frac{m^3}{s} = 0.270 \frac{m^3}{s} \quad \text{if } 10 \text{ mm} \leq d_i < 15 \text{ mm}$$

$$PIC = (0.33 \cdot 0.174 + 0.66 \cdot 0.365) \frac{m^3}{s} = 0.298 \frac{m^3}{s} \quad \text{if } d_i \geq 15 \text{ mm}$$

- Hundred Foot:

$$PIC = 1.56 \frac{m^3}{s} \quad \text{if } d_i < 15 \text{ mm}$$

$$PIC = (0.75 \cdot 1.56 + 0.25 \cdot 3.38) \frac{m^3}{s} = 2.015 \frac{m^3}{s} \quad \text{if } d_i \geq 15 \text{ mm}$$

- Queensholme:

$$PIC = 1 \frac{m^3}{s} \quad \text{if } d_i < 15 \text{ mm}$$

$$PIC = (0.66 \cdot 1 + 0.33 \cdot 1.274) \frac{m^3}{s} = 1.080 \frac{m^3}{s} \quad \text{if } d_i \geq 15 \text{ mm}$$

- Upware:

$$PIC = 1.5 \frac{m^3}{s} \quad \text{if } d_i < 15 \text{ mm}$$

$$PIC = (0.66 \cdot 1.5 + 0.33 \cdot 2.1) \frac{m^3}{s} = 1.683 \frac{m^3}{s} \quad \text{if } d_i \geq 15 \text{ mm}$$

- Cam:

$$PIC = 2.3 \frac{m^3}{s} \quad \text{if } d_i < 10 \text{ mm}$$

$$PIC = (0.5 \cdot 2.3 + 0.5 \cdot 1.217) \frac{m^3}{s} = 1.759 \frac{m^3}{s} \quad \text{if } 10 \text{ mm} \leq d_i < 15 \text{ mm}$$

$$PIC = (0.33 \cdot 2.3 + 0.33 \cdot 1.217 + 0.33 \cdot 1) \frac{m^3}{s} = 1.491 \frac{m^3}{s} \quad \text{if } d_i \geq 15 \text{ mm}$$

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2 IDB Water Balance Assessment

Table 2-1 Table summarising pump characteristics, including the number of pumps per pumping station, pump type, and individual capacity used in this analysis. The table is extracted from Table 7-1 of the Stantec report “331610105-100 Gap Analysis and Feasibility Assessment”.

Pumping station/ IDB name	Pumping type	Capacity
Lark, Burnt Fen	Diesel X1	1.7m ³ /s
	Electric X3	0.867 m ³ /s
Cawdle Fen/Cawdle Fen	Flygt submersible X2	0.365m ³ /s
	Hawthorne Davey vertical suspended	0.174 m ³ /s
Hundred Foot, Littleport & Downham	Single Gwynns (diesel)	3.38 m ³ /s
	Submersible x 3 (electric)	1.56 m ³ /s
Queenholme, Old West	Electric x2	1.0m ³ /s
	Electric	1.274m ³ /s
Upware, Swaffham	Allen electric vertical suspended	2.1 m ³ /s
	Allen electric submersible x 2	1.5 m ³ /s
Cam, Waterbeach Level	Allen Gwynne (diesel)	1.0m ³ /s
	Electric	1.217m ³ /s
	Electric (fish friendly)	2.3m ³ /s

For a subset of pump stations operating within the South Levels area — primarily those located within the Southery and District, Stoke Ferry and Northwold IDBs — pumping data was not available. These pumping stations include Catsholme, Hilgay, Southery, Oulsham, Hockwold, Old Engine, both Roxham stations, Wretton Fen, Cornerways, Fordham, Moors and Haddenham. In the absence of observed pumping records, flows were estimated using a proportional area-scaling approach, consistent with the simulation methodology described above. Pumped volumes were inferred by transferring flows from hydrologically comparable, gauged donor IDB sub-catchments with similar geographic and drainage characteristics. The scaling was applied based on relative contributing areas, following the formulation below:

$$Q_{UNMEAS} = \frac{A_{UNMEAS}}{A_{MEASURED}} Q_{MEASURED} \quad (2)$$

where Q and A represent, respectively, the pumped flow series and contributing area associated with pump stations lacking data (subscript “UNMEAS”) and those with measured pumping records (subscript “MEASURED”). Haddenham flows were derived using the Queensholme series (Figure 2-2), while Moors was estimated using Kerridge. Hilgay, both Roxham stations, Cornerways and Fordham were scaled from Ten Mile. Catsholme, Oulsham, Wretton Fen and Hockwold were estimated using Lark, whereas Old Engine was derived from Lakenheath and Southery from Whitehall.

2.1.3 Catchment Conceptualisation

The study area comprises several Internal Drainage Boards (IDB) which are public bodies that manage water levels in an area known as the Internal Drainage District (IDD). The IDBs within the study area are shown in Figure 2-1 and also listed below:



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- Haddenham Level Drainage Commissioners
- Ely Group of IDBs:
 - Burnt Fen IDB
 - Cawdle Fen IDB
 - Lakenheath IDB
 - Littleport & Downham IDB
 - Middle Fen & Mere IDB
 - Mildenhall IDB
 - Old West IDB
 - Padnal & Waterden IDB
 - Swaffham IDB
 - Waterbeach Level IDB
- Downham Group of IDBs:
 - Southery & District IDB
 - Stoke Ferry IDB
 - Stringsides IDB

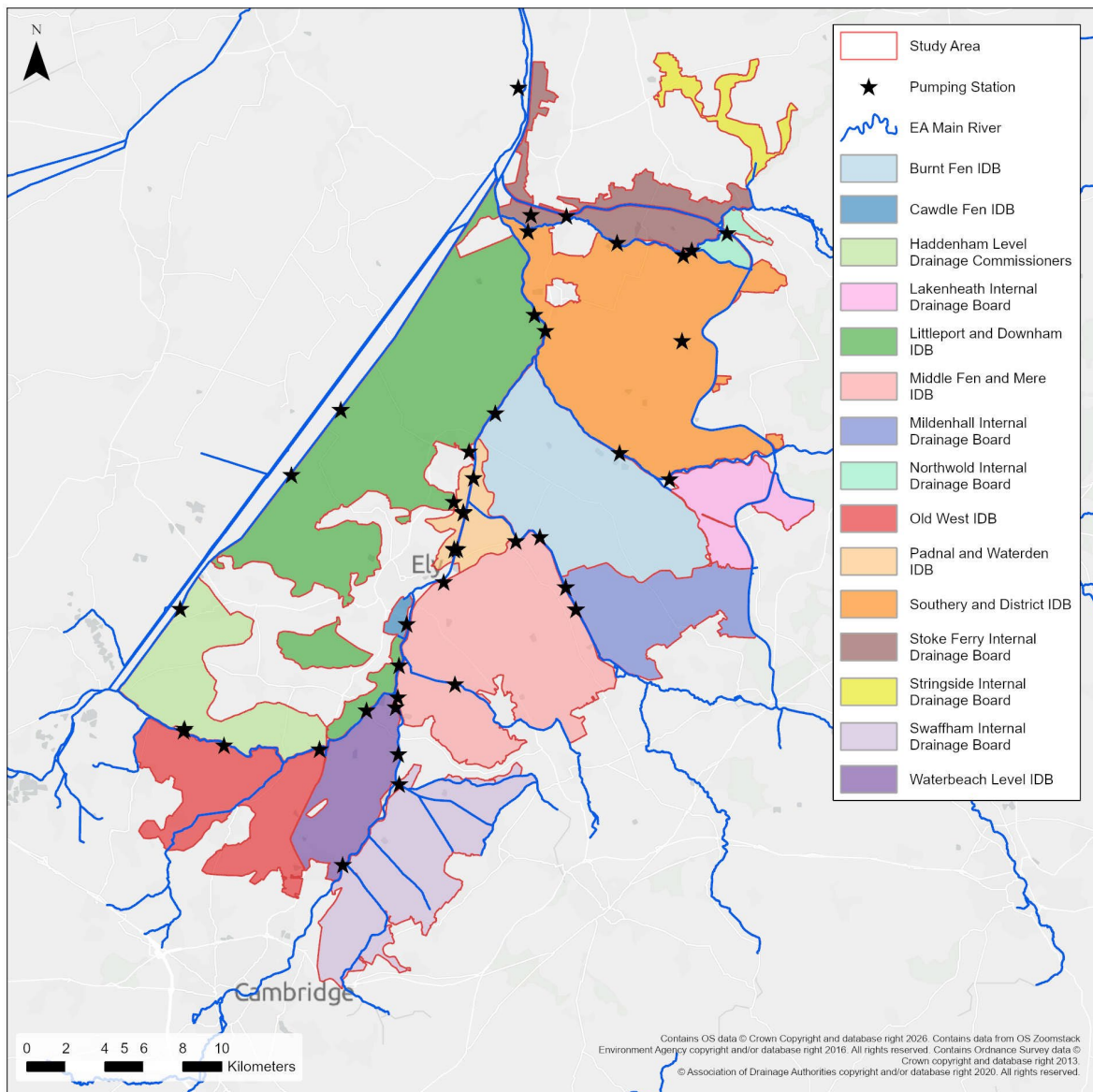


Figure 2-1: Study Area - Internal Drainage Boards



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The IDD areas are large operational catchments, with an extensive network of water management infrastructure that maintains and regulates water flow under different winter and summer operational regimes. As the IDD catchments are large in scale, with multiple inflow and outflow points, the IDB asset information and drain locations were assessed to delineate smaller contributing sub-catchments.

The Ely Group of IDBs and Downham Market Group of IDBs provided Stantec with spatial data of IDB drains and IDB assets including pumping stations, intakes / inlets, syphons, gate valves, outfalls, sluices, culverts, balancing reservoirs ditch flaps, overflows, tidal outfalls and weirs. IDB mapping publicly available on the Ely Group of IDBs, Downham Market Group IDBs and the Haddenham Level IDB websites was reviewed for additional information.

For each IDB area, ArcGIS Pro software was used to review and subdivide each IDD into individual sub-catchments. Sub-catchment delineation was initially based on the IDB ditch network and the location and operation of the pumping stations (shown in Figure 2-2) which typically pump water out from the IDB areas into the Main River network during the winter months. The IDB ditch network included flow direction arrows, however these typically represent winter flow direction, and it is not uncommon for flow direction to reverse during different operation regimes in winter compared with summer. In addition, penstocks (or also known as intakes, inlets and slackers) are typically located on drains which converge with the Main River network and are operated to open to allow water to flow into the IDB areas during the summer months. The syphons, which direct water beneath Main Rivers and into an adjacent IDB area, also connect catchments. Due to the low lying, flat topography across the South Levels IDD areas, the catchment divides could not be assessed based on changes in topography. In places where the IDB drain flow arrows converged or were unclear, the road network and presence of additional smaller drains (not classified as IDB drains) was reviewed to divide the catchments.

An initial version of the IDD sub-catchment delineations were discussed during consultation with the Principal Engineer at the Ely Group of IDBs, and delineations were subsequently altered to represent the drainage catchments to greater accuracy. The final IDB sub-catchments are shown in Appendix B.



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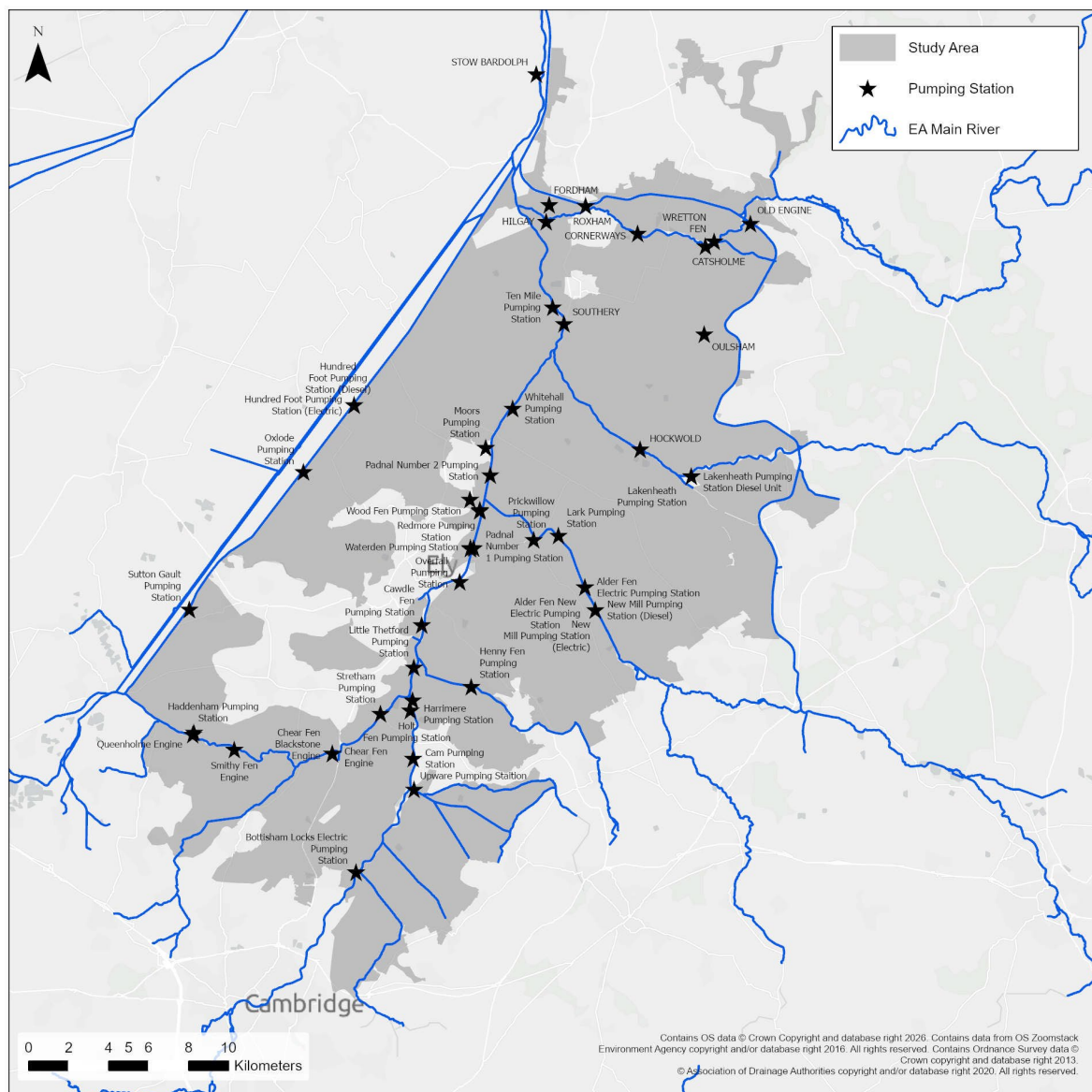


Figure 2-2: Study Area – Pumping Stations

2.1.4 IDB Abstraction licence flow

Abstraction flow series were derived using information from both the EA abstraction returns dataset and the public abstraction licensing dataset. All available licence records were first reviewed to establish licence lineage and temporal continuity (e.g., transitions from licence number 6/33/26/S/0370 to 6/33/26/S/0370/R01). Licence locations and their associated Format IDs were then spatially assigned across the South Levels study area. This was undertaken through cross-referencing information between the two datasets and, where records were incomplete, through interpretation of the site descriptions provided within the Format ID metadata. Once licences and corresponding Format IDs were matched to individual IDB sub-catchments, abstraction flow time series were constructed by distributing the reported monthly abstraction volumes evenly across the number of days within each month (i.e., monthly volume divided by days per month), based on the EA returns dataset. Both groundwater abstraction licences and

licences held by the EA were excluded from the analysis. This is because the EA licences correspond with large water transfers on main rivers which have been assessed using other methods. This study has excluded understanding of the impact of groundwater abstraction on the IDB catchments at this phase of assessment, accepting this as an uncertainty within the calculations. The number of discarded groundwater abstraction licence is 3 out of 494. All IDB abstraction licence flow series were computed externally (in R), and the final outputs were compiled in the spreadsheet “IDB Abstractions Daily Flows.xlsx”, which is described in Appendix A.

2.1.5 PET

PET impacts were prepared for the South Level study area using the Environment Agency gridded PET dataset. A representative grid cell covering the IDB catchments was selected, and daily PET series were extracted in mm/d. These values were subsequently converted to m³/d and scaled using the contributing area of each IDB sub-catchment.

2.2 Methodology

For each IDB we simulate the water balance with inputs of rainfall, and outputs of potential evapotranspiration, and surface water abstractions. For the sake of simplicity, we assume the storage as negligible during the period of records studied, which lead us to obtain an equation to estimate the volume discharged by the pumping station for each sub-catchment. This can be expressed by the following equation:

$$Q_{PUMP} = R - Q_{ABS} - PET \quad (3)$$

where the storage change is assumed to be almost zero, R is sub-catchment rainfall, Q_{PUMP} is the pumped flow, Q_{ABS} is the abstracted flow, and PET is potential evapotranspiration. All terms are expressed in m³/d. Using this balance, we will estimate Q_{PUMP} for each sub-catchment and compare it with the pump flow simulated from pump operating hours. This allows us to assess the quality of our pump station daily time series reconstruction and adequacy of the assumptions made to obtain the final pump station flows. All the terms of equation (3) were handled on Excel for all the IDB sub-catchments, and the final outputs are located in the spreadsheet “IDB Water Balance Assessment.xlsx”, which is described in Appendix A.

2.3 IDB understanding

2.3.1 Framework sensitivity and summer performance constraints

The pump station flow series derived from the water balance was compared against the series simulated from the pumping hours dataset. An example is provided for the IDB sub-catchment drained by Queensholme Pump Station. Figure 2-3 presents cumulative flows for both the simulated pump series (denoted “PUMP FLOW”) and the water balance-derived pumping estimate (denoted “PUMP FLOW WB”) over the common period of record shared across all input datasets.

For the pumping-hours-based simulation, multiple rainfall thresholds were tested to assess the sensitivity of the derived pumping regime to assumed operational triggers. These are shown as four coloured lines in the lower portion of the plot. In addition, an alternative temporal disaggregation was tested using PET

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in place of rainfall to distribute pumping activity. The resulting cumulative series are closely aligned, indicating that the simulated pumping volumes are relatively insensitive to the selected rainfall thresholds and temporal weighting assumptions.

In contrast, the water balance-derived pumping estimates are represented by two cumulative curves positioned above the pumping-hours simulations. The green curve represents the cumulative sum of all positive daily balance values (i.e., excluding negative flows), implemented to remove negative pumping estimates arising from high PET values and unmodelled storage dynamics along with unknown inflows from IDB intakes. The orange curve represents the cumulative balance where only negative summer values were set to zero prior to aggregation. Although a divergence is observed between these two balance-based estimates, both highlight the presence of additional summer losses not fully captured within the available datasets or calculation. This discrepancy is likely driven by unrecorded slacker and penstock operations, alongside seasonal soil moisture retention effects influencing catchment storage dynamics.

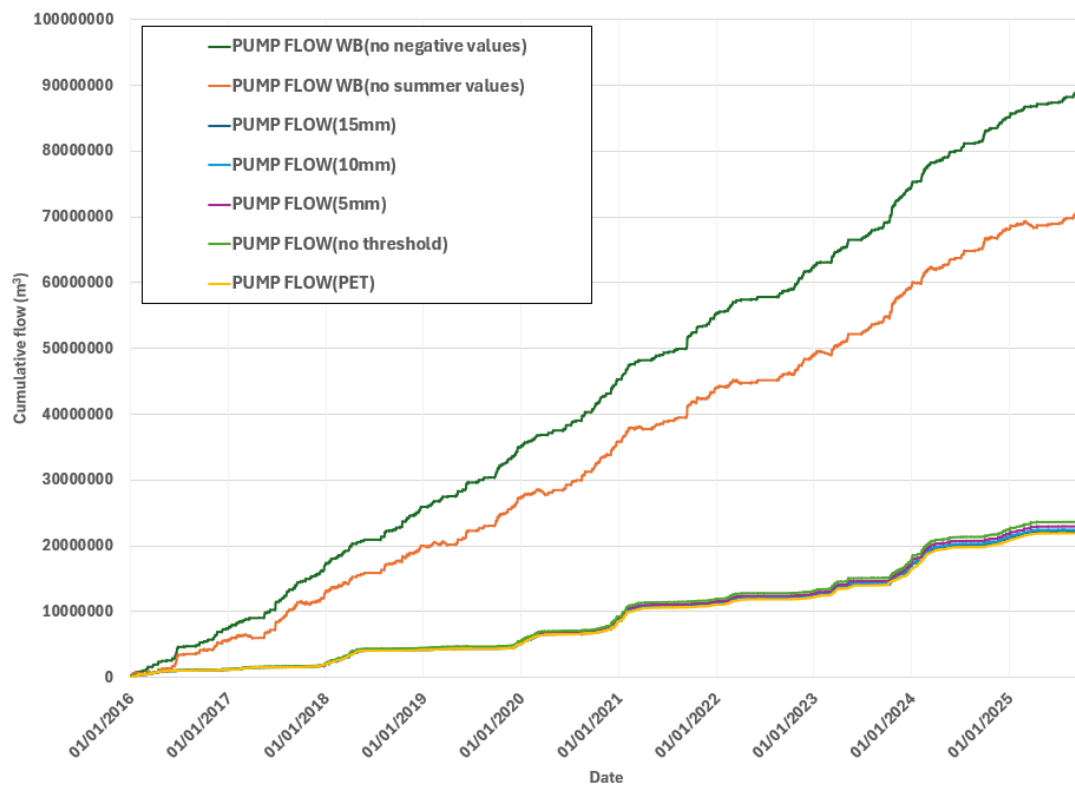


Figure 2-3 Cumulative flow at Queensholme Pump Station derived from pumping-hours data under varying rainfall thresholds and temporal weighting assumptions, compared against water balance estimates with negative daily flows excluded either entirely or for summer periods only.

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To further validate these findings, six-month cumulative flows were computed for each year over the winter period (defined as October–March, to align with the start of the water year) across the available record. This approach isolates the season during which water availability for abstraction is greatest and operational drainage processes are most active, while minimising the influence of poorly constrained summer balance components.

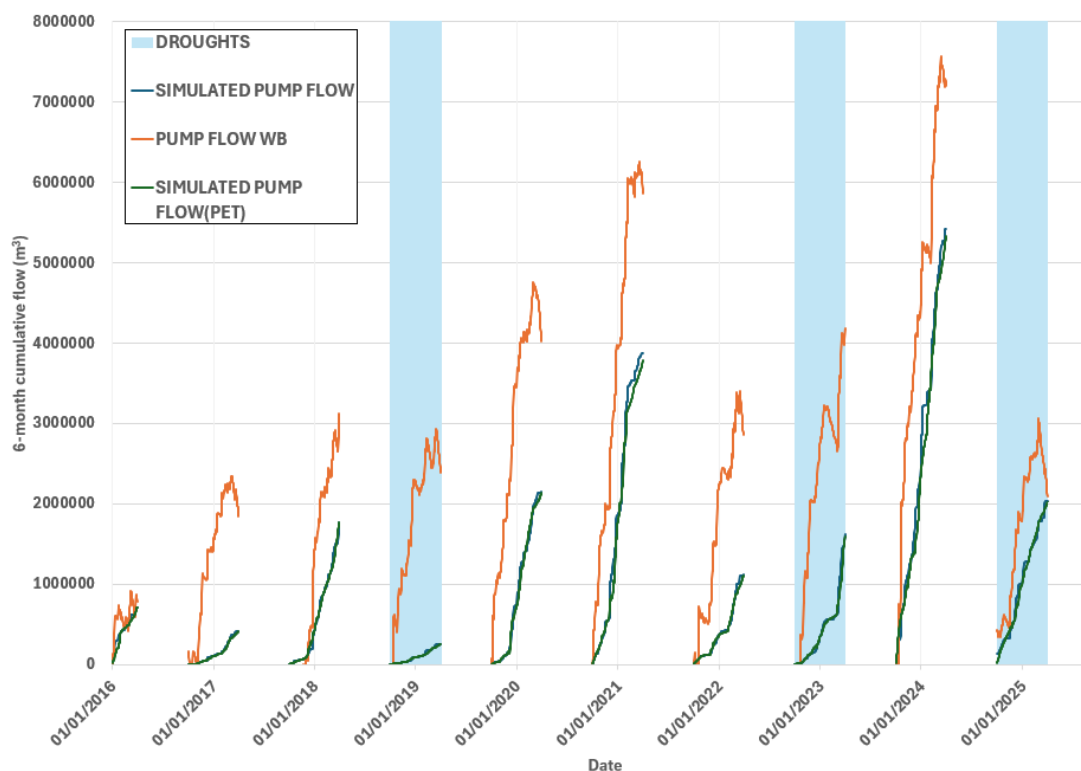


Figure 2-4 Six-month cumulative winter flows (Oct–Mar) at Queensholme Pump Station by year, comparing pump-hour-derived simulations (15 mm rainfall threshold; rainfall vs PET temporal weighting) against water balance estimates. Drought years are flagged across the records.

Results for the Queensholme Pump Station are presented in Figure 2-4. Improved agreement is observed between the simulated pumping series, and the water balance estimates during the winter period. In the figure, the orange curve represents the water balance-derived pumping series, while the blue curve corresponds to the pumping series simulated from operational data using the initially selected 15 mm rainfall threshold.

Known drought years have been highlighted within the record to support interpretation. These periods show comparatively weaker agreement between the two approaches, likely attributable to antecedent summer soil moisture deficits and the continued influence of operational controls — such as slacker and penstock management — extending into the early winter period.

Excluding these drought-impacted years, the simulated pumping series demonstrates good overall winter closure with the water balance estimates, as can be seen for the Redmore pump station in Figure 2-5, supporting its use as a representative proxy for catchment outflows within the wider system analysis.

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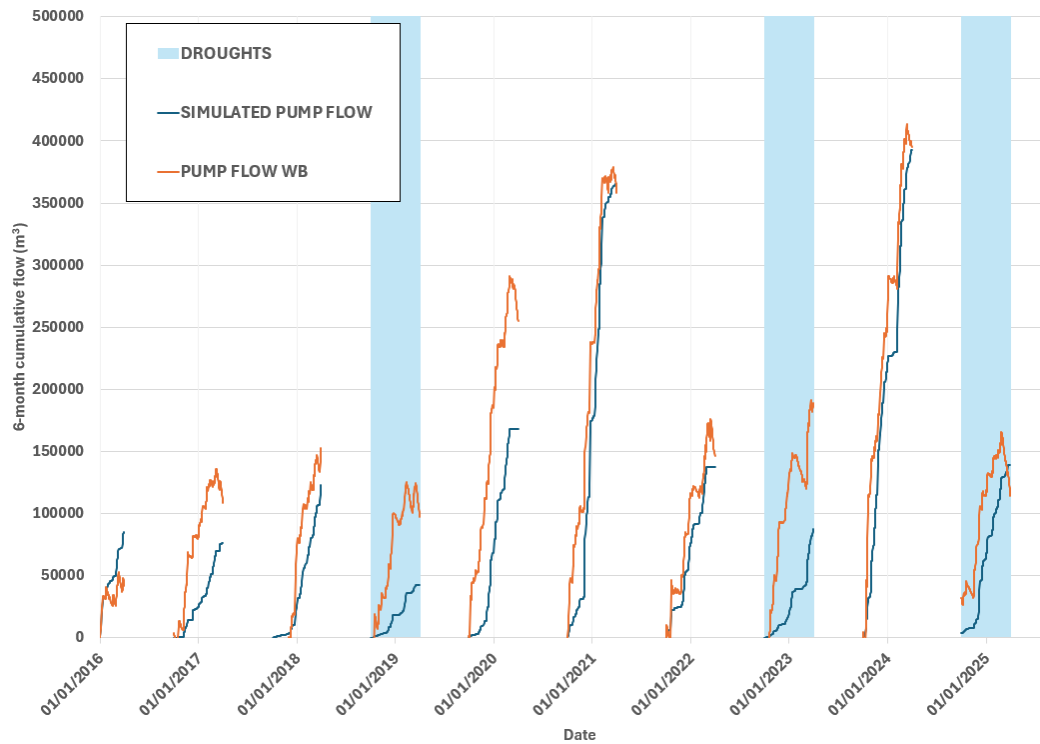


Figure 2-5 Six-month cumulative winter flows (Oct–Mar) at Redmore Pump Station by year, comparing pump-hour-derived simulations (15 mm rainfall threshold; rainfall vs PET temporal weighting) against water balance estimates. Drought years are flagged across the records.

2.3.2 Sensitivity towards the IDB sub-catchment delineation and groundwater recharge

Across the simulated pump station series, it can be observed that some stations consistently exhibit higher or lower winter flows compared to those derived from the water balance. This discrepancy is primarily associated with the initial delineation of IDB sub-catchments and their allocation to individual pump stations. An example is provided by the IDB sub-catchment drained by New Mill Pump Station, whose six-month cumulative winter flows are presented in Figure 2-6. In contrast, lower simulated pumping volumes relative to the water balance are observed for the neighbouring Prickwillow sub-catchment, as shown in Figure 2-7.

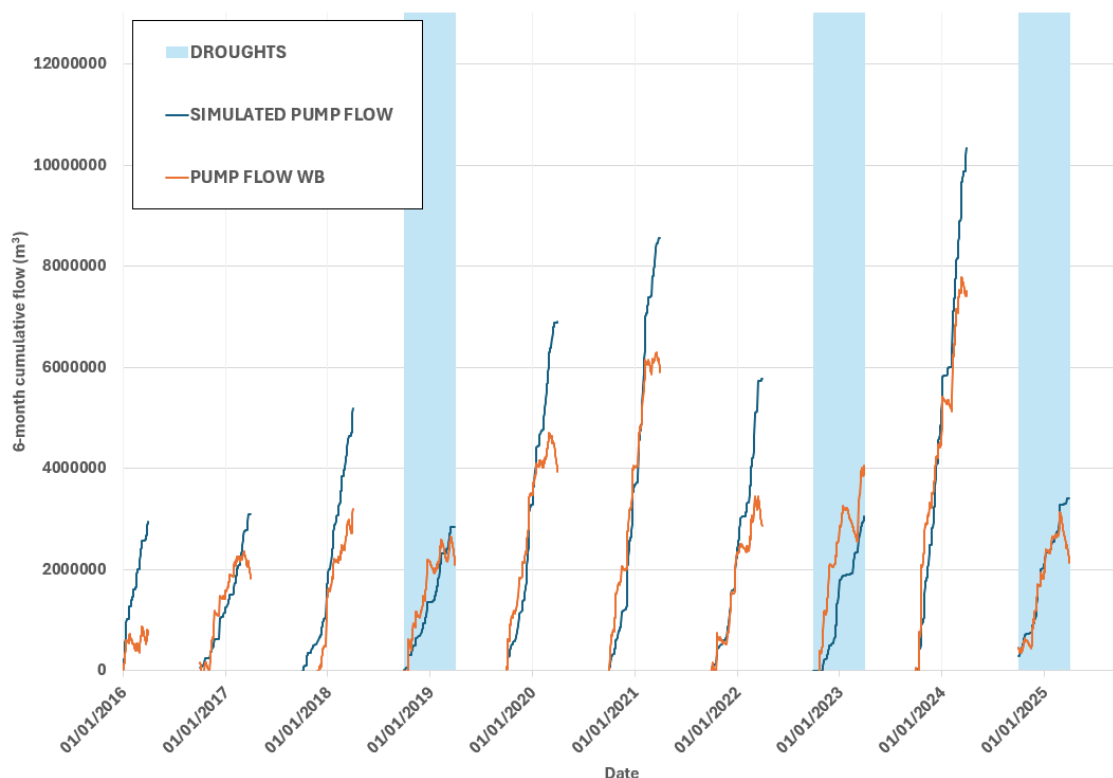


Figure 2-6 Six-month cumulative winter flows (Oct–Mar) at New Mill Pump Station by year, comparing pump-hour-derived simulations against water balance estimates. Drought years are flagged across the records.

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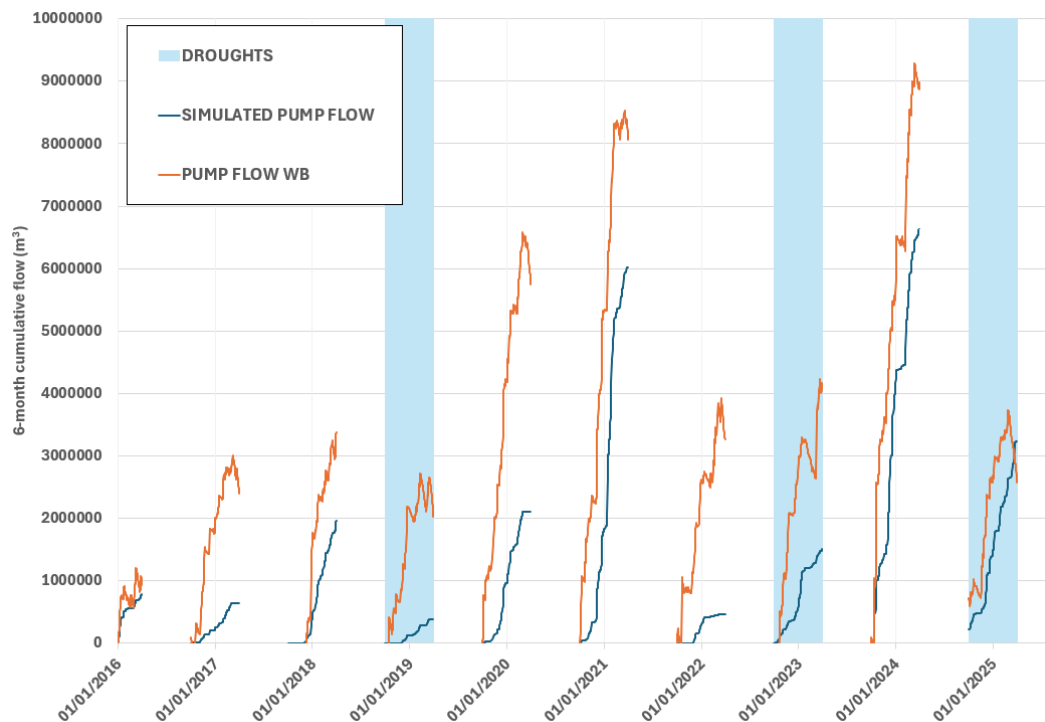


Figure 2-8 Six-month cumulative winter flows (Oct–Mar) at Prickwillow Pump Station by year, comparing pump-hour-derived simulations against water balance estimates. Drought years are flagged across the records.

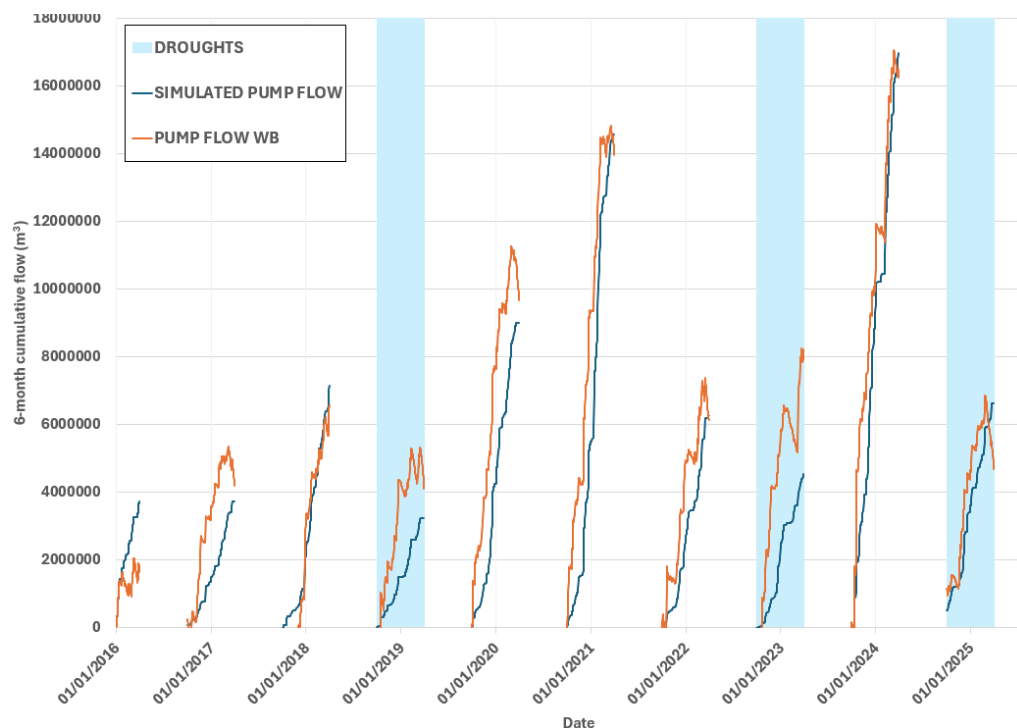


Figure 2-7 Six-month cumulative winter flows (Oct–Mar) of aggregated sub-catchment at New Mill plus Prickwillow Pump Station by year, comparing pump-hour-derived simulations against water balance estimates. Drought years are flagged across the records.



These two sub-catchments are hydraulically adjacent and part of the same wider IDB. When aggregated into a single larger drainage area, the combined inflows and losses tend to balance more effectively. This aggregation improves water balance closure as shown by Figure 2-8, reflecting the interconnected nature of the drainage network and cross-boundary flow interactions.

Another factor influencing the simulated pumping flow series is the presence of Chalk groundwater formations underlying parts of the eastern South Level catchment, as described in Section 4 of the Stantec report “331610105-100 Gap Analysis and Feasibility Assessment”. In these areas, some catchments exhibit pumping volumes that exceed those estimated through the surface water balance. This discrepancy reflects additional hydrological influences — particularly groundwater contributions — that are not currently represented within the water balance calculation. As a result, balance closure is weaker in groundwater-influenced systems where subsurface inflows supplement pumped drainage. An example is the IDB sub-catchment drained by Old Engine Pump Station, where water balance-derived pumping estimates are lower than those simulated from pumping hours data, as illustrated in Figure 2-9.

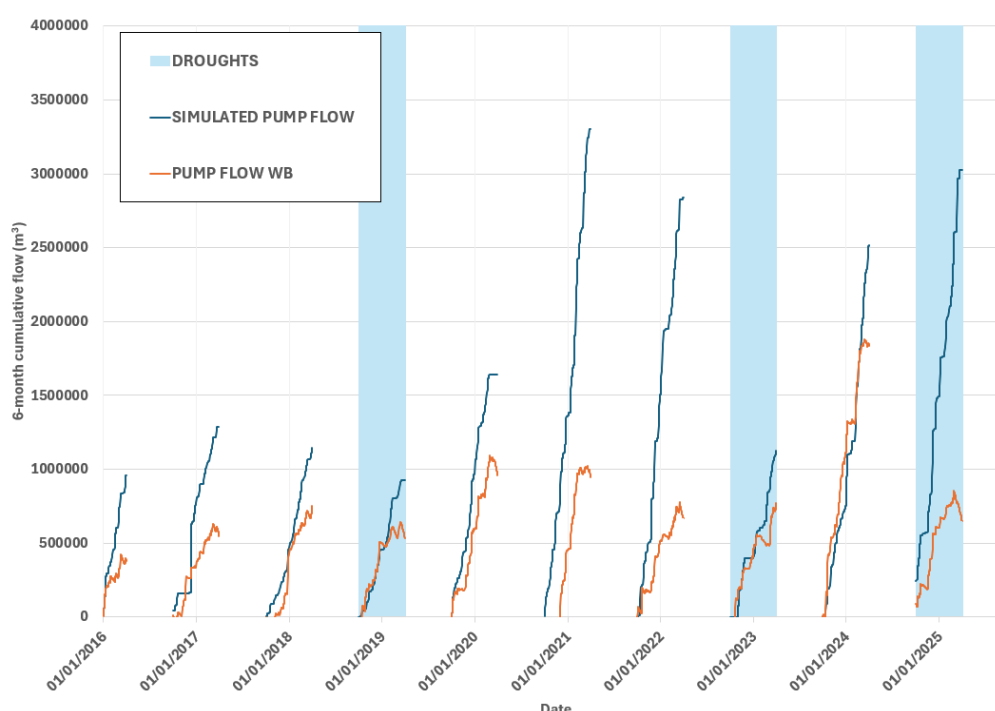


Figure 2-9 Six-month cumulative winter flows (Oct–Mar) at Old Engine Pump Station by year, comparing pump-hour-derived simulations against water balance estimates. Drought years are flagged across the records.

2.3.3 Reservoir planning feasibility

To identify areas most suitable for potential reservoir development, an optioneering assessment was undertaken across the South Level area. IDB sub-catchments were grouped into candidate development zones based on hydrological similarities and drainage connectivity.

For each group, previously simulated pumping series were analysed to assess water availability under low-flow conditions. The driest year within the period of record was first identified based on annual cumulative pumped volume. Within this lowest-flow year, the highest cumulative value achieved was extracted and compared against a threshold of 500,000 m³/year. For most sub-catchments, the driest

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year was identified as 2019, a drought-affected year across the study area. Sub-catchments previously aggregated for hydrological consistency (as described in Section 2.3.2) were assessed as combined units. This approach allows evaluation of whether sufficient water would be available even under adverse hydrological conditions.

Figure 2-10 summarises the results for all groups, distinguishing between sub-catchments where the threshold is met individually, met only when combined with neighbouring catchments, or not met even under aggregated conditions. The drainage areas of the Upper Lark, Little Ouse and Wissey appear particularly suitable for consideration in reservoir planning, while much of the Cam catchment and parts of the downstream Ely–Ouse area also demonstrate adequate potential.

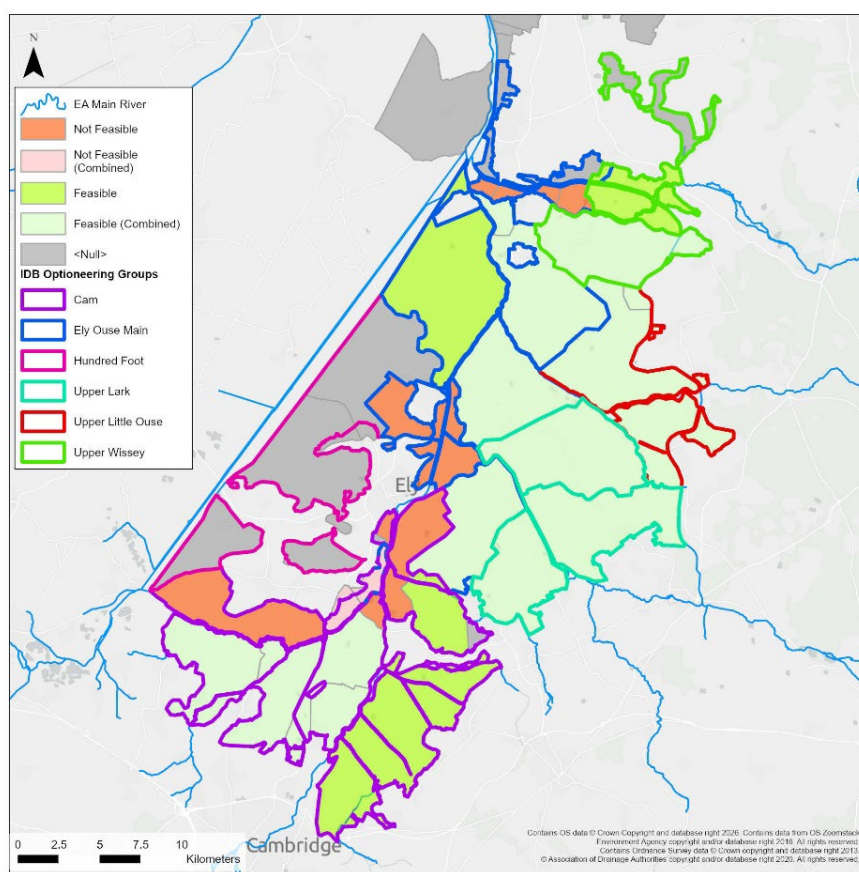


Figure 2-10 Spatial distribution of reservoir optioneering feasibility across IDB catchment groups, based on the highest cumulative flow total observed during the driest year on record.

3 Water Availability and Catchment Overview

3.1 Data input preparation

3.1.1 Upstream channel flow

To quantify flows along the Ely–Ouse River, it was necessary to account for all tributary inflows entering from the right bank across the South Levels area. These confluences convey both pumped discharges from IDB systems (as described in previous sections) and natural upstream catchment inflows. All upstream tributaries flow series were calculated and the final outputs were reported in the spreadsheet “South Levels Upstream flows.xlsx”, which is described in Appendix A.

To characterise these upstream inflows over the study period, flow records from multiple gauging stations located upstream of the IDB catchments were analysed. Gauges were selected across the principal catchments draining into the South Levels system, namely the Wissey, Little Ouse, Lark and Cam rivers, together with their associated upstream contributing areas as shown in Figure 3-1. Further details on the study area and tributary configuration are provided in Section 3 of the Stantec report “331610105-100 Gap Analysis and Feasibility Assessment”.

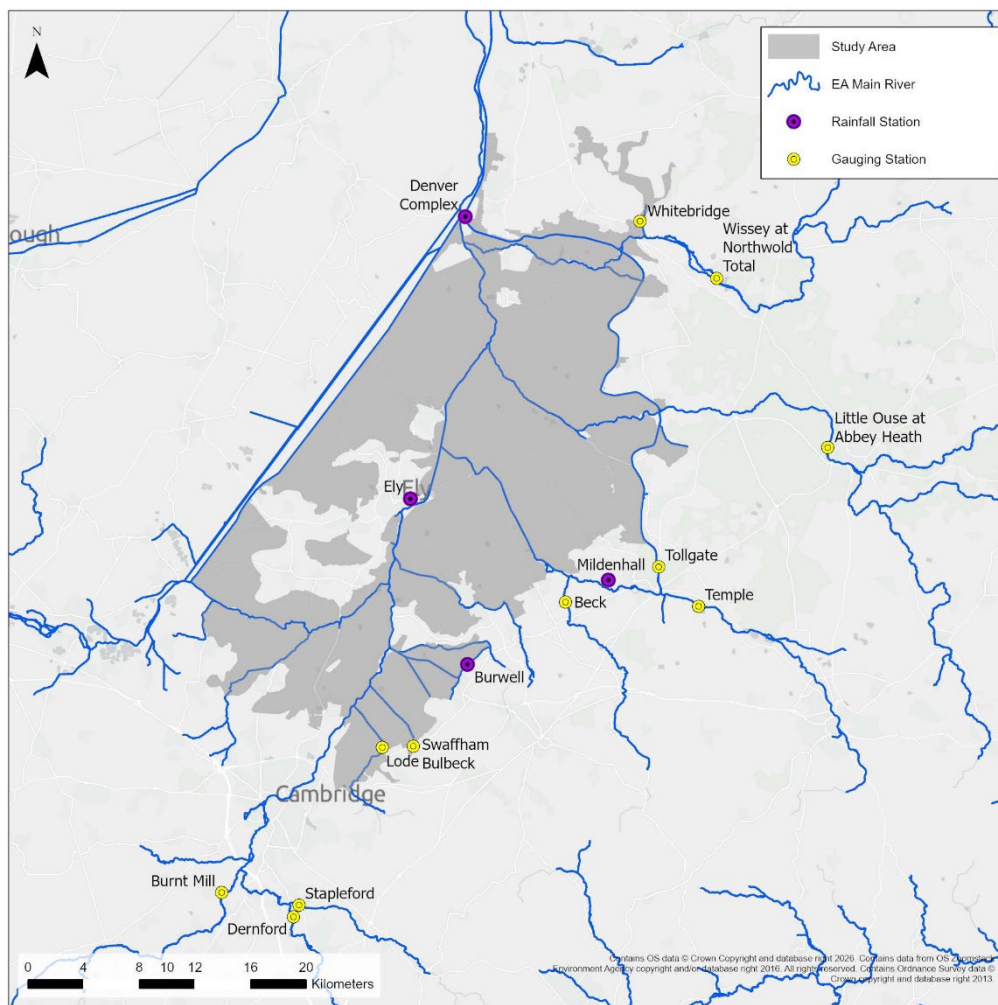


Figure 3-1: Study Area – Rainfall and Gauging Stations

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3 Water Availability and Catchment Overview

For each catchment, available flow time series and corresponding catchment areas were compiled. The flow series were firstly converted from m³/s to m³/d. To account for ungauged areas located between the upstream gauging stations and the IDB catchment boundary, an area-scaling approach was applied. This enabled estimation of tributary inflows at the interface between the upper catchments and the South Levels drainage system. The formulas used are reported below, where Q and A represent respectively the flow and the contributing area specified by their subscript.

- Wissey: there are two flow gauges available, namely “Wissey at Northwold” and “Stringside” at Whitebridge”. We perform the following scaling:

$$Q_{WISSEY\ UPSTREAM} = \frac{A_{WISSEY\ UPSTREAM}}{(A_{NORTHWOLD} + A_{WHITEBRIDGE})} (Q_{NORTHWOLD} + Q_{WHITEBRIDGE}) \quad (4)$$

- Little Ouse: there is only one flow gauge available, namely “Little Ouse at Abbey Heath”. We perform the following scaling:

$$Q_{LITTLE\ OUSE\ UPSTREAM} = \frac{A_{LITTLE\ OUSE\ UPSTREAM}}{A_{ABBEY\ HEATH}} Q_{ABBEY\ HEATH} \quad (5)$$

- Lark: there are two flow gauges available, namely “Lark at Temple” and “River Kennett at Beck”. We perform the following scaling:

$$Q_{LARK\ UPSTREAM} = \frac{A_{LARK\ UPSTREAM}}{(A_{TEMPLE} + A_{BECK})} (Q_{TEMPLE} + Q_{BECK}) \quad (6)$$

- Cam: We first perform the scaling for the upper Cam catchment, comprising of the Upper Cam river and the streams Rhee and Granta. In this catchment there are three flow gauges available, namely “Granta at Stapleford”, “Cam at Dernford” and “Rhee at Burnt Mill”. We perform the following scaling:

$$Q_{UPPER\ CAM} = \frac{A_{UPPER\ CAM}}{(A_{STAPLEFORD} + A_{DERNFORD} + A_{BURNT\ MILL})} (Q_{STAPLEFORD} + Q_{DERNFORD} + Q_{BURNT\ MILL}) \quad (7)$$

Then we compute the scaling for the lower Cam catchment, consider the upper Cam flow alongside the two flow gauges “Gutter Bridge Ditch at Swaffham Bulbeck” and “Quy Water at Lode”. We perform the following scaling:

$$Q_{CAM\ UPSTREAM} = \frac{A_{UPPER\ CAM} + A_{LOWER\ CAM}}{(A_{UPPER\ CAM} + A_{SWAFFHAM} + A_{LODE})} (Q_{UPPER\ CAM} + Q_{SWAFFHAM} + Q_{LODE}) \quad (8)$$



3.1.2 Stream abstraction licences

Time series were derived for all licences associated with surface water abstractions, following the methodology described in Section 2.1.3 for IDB abstractions. Licences held by the EA were excluded from the assessment to avoid double counting. For licences identified within the EA abstraction returns dataset, monthly reported abstraction volumes were assigned to the relevant watercourse and evenly distributed across the number of days in each month to generate daily flow series. For licences retrieved from the public abstraction licensing dataset (where only authorised volumes were available), abstraction flows were derived based on the annual maximum licensed quantity and the stated licence purpose. For licences with the purpose “Spray Irrigation – Direct”, one third of the annual maximum licensed volume (based on the landowner questionnaire response (subsection 2.1.1 in Stantec report “331610105-100 Gap Analysis and Feasibility Assessment”) was assumed to occur over the irrigation season (April–September) and distributed evenly across that six-month period. Conversely, for licences with the purpose “Spray Irrigation – Storage”, one third of the annual maximum licensed volume was assumed to occur over the winter abstraction period (October–March) and distributed evenly across those six months. For all other licence purposes, the annual maximum licensed volume was distributed uniformly across the year (i.e., annual maximum divided by 365 days). All abstraction licence series were computed externally (in R) and the final outputs were compiled in the spreadsheet “River Abstractions Daily Flows.xlsx”, which is described in Appendix A.

3.2 Methodology

3.2.1 Ely-Ouse river at Denver complex

To estimate Ely–Ouse River flows entering the Denver Complex, travel time within the river network was assumed to be negligible. This assumption is considered reasonable given the very low channel gradients and ponded nature of the South Levels system. Under this simplification, all upstream contributions discharged into the main river network are assumed to reach the Denver Complex within the same daily timestep. Accordingly, Ely–Ouse inflow at Denver (Q_{EO}) was derived using a mass balance formulation, expressed by the following equation:

$$Q_{EO} = Q_{WISSEY} + Q_{LITTLE OUSE} + Q_{LARK} + Q_{SOHAM LODGE} + Q_{CAM} + Q_{PUMPS} - Q_{ABSTRACTIONS} \quad (9)$$

where Q_{WISSEY} , $Q_{LITTLE OUSE}$, Q_{LARK} , $Q_{SOHAM LODGE}$ and Q_{CAM} represent the tributary inflows entering the Ely–Ouse River. Q_{PUMPS} denotes the contribution from the pumping stations discharging directly into the main Ely–Ouse channel, while $Q_{ABSTRACTIONS}$ represents the total licensed surface water abstraction flows associated to the whole Ely–Ouse river network interesting the South Levels area, as derived in Section 3.1.2. Each tributary term is defined as the sum of pumped discharges routed into the tributary and the upstream natural flows estimated in Section 3.1.1:

$$Q_{WISSEY} = Q_{HILGAY} + Q_{CORNERWAYS} + Q_{CATSHOLME} + Q_{WRETTON FEN} + Q_{OLD ENGINE} + Q_{WISSEY UPSTREAM} \quad (10)$$

$$Q_{LITTLE OUSE} = Q_{HOCKWOLD} + Q_{LAKEHEATH} + Q_{LITTLE OUSE UPSTREAM} \quad (11)$$

$$Q_{LARK} = Q_{PRICKWILLOW} + Q_{LARK} + Q_{ALDER FEN} + Q_{NEW MILL} + Q_{LARK UPSTREAM} \quad (12)$$

$$Q_{SOHAM LODE} = Q_{HENNY FEN} \quad (13)$$

$$Q_{CAM} = Q_{HARRIMERE} + Q_{HOLT FEN} + Q_{CAM PUMP} + Q_{UPWARE} + Q_{BOTTISHAM LOCKS} + Q_{CAM UPSTREAM} \quad (14)$$

while the pump flow discharging into the Ely–Ouse is defined as the combined contribution of all pump stations discharging directly into the main channel:

$$\begin{aligned} Q_{PUMPS} = & Q_{TEN MILE} + Q_{SOUTHERY} + Q_{WHITEHALL} + Q_{MOORS} + Q_{PADNAL2} + Q_{WOOD FEN} + Q_{KERRIDGE} \\ & + Q_{REDMORE} + Q_{WATERDEN} + Q_{PADNAL1} + Q_{OVERFALL} + Q_{CAWDLE FEN} \\ & + Q_{LITTLE THETFORD} + Q_{STRETHAM} + Q_{CHEAR FEN} + Q_{QUEENSHOLME} + Q_{HADDENHAM} \end{aligned} \quad (15)$$

All the above flows are expressed in m³/d. All the balance flow series were computed and the final outputs were reported in the spreadsheet “Denver complex water balance.xlsx”, which is described in Appendix A and includes also the Cut-off channel flow series introduced below.

3.2.2 Cut-off channel flow at Denver complex

The flow entering the Denver Complex via the Cut-off Channel (Q_{COC}) was estimated using an approach analogous to that described above. However, upstream contributions diverted from the main tributaries (Lark, Wissey and Little Ouse) into the Cut-off Channel were not explicitly included, due to the absence of sufficiently detailed flow data. This simplification is not expected to materially affect the overall volume balance, as these flows remain accounted for within the main tributary pathways ultimately reaching Denver. Accordingly, the Cut-off Channel inflow was defined as the aggregate discharge from pump stations ($Q_{ROXHAM1}$, $Q_{ROXHAM2}$, $Q_{FORDHAM}$) directly connected to it, minus licensed surface water abstractions ($Q_{COC ABSTRACTIONS}$), expressed in m³/d as follows:

$$Q_{COC} = Q_{ROXHAM1} + Q_{ROXHAM2} + Q_{FORDHAM} - Q_{COC ABSTRACTIONS} \quad (16)$$

4 Denver Sluice Balance Assessment

4.1 Data input preparation

To derive flow time series suitable for the water balance assessment at the Denver Complex, it was first necessary to standardise both units and temporal resolution of the Denver complex sluice data. Raw sluice flow data provided by the EA were supplied at a 15-minute timestep for each of the five principal sluices. The dataset also contained a number of missing records, as well as some negative flow values which are not physically meaningful and are attributed to recording or instrumentation errors.

The series were therefore aggregated to a daily resolution. This was undertaken by converting each 15-minute flow observation (m^3/s) into a corresponding discharge volume. For each record, the volume transferred during the 15-minute interval was calculated as:

$$\text{Volume} = Q \times 15 \times 60 \quad (17)$$

where Q is the recorded flow (m^3/s), 15 represents the interval duration in minutes, and 60 is the conversion factor from minutes to seconds. Daily discharge volumes were subsequently obtained by summing all 15-minute interval volumes within each day. Where individual days contained only a small number of missing intervals, aggregation proceeded using the available records. Conversely, where an entire day comprised missing 15-minute observations, the daily discharge was assumed to be zero.

Following aggregation to a daily timestep, negative flow values were reviewed and treated separately for each sluice. The Denver, Diversion and Head sluices contained only a limited number of isolated negative daily records, typically bounded by zero-flow conditions. These values were corrected through linear interpolation. A different treatment was required for the Residual and Impounding sluices, where negative daily values were more prevalent and could not be reliably infilled through simple interpolation. Infilling of these gaps required derivation of the mass balance equations and is addressed in the following subsection, once the governing relationships have been established. All daily sluice flow series were computed externally (in R) and the final outputs were compiled in the spreadsheet “Sluices_daily_flows.xlsx”, which is described in Appendix A.

4.2 Methodology and flow data infilling

The Denver Complex is a group of five major hydraulic control structures on the River Great Ouse. The complex comprises several sluices — Denver, Head (A.G. Wright), Diversion, Impounding and Residual sluices — which collectively manage discharges to the Flood Relief Channel and tidal Great Ouse, and diversions to the Cut-off Channel, while maintaining upstream water levels for navigation and water resource management. More details about it can be found in section 7 of the Stantec report “331610105-100 Gap Analysis and Feasibility Assessment”.

To understand the water available at Denver, and how accurate the sluice data was, a mass balance was developed. The analysis considers upstream inflows (Q_{IN}) entering the complex and downstream outflows (Q_{OUT}) discharged via the Flood Relief Channel and the tidal river system. These flow components can be expressed as follows:

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$$Q_{IN} = Q_{EO} - Q_{DIVERSION} + Q_{COC} \quad \text{if } Q_{IMPOUNDING} > 0 \quad (18)$$

$$Q_{IN} = Q_{EO} - Q_{DIVERSION} \quad \text{if } Q_{IMPOUNDING} = 0 \quad (19)$$

$$Q_{OUT} = Q_{DENVER} + Q_{HEAD} + Q_{RESIDUAL} + Q_{IMPOUNDING} \quad (20)$$

where Q_{HEAD} , $Q_{IMPOUNDING}$, $Q_{RESIDUAL}$, $Q_{DIVERSION}$ and Q_{COC} represent flows through the five principal sluices expressed in m³/d. The inflow formulations reflect the operational role of the Cut-off Channel. When the Impounding Sluice is open — typically during winter conditions — flows conveyed via the Cut-off Channel contribute to the total inflow entering the complex. Conversely, during summer periods the Cut-off Channel operates primarily as a storage system to support water transfers (toward Essex supply), and the Impounding Sluice is generally closed, under these conditions, inflow to the complex is defined solely by Ely–Ouse River discharge minus the volume diverted into the Cut-off Channel for transfer. Q_{IN} in [00], even though it transfers flow into the Flood Relief Channel as the Q_{COC} there were high risks in double counting the tributary flow, this is why [00] is used to account for additional flow from pumping stations entering the channel instead.

The mass balance equations presented above were also employed to support the data gap-infilling process described in Section 4.1. Negative daily values were more prevalent within the Residual and Impounding sluice series and could not be reliably corrected through simple interpolation, particularly where gaps extended beyond a single day. An initial linear interpolation was applied to both series where negative values were isolated and bounded by positive or zero flows. However, where longer gaps were present, a mass balance approach was adopted. For the Residual Sluice, missing daily values were estimated using the relationship:

$$Q_{RESIDUAL} = Q_{EO} - Q_{DENVER} - Q_{HEAD} - Q_{DIVERSION} \quad (21)$$

For the Impounding Sluice, longer gaps were infilled by considering that total inflow to the Denver Complex equalled total outflow. Under this balance condition:

$$Q_{IN} = Q_{OUT} = Q_{DENVER} + Q_{HEAD} + Q_{RESIDUAL} + Q_{IMPOUNDING} \quad (22)$$

Rearranging yields:

$$Q_{IMPOUNDING} = Q_{IN} - Q_{DENVER} - Q_{HEAD} - Q_{RESIDUAL} \quad (23)$$

We also tested an alternative approach whereby gaps in the $Q_{IMPOUNDING}$ series were estimated as the sum of the Cut-off Channel flow and the flow through the Diversion Sluice. However, this method produced lower cumulative volumes in several years which provided a poorer fit with the existing data, leading us to retain the primary approach, which relies on the Ely–Ouse inflow and the associated pumped contributions used in its computation. All the flow series and gaps infilling discussed in this subsection, as well as the following analysis, are organised and presented in the spreadsheet “Denver complex water balance.xlsx”, described in Appendix A.



4.3 The balance assessment

Ideally, the computed inflow should equal the outflow from the complex. This was assessed by plotting the two daily volume series for comparison. As shown in Figure 4-1, the inflow and outflow demonstrate

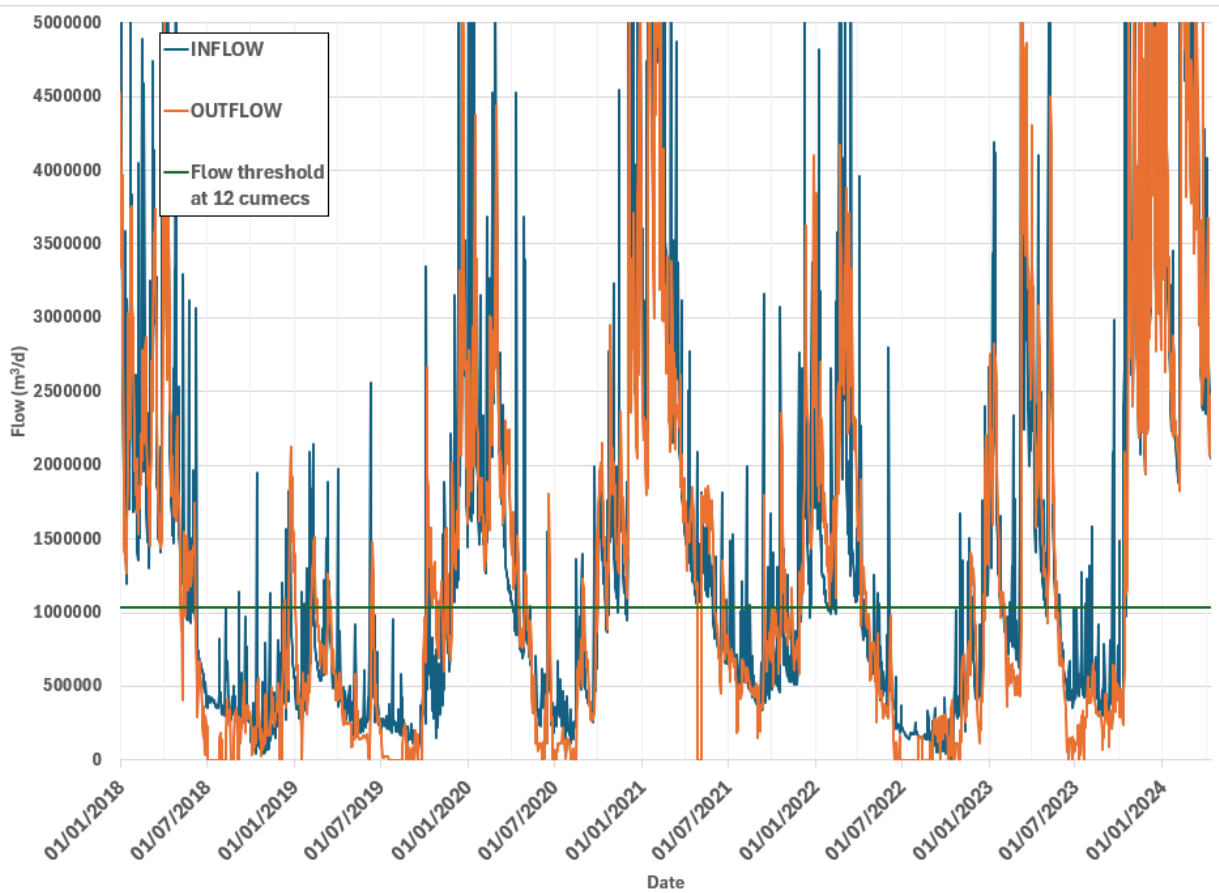


Figure 4-1 Time series of Q_{IN} (INFLOW, blue) and Q_{OUT} (OUTFLOW, orange) over the analysis period. The green horizontal line represents the winter Hands-off Flow (HoF) abstraction threshold, set at 12 m³/s.

good agreement during the winter period, with weaker alignment observed in summer months due to the reasons discussed in subsection 2.3.1. Overall, there is strong correspondence between the simulated inflow to the Denver Complex (blue) and the outflow discharged through the sluice system (orange) during winter conditions, which confirms the acceptability of the modelling assumptions and results. The green horizontal line represents the 12 m³/s winter abstraction Hands-off Flow (HoF), this was used as a 7-day rolling average, above which abstraction is permitted to commence. This is based on a 7-day average as this is the form of the Ely Ouse to Essex licence and helps smooth out the tidal influences in the daily volume series.

Assuming equivalence between Q_{IN} and Q_{OUT} , as previously demonstrated, the total annual volume available for abstraction was estimated under licensed conditions where the 7-day average flow exceeded 12 m³/s (1,036,800 m³/d). This calculation was undertaken using Q_{OUT} , as defined in Equation (20), considering the winter abstraction period from November to March. In accordance with licence conditions, abstraction volumes were computed only for days on which the 7-day rolling average flow exceeded the

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1,036,800 m³/d threshold. The number of qualifying abstraction days was calculated for each year within the period of record and is summarised in the third column of Table 5-1.



5 Water Balance Feasibility Assessment

To evaluate the feasibility of reservoir filling and its compatibility with the hydrological regime of the study area, it was necessary to assess whether sufficient water would be available to sustain abstraction throughout the winter. The South Levels system was affected by drought conditions during the period analysed, so the period was considered acceptable for looking at reliability for an early feasibility assessment. To be acceptable for public water supply the reservoir yield would need to be reliable (though agreed early on, this would not be to the 1:500 year public water supply standard). The number of days abstraction would be available was assessed to investigate the reliability of water being available in any given year to refill the reservoirs. These estimates are reported in Table 5-1

Table 5-1 Available abstraction volume and number of abstraction days per year across the period of record.

Year	Available flow above 12 cumeecs (m ³)	Sum of days per year (-)
2009	24156180	31
2010	164228856.3	137
2011	75738492	81
2012	14835788.1	17
2013	90476046	70
2014	86593348.8	47
2015	129431101.5	126
2016	120419352	111
2017	70544614.5	89
2018	121737537	99
2019	46037790	50
2020	191040453	152
2021	223528535.1	119
2022	110880845.6	103
2023	255312407.6	115
2024	315858223.1	140
2025	102685152.6	88
Gran Total	2143504723	1575

However, the water to be used to fill the reservoir would be upstream of the licenced HoF location, meaning that as abstraction is increased it would impact the number of days and available water. To understand the risks to the feasibility study, a series of abstraction scenarios were developed to model this. Each scenario assumed a fixed daily abstraction volume, representing water diverted from the outflow at the Denver Complex for reservoir storage during the period that Q_{OUT} was above the HoF. The abstraction volumes were therefore deducted from Q_{OUT} , and the abstraction availability analysis was repeated.

For each scenario, the number of qualifying abstraction days per was recalculated across the period of record. Results are summarised in the Table 5-2. The assessment was undertaken for multiple abstraction

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scenarios: 50,000 m³/d, 75,000 m³/d, 100,000 m³/d, 125,000 m³/d, 150,000 m³/d, 175,000 m³/d, 200,000 m³/d, and 250,000 m³/d. The feasibility calculations discussed in this section can be found in the spreadsheet “Denver complex water balance.xlsx”, described in Appendix A.



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Table 5-2 Number of abstraction days per year across the period of record under different abstraction scenarios.

Year	Number of days for abstraction per year								
	No additional abstraction	Abstraction of 50,000 m ³ /d	Abstraction of 75,000 m ³ /d	Abstraction of 100,000 m ³ /d	Abstraction of 125,000 m ³ /d	Abstraction of 150,000 m ³ /d	Abstraction of 175,000 m ³ /d	Abstraction of 200,000 m ³ /d	Abstraction of 250,000 m ³ /d
2009	31	28	25	24	24	23	22	22	17
2010	137	136	135	135	134	133	131	130	130
2011	81	77	75	75	74	73	71	68	61
2012	17	15	15	13	12	12	9	9	8
2013	70	68	66	61	59	54	52	49	47
2014	47	45	45	45	44	44	44	44	44
2015	126	122	118	113	109	104	104	102	95
2016	111	106	104	103	103	102	98	97	93
2017	89	81	78	73	69	65	64	62	61
2018	99	98	98	98	98	98	98	98	96
2019	50	44	41	41	40	39	37	37	34
2020	152	152	151	150	150	150	150	150	148
2021	119	119	118	117	116	116	115	115	114
2022	103	100	98	98	97	96	94	93	90
2023	115	111	106	105	103	103	103	103	103
2024	140	135	134	133	133	133	133	132	132
2025	88	87	86	86	85	84	84	84	82
Gran Total	1575	1524	1493	1470	1450	1429	1409	1395	1355



6 Potential Quantity Available

The results in Table 5-1 show there is potentially water available in every year assessed, however in dry years there would not be sufficient days available to abstract water to fill the reservoirs reliably. As such, to ensure an appropriate reliability for Public Water Supply, it is suggested that a supply or yield across 2 years should be considered going forward. This will need to be confirmed with further, more detailed modelling, including accounting for climate change.

The EA have confirmed not all water above the HoF would be available for abstraction. Any new abstraction would need to fall within the 'available take', defined as the portion of flow above the environmental flow requirement. This requirement varies with flow conditions (i.e. follows a flow duration relationship rather than a fixed threshold), and existing licensed abstractions may continue when flows are above the current HoF. For the purposes of this preliminary assessment, an indicative maximum abstraction of approximately 30% of the available flow has been assumed under high flow conditions, this aligns with the EA's RAM guidance on 'available takes' which has been shared with Stantec.

Combined with the quantity of water available across the days, as shown in Table 5-2, this would allow a reliable abstraction of around 64 million cubic meters. However, much of this is considered to be within discrete flood events, and so the entire quantity would not be possible to abstract during these short-term peak events. If an abstraction rate of 250,000 m³/d is considered over the number of days reported in Table 5-2, the resulting volume would need to be abstracted over relatively short periods in some drier years. Considering availability across a two-year period provides a more realistic basis for storage and use. This gives an indicative two-year volume of approximately 43,500 MI, with a minimum annual value of around 20,000 MI observed within the rolling two-year series. These figures are preliminary and will need to be refined in future stages using more detailed draught modelling, a more robust assessment of dry-period behaviour and will also need to consider the impacts of climate change.

Accounting for the pumping and reliability considerations, and during discussions with the landowners, 40 reservoirs holding 500,000 cubic meters was assessed to understand how this aligns the water availability and the available yield.

500,000m³ x 40 reservoirs gives a total capacity of 20,000,000m³

Assuming that this is drawn down across two years would yield of 27,397m³/d, or 27,397,260 l/day.

Assuming a per person use of 110l/p/d this could supply circa. 249,066 people.

The Cambridge Water WRMP, People per Household conversion is 2.4 people per household. Therefore, this could supply 103,778 households. This provides a high-level sense check only and does not account for reservoir operating constraints.

7 Conclusions

7.1 Summary

This study developed a conceptualised water balance framework for the South Level IDB system to quantify water availability and assess the feasibility of reducing pumped flows for strategic abstraction and storage. The assessment integrated rainfall, pumping records, evapotranspiration, abstraction licensing data and river inflows to provide an estimate of water volumes conveyed through the drainage network to the Denver Complex.

Comparison between pumping-hours-derived flows and water-balance-derived estimates demonstrated good agreement during winter periods, confirming that the adopted modelling framework provides a reasonable representation of catchment drainage behaviour under high-flow conditions in most sub-catchments. Sensitivity testing showed that sub-catchment delineation influences local balance closure, particularly where drainage systems are hydraulically interconnected. Improved closure was achieved where neighbouring sub-catchments were aggregated. In addition, parts of the eastern South Level area underlain by Chalk geology exhibited pumping volumes exceeding surface balance estimates, indicating groundwater contributions not currently captured within the modelling framework. Summer performance was weaker, reflecting the influence of unquantified operational controls (e.g. slackers and penstocks) and seasonal soil-moisture storage processes that are not explicitly represented within the balance.

The optioneering assessment identified spatial variability in water availability for potential reservoir development. Using the highest total cumulative flow within the driest winter on record as a planning metric, several catchment groups — notably within the Upper Lark, Little Ouse and Wissey systems — demonstrated the strongest feasibility for storage development. Other areas were viable only where hydrologically combined.

The mass balance developed at the Denver Complex showed strong winter agreement between simulated inflows and recorded sluice outflows, supporting the robustness of upstream flow reconstruction. Application of the licensed Hands-off Flow threshold (12 m³/s, 7-day average) enabled estimation of abstraction availability across the period of record. Scenario testing indicated that abstraction would reduce the number of licensed abstraction days, though abstraction opportunities remain available across most years under the tested reduction ranges. This provides an initial indication that winter water reallocation could be feasible without materially constraining downstream flow availability.

A discrepancy was identified when comparing abstraction-day estimates from this study with those previously derived by the Environment Agency (EA), particularly for 2012 under the baseline scenario. EA analysis identified fewer qualifying abstraction days, which was subsequently clarified to result from corrections applied to the Denver flow record in January 2012 (Appendix C). These adjustments removed flow peaks considered anomalous when compared with scaled upstream gauged flows and estimated South Level contributions, alongside prevailing hydrometeorological conditions, including high soil moisture deficit and limited antecedent rainfall. The EA further highlighted the operational complexity of the Denver sluice system, where gate operations and upstream retention can produce non-natural flow responses within the record. As such, short-duration anomalies within individual years should not be relied upon when assessing scheme feasibility.

A series of assessments accounting for the impact that abstraction would have on the time periods over which abstraction can occur, along with reasonable considerations for pumping capacity over these time periods and reservoir storage have led to initial discussions with the landowners concluding that there would be water available over a two year period to supply forty 500,000m³ reservoirs, providing water for around 100,000 households. The interaction between reliability of supply and quantity available in a given year should be further refined with modelling using the water company WRMP data sets to ensure that any scheme suggested would meet future needs under climate change.

7.2 Next steps

While the study demonstrates promising potential for redistributing winter drainage water, several uncertainties remain that warrant further investigation:

- **Operational monitoring** – Establish a monitoring programme to better quantify penstock, slacker and intake structure operation, and to inform how water trading and displacement permitting could function in practice.
- **Soil-moisture processes** – Collaborate with academic research to better characterise soil-moisture retention and “wicking” effects within fen soils, which may extend to significant depths and influence seasonal storage dynamics.
- **Groundwater interactions** – Further investigation is required in groundwater-influenced catchments, particularly near the Cut-off Channel, to better quantify subsurface contributions and reconcile differences between observed pumping and surface balance estimates and what the summer impacts of this might be. Nattergal’s High Fen project involves rehabilitating the area where the River Wissey meets the Cut-Off Channel to restore wetland, requiring detailed hydrological analysis for rewetting. The site, located near Stoke Ferry, relies on the channel for water management, with plans to use winter water abstraction to maintain high water tables. Any report output from the project might provide good indications about the groundwater influence across the area.
- **Climate change and system modelling** – Future modelling should incorporate climate-change projections, drought modelling, and enhanced operational datasets to align water availability assessments with long-term water-company planning needs including Water Resources Management Plans.

This assessment provides a robust preliminary framework for understanding water movement across the South Level system and its potential role in supporting strategic water storage and redistribution. Results indicate that, particularly during winter periods, meaningful volumes of water may be available for abstraction and reservoir filling. With enhanced monitoring, improved representation of groundwater and soil processes, and integration of future climate scenarios, the framework developed here can support more detailed feasibility assessments and regional water-resource planning and feed into the feasibility optioneering report (Stantec report “331610105-300 Optioneering”).

Appendix A Spreadsheet descriptions

IDB Pumping Stations Daily Flows.xlsx: This file contains the daily flow time series for each IDB pumping station, developed to support the water balance assessment of the associated catchments. Pumping series were generated externally using an R script and subsequently compiled within this spreadsheet. Monthly totals of pumping operating hours were first collated for each station. These totals were then disaggregated to daily values based on the temporal distribution of monthly rainfall. Daily pumping hours were subsequently converted to discharge volumes using the individual capacity of each pump, thereby producing continuous daily flow time series for use within the wider water balance analysis.

IDB Abstractions Daily Flows.xlsx: This file contains the abstraction flow time series for licences provided by the EA, organised by IDB subcatchment to support the water balance assessment of the designated catchments. Time series were generated externally using an R script and are expressed as daily abstraction volumes. Flows were derived from monthly abstraction returns reported for each licence, with monthly volumes evenly distributed across the corresponding number of days in each month. A daily time series was produced for each Format ID, which may not correspond uniquely to a single abstraction licence. Both the Format ID and licence number are identified within the header of each series using the naming convention "FormatID_LicenceNumber". All licences associated with a given subcatchment were compiled within a single worksheet. The final column in each worksheet ("Total") represents the aggregated abstraction volume for that sub-catchment, calculated as the sum of all individual abstraction time series.

IDB Water Balance Assessment.xlsx: This file contains the water balance developed for all IDB sub-catchments, each associated with a specific pumping station. The balance is simulated over the period 1 January 2016 to 30 September 2025, representing the minimum common record shared across all input datasets. The water balance incorporates rainfall (R), potential evapotranspiration (PET) and IDB abstraction flows (ABS), and compares simulated pump station discharge derived from pumping-hours data (SIMULATED PUMP FLOW) with pumping estimates obtained through the water balance formulation (PUMP FLOW WB ($R - PET - ABS$)). For each sub-catchment, calculations are presented within an individual worksheet. These are followed by two additional sheets containing graphical summaries:

- Plot a presents 6-month cumulative flows calculated for winter periods only (October–March). This compares cumulative simulated pump flows derived from pumping-hours data with cumulative water-balance-derived pumping estimates. Known drought years are also highlighted.
- Plot b presents cumulative flow series across the full period of record. This compares cumulative simulated pump flows with cumulative water-balance-derived flows, with the latter calculated after setting April–September negative values to zero to account for negative summer balances driven by PET and unrepresented storage processes.

South Levels Upstream flows.xlsx: This file contains the flow computations for the major upstream tributaries at their interface with the IDB catchments. The four tributaries considered enter the Ely–Ouse River from the right bank and comprise the Cam, Lark, Little Ouse and Wissey rivers. Flows were estimated using an area-proportional scaling approach, incorporating all available EA flow gauges within each upstream catchment. The Cam catchment was analysed in two components: the upper basin, encompassing the Rivers Rhee and Granta, and the lower basin, including the Lode and Swaffham Bulbeck systems. Flow time series and associated catchment areas were sourced from the EA gauging network. Available gauges include:

- Wissey: Northwold and Whitebridge
- Little Ouse: Abbey Heath
- Cam: Stapleford, Dernford, Burnt Mill, Lode and Swaffham Bulbeck
- Lark: Beck and Temple

The period of record adopted for all tributary computations aligns with that used in the Denver Complex mass balance assessment, ensuring temporal consistency across the wider analysis.

River Abstractions Daily Flows.xlsx: The data are organised by abstracted water body and are used to support the water balance assessment at the Denver Complex for the South Level catchment. Each abstraction flow time series was generated externally using an R script, with daily flows expressed in cubic metres per day. The series are primarily derived from monthly abstracted volumes reported for each licence within the EA abstraction returns dataset. Monthly abstraction totals were evenly distributed across the corresponding number of days in each month (i.e., monthly volume divided by the number of days in that month). In addition, some licences were sourced from the EA trading dataset, which reports the maximum annual volume authorised for abstraction. For these licences, daily time series were constructed by evenly distributing the annual maximum volume across the year (i.e., maximum annual volume divided by 365 days). An exception applies to licences associated with the purposes “*Spray Irrigation – Direct*” and “*Spray Irrigation – Storage*”. For these licence types, the daily abstraction volume corresponds to one third of the annual maximum volume and is distributed seasonally as follows:

- Spray Irrigation – Storage: evenly distributed across October–March only.
- Spray Irrigation – Direct: evenly distributed across April–September only.

A daily flow time series was produced for each Format ID, which may not correspond uniquely to a single abstraction licence. Both the Format ID and licence number are specified within the header of each series using the naming convention “FormatID_LicenceNumber”. Licences originating from the trading dataset do not have associated Format IDs. All licences associated with a given abstracted water body were compiled within a single worksheet. The final column in each worksheet (labelled “Total”) represents the aggregated abstraction volume for that water body, calculated as the sum of all individual abstraction time series.

Denver complex water balance.xlsx: This file compiles all computations required to develop the mass balance at the Denver Complex. It includes the derivation of Ely–Ouse River and Cut-off Channel inflows from pumped discharges, upstream tributary contributions, and surface water abstractions, followed by the calculation of total inflow and outflow through the sluice system. The workbook also incorporates gap infilling of sluice flow series, verification of balance closure between computed inflows and outflows, and estimation of water availability under licensed abstraction conditions. Abstraction volumes and eligible days are further assessed under a range of pumping/flow reduction scenarios to support reservoir feasibility analysis.

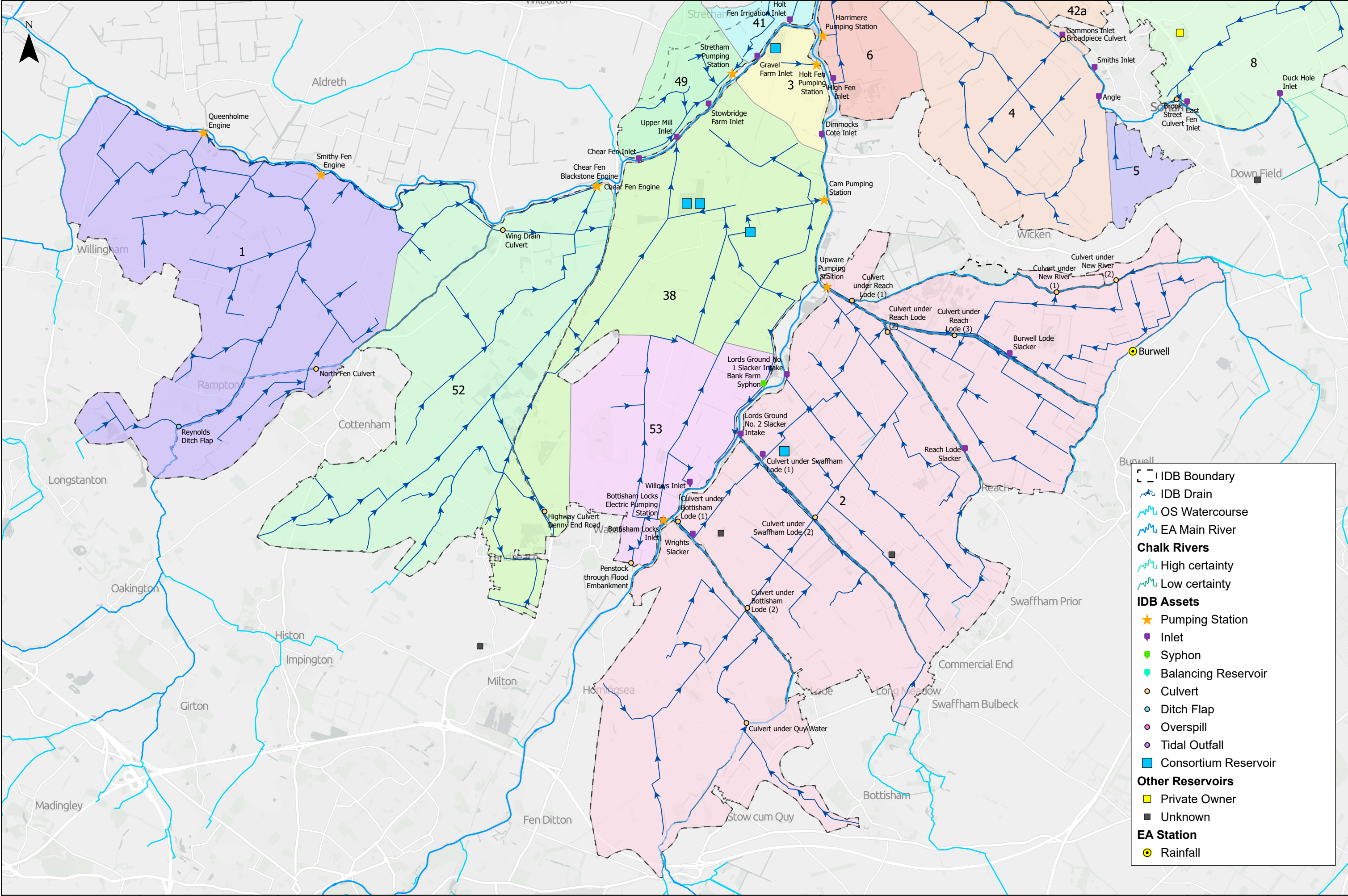
Sluices_daily_flows.xlsx: This file contains the daily flow time series for the principal sluices located at the Denver Complex. The dataset supports the mass balance assessment undertaken at this hydraulic control point within the South Level system. Raw flow records, provided by the EA, were supplied at a 15-minute temporal resolution. These data were processed externally using an R script to standardise units and aggregate flows to a daily timestep suitable for water balance calculations. For each 15-minute

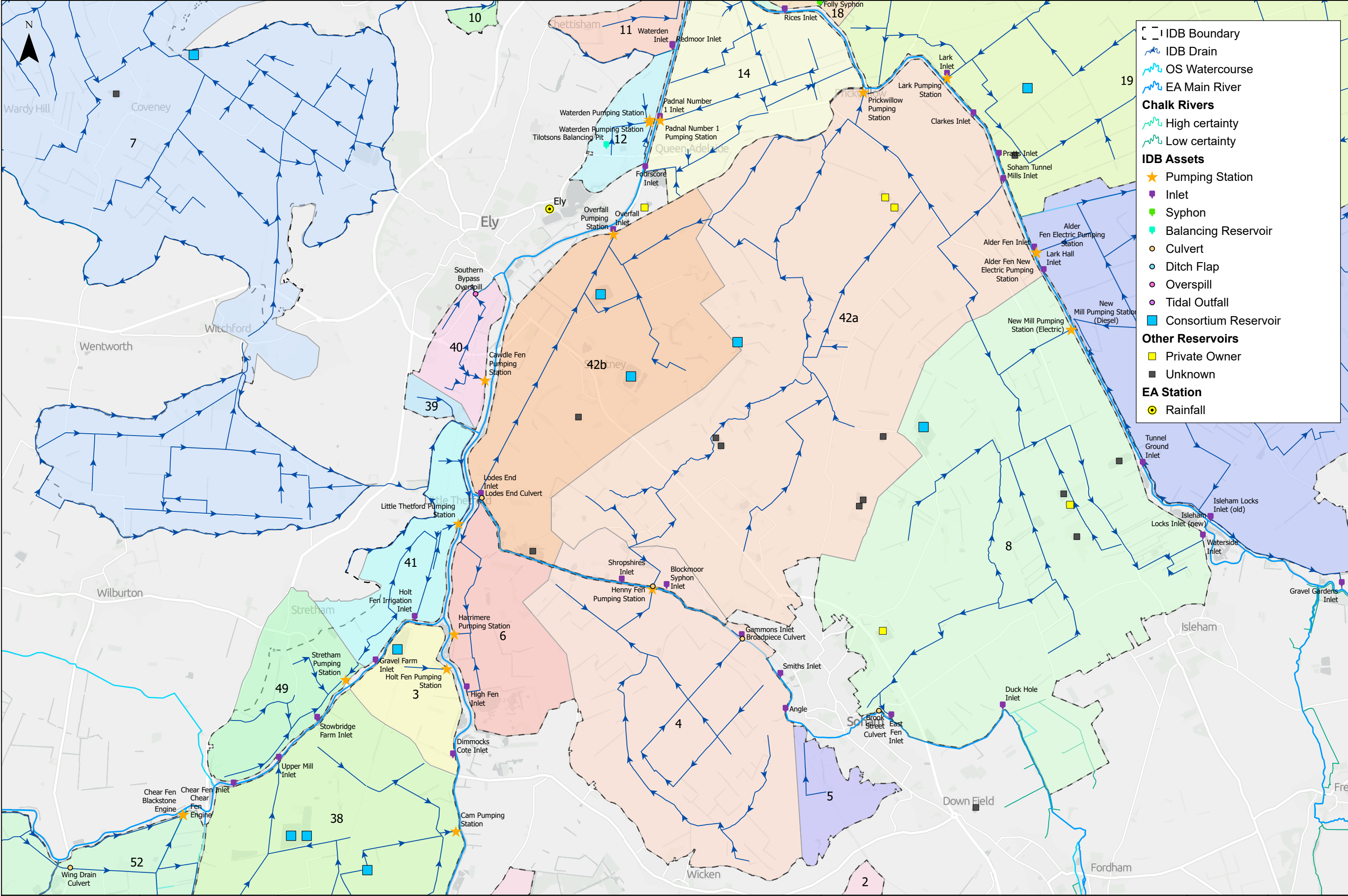
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Appendix A Spreadsheet descriptions

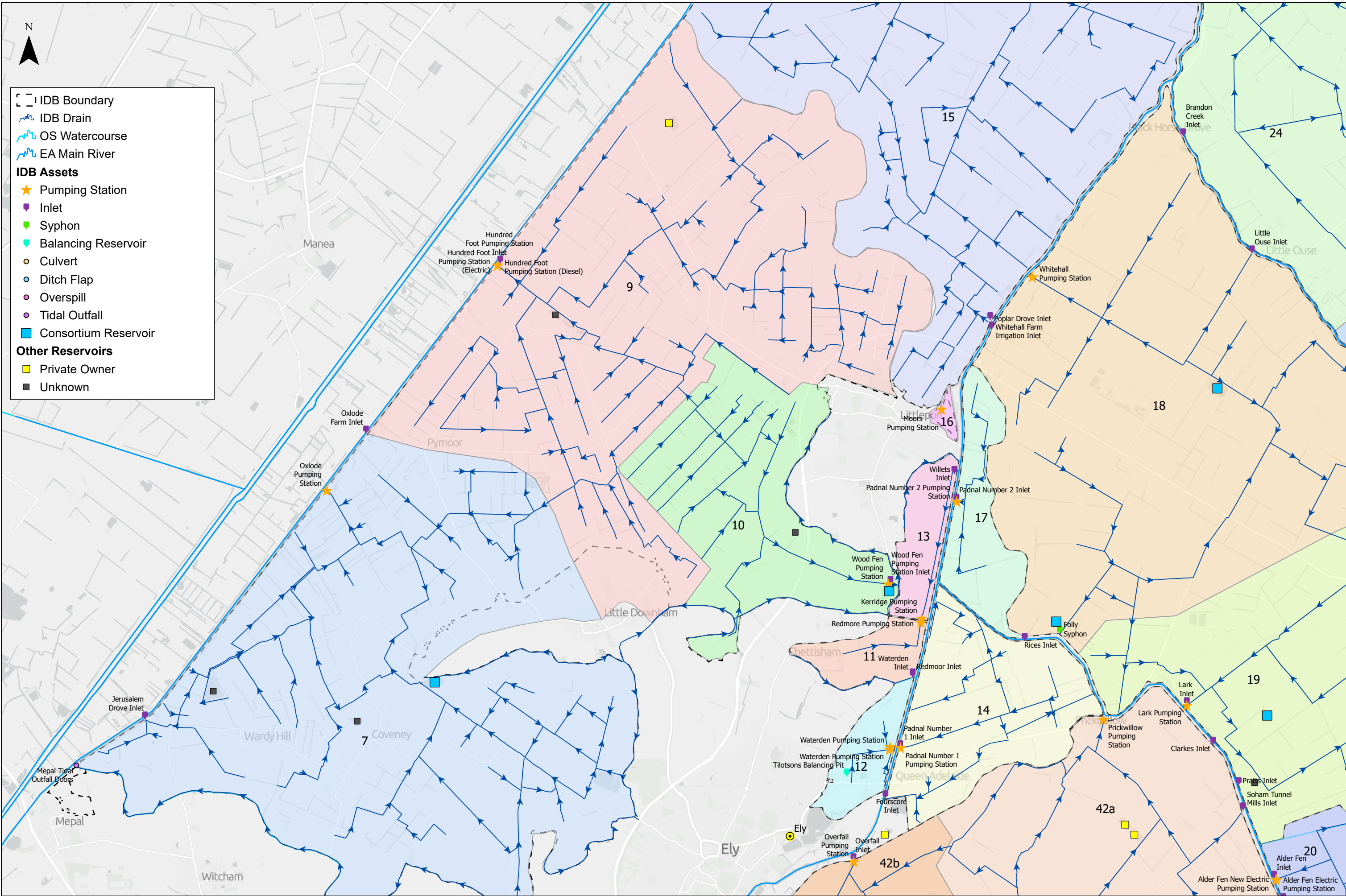
observation, instantaneous discharge values were converted to volumetric flow by multiplying by the duration of the interval. Daily flow volumes were then derived by summing all interval volumes within each day, producing continuous time series expressed in cubic metres per day.

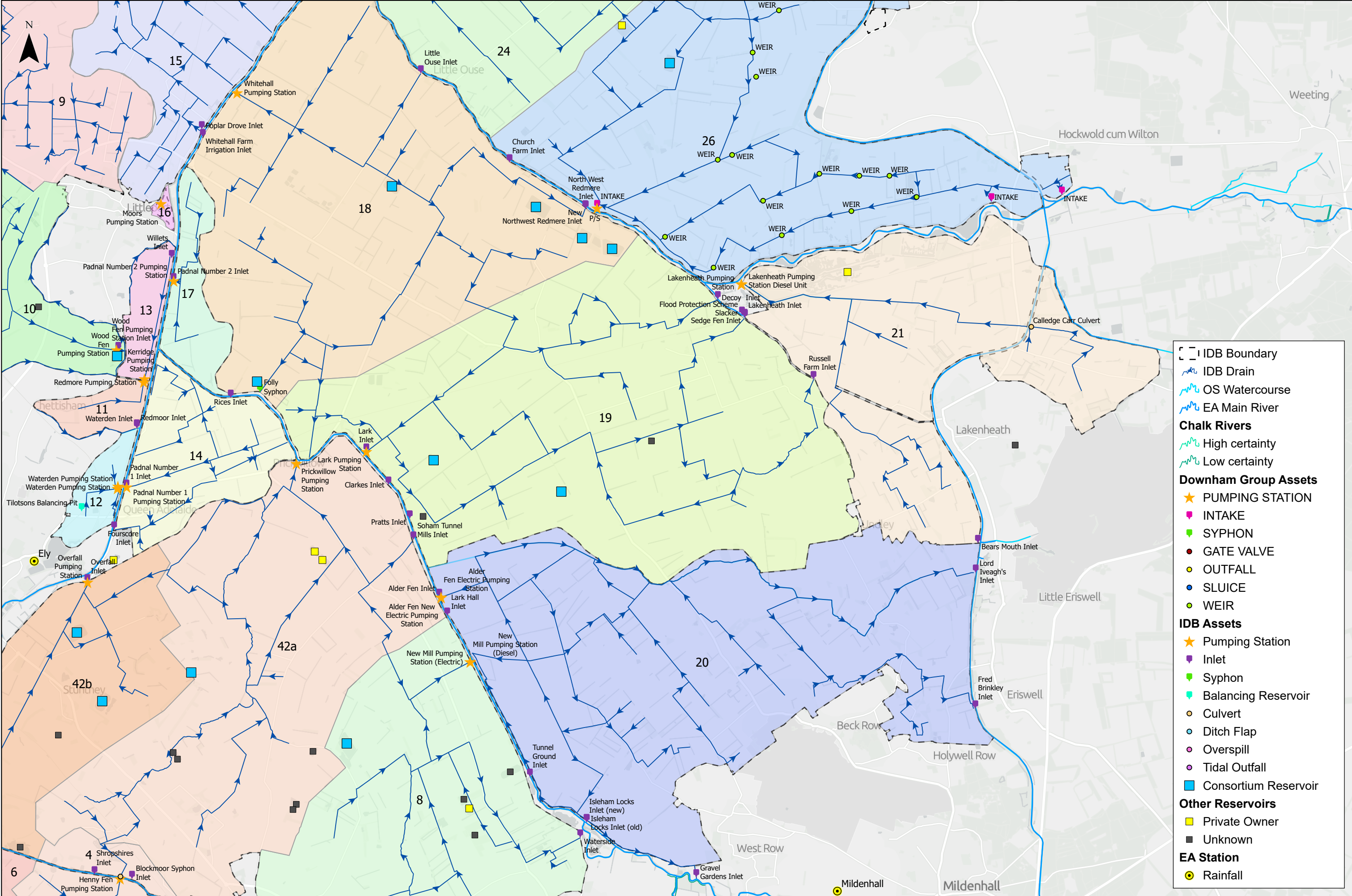
Appendix B IDB sub-catchment conceptualisation

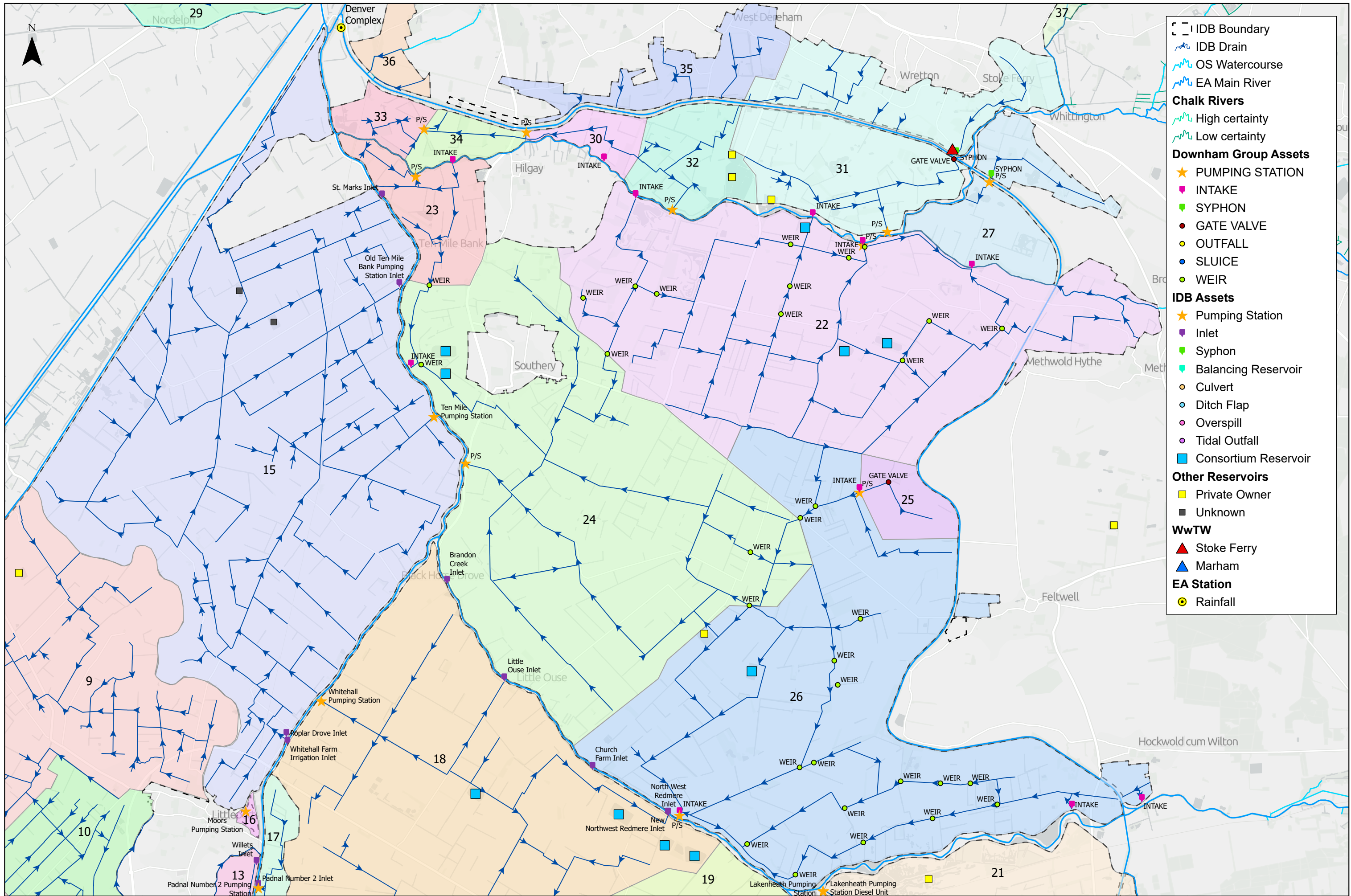












Appendix C EA abstraction days above HoF dataset

The Table below gives the number of days the flow was above the Denver hands-off flow in recent winters, 1991-2024. These are provided for indicative figures only, and the availability under even drier years during which public water supply is required to be resilient could be even less. In particular, there could be multiple dry winters in succession which could increase the total storage required.

Table C-1 Number of days the flow was above the Denver hands-off flow in recent winters, 1991-2024.

Winter abstraction season ending	Days above hands-off flow
31/03/1992	13
31/03/1993	131
31/03/1994	149
31/03/1995	130
31/03/1996	48
31/03/1997	21
31/03/1998	91
31/03/1999	151
31/03/2000	122
31/03/2001	151
31/03/2002	149
31/03/2003	149
31/03/2004	115
31/03/2005	143
31/03/2006	62
31/03/2007	135
31/03/2008	130
31/03/2009	149
31/03/2010	125
31/03/2011	95
31/03/2012	9
31/03/2013	150
31/03/2014	125
31/03/2015	142
31/03/2016	143
31/03/2017	107
31/03/2018	103
31/03/2019	45
31/03/2020	132
31/03/2021	150
31/03/2022	122
31/03/2023	74
31/03/2024	152

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