An investigation into the feasibility of solar-powered pumping and above-ground storage to maintain suitable conditions for key species and peat preservation in the Somerset Levels and Moors.

Addressing the increased likelihood of extended dry weather/ drought periods and their effect on 'Raised Water Level Areas'

Funding was provided by Natural England through the Nature Recovery Project

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Contents

1 Rationale

Irrigation of peatland within the Somerset Levels and Moors (SL&M) will become increasingly necessary to ensure that periods of drought, which are predicted to become more extreme due to climate change (MetOffice; *UK Climate Projections: Headline Findings July 2021*), do not exacerbate peat-loss and CO_2 emissions through the process of oxidation, and also negatively impact on ground nesting wading birds, a designated feature of many of the Sites of Special Scientific Interest (SSSIs).

<u>Purpose of Raised Water Level Areas</u>

Raised Water Level Areas (RWLAs) are sections of floodplain which are hydrologically isolated to hold (pen) water levels higher than the surrounding ditch systems during the winter and spring. The surrounding ditches are generally managed at a lower winter level from November to April (winter pen) to assist drainage, and a higher summer level April to November (summer pen) to provide water for cattle drinking and for ditches to act as effective wet fences. There are four main reasons for maintaining RWLAs. Not all of these reasons apply to all RWLAs.

I. To deliver appropriate conditions for breeding wading birds, a designated feature of many of the floodplain SSSIs, during March/April/May.

These conditions are created through maintaining high ditch levels and high water tables across fields. This management ensures good feeding opportunities for both adult and immature birds, as a high water table keeps soil invertebrates at or near the surface and high water levels lead to maintenance of ephemeral pools through the spring, providing good surface invertebrate feeding opportunities. High ditch levels allow easy access to ditch edges which present additional, high quality feeding opportunities for both sub-surface and surface feeding birds and their young.

II. To maintain surface water ‘splash conditions’ for the wintering SPA/RAMSAR designated interests ie feeding conditions for wintering migratory waders and wildfowl.

Maintaining high ditch levels means that rainfall and river overtopping events create lasting splashy conditions, rather than being drained off the floodplain.

III. To create areas of deeper water for the SPA/RAMSAR designated interests – i.e. roosting conditions for wintering migratory waders and wildfowl.

IV. To slow the rate of peat loss and CO_2 emissions, which are exacerbated during dry weather/ drought conditions.

The last point (IV) was not one of the original reasons RWLAs were set up, but, in the face of climate change, and in line with government strategy on peat as outlined in the DEFRA England Peat Action Plan (published May 2021) this will become an increasingly important factor. RWLAs could function to maintain peat conditions and could be extended to incorporate more of the 10,000ha of floodplain where peat is exposed.

Peatlands converted to Grassland occupy 8% of the UK’s peat area and emit ca. 6,300 kt CO_2/ year; 27% of total UK peat emissions. Drained intensive grasslands in lowland areas are the primary source of these emissions (Evans *et al* 2017).

Peat loss on pasture throughout the SL&M was estimated to be between 0.44 m to 0.79 m every 100 years – i.e., an annual average of over 0.5cm with corresponding CO_2 emissions reaching to several tens of thousands of tonnes of CO_2e every year (Brunning 2002).

For every 10cm that ditch levels and corresponding water tables within the peat are lowered an extra 3 tonnes of CO_2 per ha per year is emitted. (Evans et al., 2021). Action to prevent low ditch levels during the summer months will therefore help minimise peat losses and CO_2 emissions.

Climate change itself is a significant threat to peatlands, with rising temperatures and reduced rainfall accelerating the loss of peat, increasing the effects of climate change, and creating a negative feedback loop.

Initiatives to preserve peat resources

To prevent further peat losses and to minimise CO_2 emissions from peat, there are a number of strands of work underway. There is much current emphasis on peat restoration, and RSPB, SWT, AWT, NE and others are currently involved in a Nature for Climate 'Discovery' grant that will lead to parcels of land being put into full restoration to peat forming conditions. In order to achieve restoration of isolated blocks of peat irrigation in some form, will almost certainly be inevitable to ensure that the peat within the SL&Ms highly engineered hydrological systems retains peat-forming anaerobic conditions throughout the year.

In addition to these peat restoration projects DEFRA set up the South West 'Lowland Agriculture Peat Task Force'. This has recommended the current Peat-preservation Tests and Trial, which is likely to require higher water levels to minimise CO_2 emissions from peat. It is not envisaged that land within these test areas will get to zero emissions or lead to peat-forming conditions being created, but that reductions can be made from current emission levels, brought about through a combination of activities, including raising of ditch and in-field water tables. At a larger, more landscape scale, it may well be necessary to maintain higher pen levels throughout the year across the peat floodplains to maximise landowner incomes for carbon reductions through the emerging carbon markets. It is very likely that in times of drought, these areas will also require additional irrigation to meet the targets of reducing CO_2 emissions.

This study may therefore be helpful to inform not only management on the current RWLAs, but also across wider area of 10,000 ha.

Issues maintaining pen level within Raised Water Level Areas

Currently, RWLAs can fail to deliver appropriate water levels to meet their conservation aims regarding breeding wader habitat for a number of reasons including: leaking/ aging infrastructure; vegetation blocking (choking) ditches; slumping and shrinkage of banks causing leaking; water abstraction upstream causing reduced/low flows and increased evaporation and evapotranspiration during extended periods of dry weather during March, April and May.

With periods of dry weather predicted to become more frequent and more extreme due to climate change, often exacerbating and compounding some of the issues listed above, a solution is needed to ensure that water levels within RWLAs can be adequately maintained to provide conditions as required, particularly during the spring and summer months.

Where do Raised Water Level Areas function best for breeding waders?

The best performing sites for breeding waders, according to Royal Society for the Protection of Birds (RSPB), British Trust for Ornithology (BTO) and/ or Natural England (NE) breeding wader surveys in 2018 and 2021, are where either the land height is so low that adequate irrigation can be provided through gravity feed, or where water is pumped up (via 3-phase electrical submersible pumps – originally/initially diesel pumps) from the IDB system (RSPB 2018).

These sites are: Greylake (low-lying, externally gravity-fed site) and West Sedgemoor (pumped and internally gravity-fed).

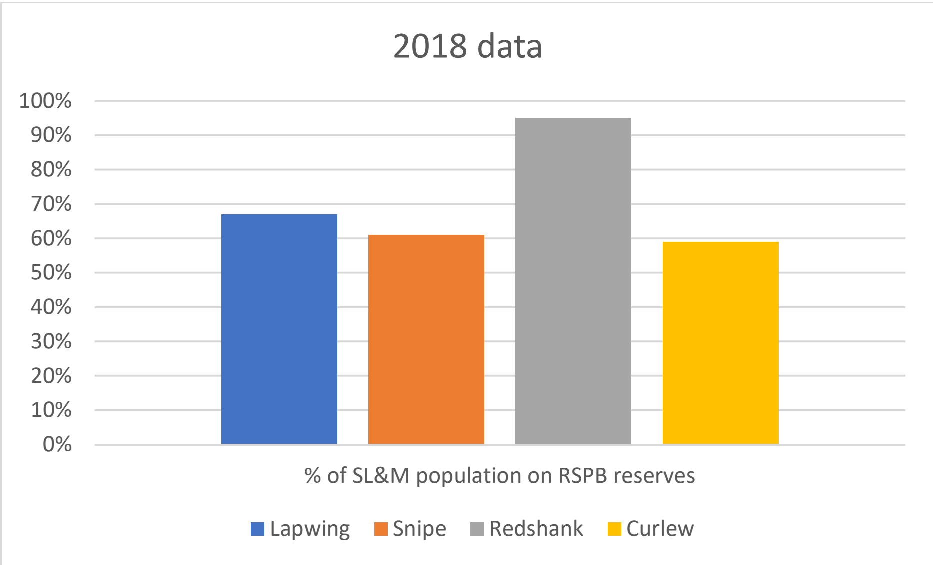


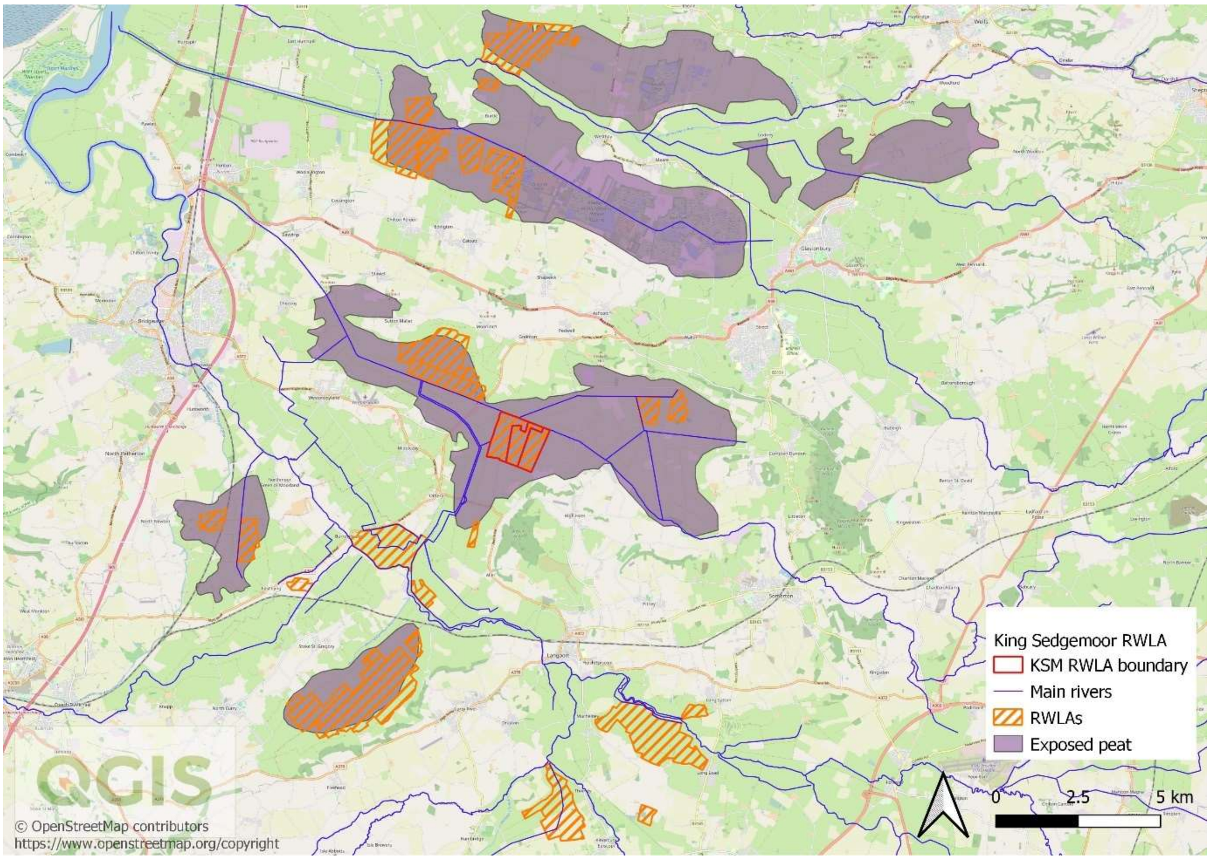
Figure 1. Showing the % of total breeding waders in the Somerset Levels and Moors on the two RSPB sites Greylake and West Sedgemoor in 2018 (NB: Lapwing figures include birds recorded at RSPB Ham Wall).

The area of the reserves makes up around 20% of the area surveyed in 2018. Note that the survey areas were not recorded in detail and these figures are a rough estimate only. They are still useful to emphasise the importance of these site for breeding waders. Between 50% and 90% of the breeding waders on the survey were recorded on only 20% of the survey area.

A total of 13 sites (14 if including Ham Wall) are included in the figures for the 2018 wader survey.

<u>Where are the RWLAs</u>

Map 1 RWLAs, Areas of peat in the SL&M, and the location of the King's Sedgemoor RWLA



NB Not all RWLAs are on sites with exposed deep peat resources, but many are.

Table 1. RWLAs, size and area on exposed peat within the RWLA

Raised Water Level Area	RWLA Ha	RWLA Ha within SPA	Ha Peat in RWLA
Wetmoor	313	313	
Town Tree	21	0	
Wet crouds	23.5	23.5	
Westmoor	191.9	171.9	
Mitchell, Northmoor Aller	13.2	0	13.2
Perrin, West Sedge	21.4	21.4	21.4
West Sedge	515.7	515.7	515.7
Southlake	197	197	
Hector, Allermoor	30.5	0	
Northmoor New	66.1	0	66.1
Northmoor Old	37.7	0	37.7
Moorlinch	200.4	174.4	200.4
Greylake	109.7	0	109.7
Kings Sedgemoor	208.1	208.1	208.1
Walton West	46.1	0	36.1
Walton East	36.7	0	36.7
Tealham & Tadham	254	254	254
T&T east	3.9	3.9	3.9
Gold corner	215.2	86.2	215.2
Chilton S	70.45	70.45	70.45
Edington	64.2	64.2	64.2
Catcott	129.8	129.8	129.8
Chilton N	49.4	49.4	49.4
Burtle	15.2	15.2	15.2
Curry Moor N	21.2	0	
TOTALS	2855.35	2298.15	2047.25

There are also vast resources of deep peat outside of the current RWLAs. Currently, there are a total of 10,000 ha of peatland (5000 ha north of the Polden Hills and 5000 ha to the south) which are under threat of degradation under the current management.

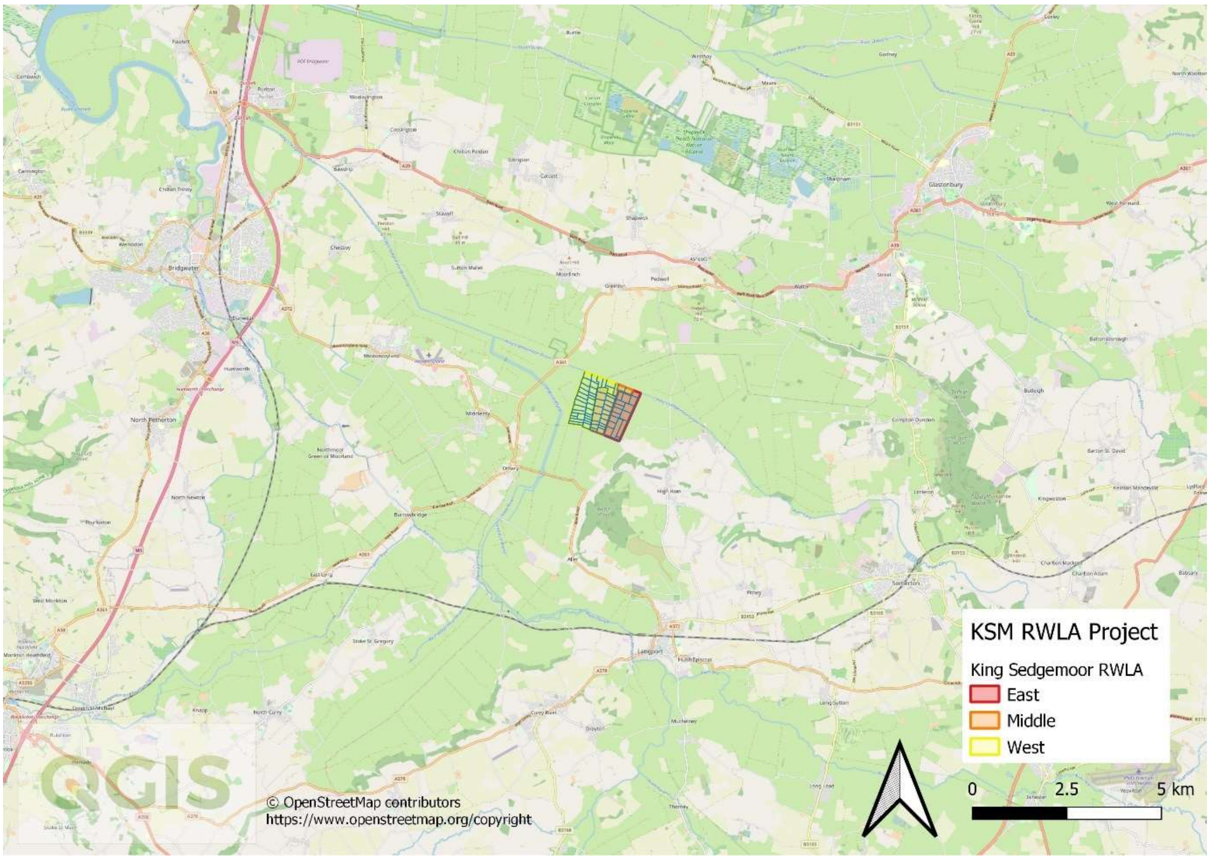
2 Introduction

This study was commissioned to investigate options of providing sufficient water volume to maintain target water levels on three areas of raised water levels identified in the King Sedgemoor Favourable Condition Project in 2009.

The site at King's Sedgemoor is being used as an example of a RWLA, which is currently failing to deliver the water levels required for breeding waders and the preservation of peat. It is hoped that this study can contribute towards development of a methodology to deliver sufficient volumes of water to meet the objectives of a RWLA.

The location of the RWLA is shown in map 2. A more detailed view of the RWLA is shown in map 3.

Map 2. Location of the King's Sedgemoor RWLA in Somerset



Map 3. Three compartments of the RWLA. Ditches, rhynes and other water features within the RWLA shown in blue

Table 2. Current summer IDB system pen levels and winter targets. The winter water levels are also the target levels throughout the spring months in the three RWLA compartments

Field	Summer water level (m AOD)	Winter water level (m AOD)
East	3.75	4.05
Middle	3.75	3.95
West	3.65	3.85

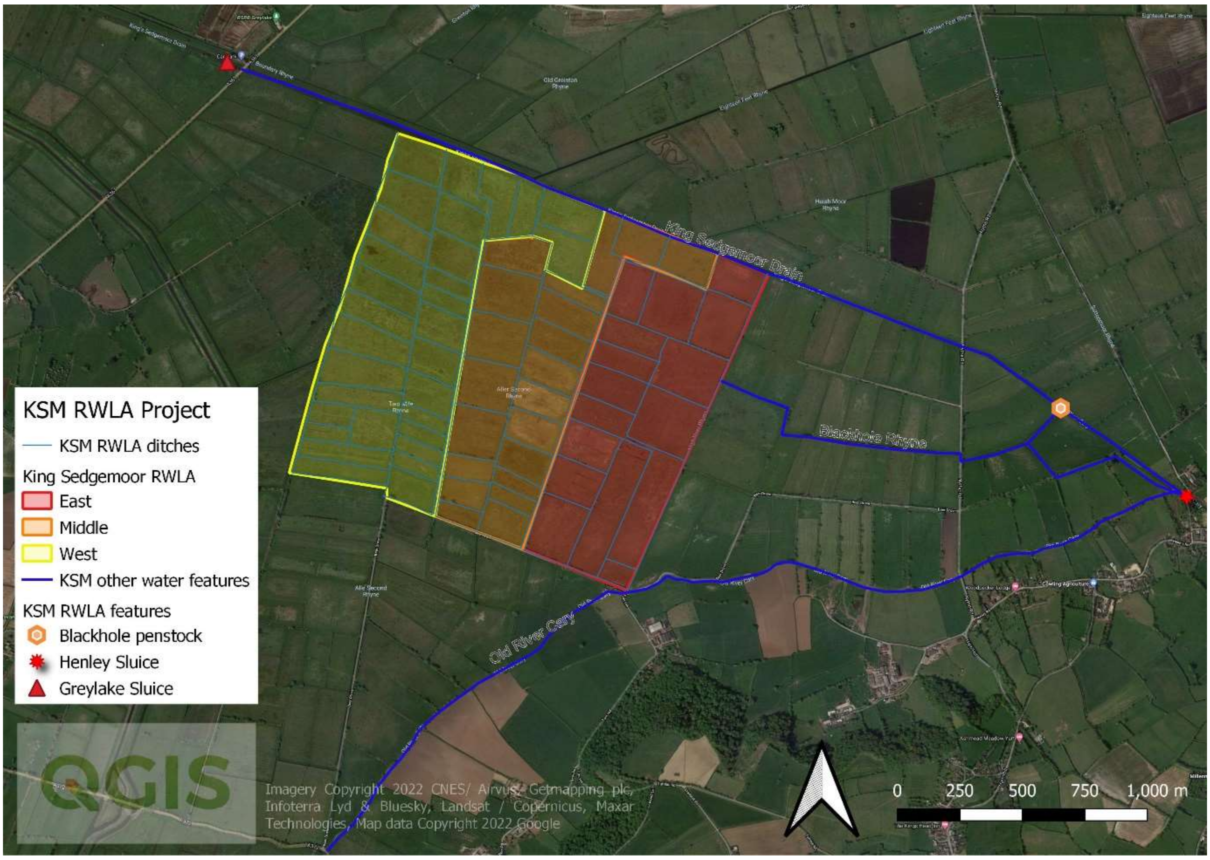
The RWLA is entirely dependent on water supplied by rainfall and water diverted from the River Cary at the Henley sluice and from King's Sedgemoor Drain at the Blackhole Penstock (see map 3) into the triangular area to the east of the RWLA, through the Blackhole Rhyne into the RWLA.

In winter, rainfall is generally sufficient to maintain the target levels, but achieving and maintaining these higher levels into the spring becomes problematic as this relies on sufficient rainfall to 'top up' ditches and wet features/ pools. Maintaining the summer pen levels (which are significantly lower than the desired target levels in the spring) is dependent on water diverted from the River Cary and the King's Sedgemoor Drain and let into the Rhyne and ditch system, and low flows in the Cary can limit availability.

The aims for the Kings Sedgemoor RWLA are twofold: to create and enhance habitat for breeding waders, which requires the maintenance of the winter target levels through March, April and May and to maintain suitable conditions for feeding wintering migratory birds ie shallow surface 'splash' during the winter months.

Providing conditions for breeding and wintering birds is compatible with aims to preserve and restore peat, although a restored system would require the maintenance of the winter target levels in the ditches all year round – ie extended through the summer and autumn months until November or until rainfall tops the levels back up. These levels would need to be maintained either by pumping water up into the block from the adjacent water courses, or through a complete change in operating levels across a much larger section of floodplain following consultation and agreement via Water Level Management Plans .

Map 4. Water control features and water supply into the RWLA during winter



The King's Sedgemoor Drain was completed in 1795 and this diverts the water from the River Cary at the Henley Sluice in a north-westerly direction, along the northern edge of the RWLA and into the River Parrett near Bridgwater via the Dunball Sluice. As a result, the Old River Cary, which runs south-east from the Henley Sluice carries very little water and cannot be considered as a source for additional water for the RWLA, even though the topography is more favourable. The RWLA is slightly higher in the south and the east. Gravity would therefore irrigate the entire RWLA if water could be abstracted in the south-east of the RWLA, but the volume of water is not available in the Old River Cary during periods of low flow – when it would be most needed.

An alternative option would be to pen the water at the required levels for this whole hydrological block at the Greylake Sluice or install an additional water control structure to hold the water in the King's Sedgemoor Drain. As this would affect water levels across a wider area and not just the RWLA which is the subject of modelling in this report, this must remain a speculative option only. It is mentioned here in the eventuality that raising water levels in the wider area becomes desirable in the future.

This study therefore concerns itself with the following two options:

1. Abstraction of water from King's Sedgemoor Drain and lift it over the water control features at the northern edge of the RWLA. Water abstraction at this point may have a negative effect on land downstream of KSM and will require discussions with and, potentially, licencing from the Environment Agency (EA). Assessing such impacts would go beyond the scope of this report and would form part of investigations when and if the findings of this report are implemented

2. Penning of winter rainwater above field level to form a shallow reservoir in areas to the east and north of the RWLA to provide water through the spring and summer, either by gravity feed or additional water control measures

The study will consider whether either of the options can in isolation provide the volumes of water required or whether a combined approach would be the most desirable approach.

3 Calculation of water volumes required

In order to determine which, if any, of the approaches outlined above may be suitable to maintain the desired water levels, it is necessary to calculate the volume of water required throughout the year.

The RSPB maintains a RWLA at West Sedgemoor (WSM), which uses pumps to abstract water from a nearby water course. The volumes pumped are calculated by pump capacity multiplied by hours the pump was in use and the pump capacity measured with a meter.

The area in the RWLAs at West Sedgemoor and King Sedgemoor (KSM), as well as the cumulative length of the ditches have been measured.

The latter is considered to be a more accurate measure of the volumes required as water movement through the soil is thought to be limited, but both measures have been provided here.

The volume of water each ditch is able to carry is here considered to be comparable between the sites.

Table 3 Water level targets in different hydrological units at West Sedgemoor. Highlighted in yellow are months during which the pump is required to augment water levels to meet summer water level targets.

Block	Mar-15	Apr-01	May-01	Jun-01	Jul-01	Jul 15 -Oct 01	Nov-01	Dec 01-Mar 01	Mean
24W	4.9	4.9	4.9	4.9	4.9	4.8	4.8	4.97	4.86
24C	5.05	5.05	5	4.95	4.85	4.85	4.85	5.15	4.9
24E	5.05	5.05	5.05	4.95	4.85	4.85	4.85	5.15	4.91
25	5.05	5.05	5.05	4.95	4.85	4.85	4.85	5.15	4.91
26W	5.05	5.05	5.05	4.95	4.85	4.85	4.85	5.15	4.91
26E	5.05	5.05	5.05	4.95	4.85	4.85	4.85	5.15	4.91
27	4.95	4.95	4.88	4.83	4.73	4.7	4.85	5	4.798

NB The reasons for the provision of additional water at WSM is NOT peat preservation, but for maintaining good conditions for wading birds in spring and summer and a deep water roost in winter.

Table 3 illustrates the target water levels at West Sedgemoor, which are ca. 1m AOD higher than those at King Sedgemoor. As West Sedgemoor lies ca. 1m higher than King Sedgemoor, penning levels relative to land height are similar between the two sites, i.e., water is not penned 1m higher at West Sedgemoor than at King Sedgemoor.

It is therefore assumed that requirements per unit of area or length of ditch are going to be broadly comparable between the two sites.

Table 4 Volume of water abstracted annually at West Sedgemoor, rainfall, hours of sunshine in that period and water abstracted per unit or area and ditch length.

Year	Water abstracted m^3	Rainfall (mm cumulative)	Sunshine (hours, cumulative)	Abstraction m^3/ha	Abstraction m^3/m Ditch length
April 2014-March 2015	72999	723.1	1620	445.1158537	3.844653
April 2015-March 2016	178101	733.8	1317.8	1085.981707	9.380081
April 2016-March 2017	188470	612	1421.3	1149.207317	9.926187
April 2017-March 2018	279576	703	1284	1704.731707	14.72448
April 2018-March 2019	286560	609	1607.2	1747.317073	15.09231243
April 2019-March 2020	79695	829.2	1489	485.945122	4.197312
April 2020-March 2021	143008	740.9	1634.6	872	7.531831

NB Total area at WSM is 164 hectares and total ditch length is 18,987.15 metres.

Annual rainfall and sunshine hours (source: MetOffice) have been included as a matter of interest and statistical tests looking for correlations between the weather and amount of water abstracted have been carried out. There was a moderate negative correlation between sunshine hours and water abstracted of -0.369 and a stronger negative correlation between rainfall and water abstracted of -0.679.

The negative correlation between sunshine hours and abstraction is perhaps surprising as it might be expected that the correlation be a positive one. With increasing sunshine and therefore evaporation one might expect an increase in water required. Sunshine hours, in this case, do not seem to have a major effect on the amount of water required to maintain the levels.

However, the requirement for additional use of the pump is not directly correlated to availability of rainwater and water loss through evapo-transpiration. During the summer months external supply is higher and target levels are lower, so supply is largely achieved from direct gravitational connection with surrounding water supplies rather than using the pump. There is also have a very large demand in the Autumn to bring in a managed flood, so even if it is cloudy with some rainfall, there is still a need to pump. These two factors might contribute to the correlations found and more in-depth analysis of weather, gravitational supply and pumping rates would be required to. These would go beyond the scope of this report, however.

With increased rainfall, less additional water is required to maintain the target water levels, as might be expected. While this is unsurprising it does reinforce the need for additional future irrigation in the face of rising temperatures and potentially drier springs and summers.

Map 5. RWLA at West Sedgemoor showing the ditches within the RWLA.

Based on the figures in Table 4 and a site area of ca. 211 hectares and cumulative ditch length of 29360.77 metres at KSM, the theoretical water volumes required are between 93931.5 m³ and 368731.1 m³, based on total surface area and between 112882 m³ and 443121.9 m³, based on cumulative ditch length (see table 10 in appendix). The means for these figures, based on years between 2014 and 2021 are 225807.9 m³ (area) and 271364.2 m³ (ditch length)

As the above figures show, there is a difference when considering the area of the RWLA or the length of the ditches contained within it. Predictions as to the volume of water required are ca. 20% lower when using area as a metric.

The site at King Sedgemoor will not require additional water input in late autumn ahead of the winter period for the current 2 functions. At West Sedgemoor, water is moved in these months to create a deep-water bird roost, which is not to be replicated at King Sedgemoor. The following table has separated the water pumped in each month to provide a better estimate of the requirements on a monthly basis.

Table 5 Water volumes (m³) abstracted at West Sedgemoor by month, including mean average over all years, as well as minimum and maximum abstracted each month.

Totals month	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
April 2020-March 2021	14208	54264	46704	10656	0	0	0	17176	0	0	0	0
April 2019-March 2020	9039	14904	20976	0	0	0	1656	33120	0	0	0	0

April 2018-March 2019	0	21528	46368	33120	0	0	66600	107352	0	0	0	0
April 2017-March 2018	62160	35640	31344	13320	0	0	9000	92592	35520	0	0	0
April 2016-March 2017	16872	16108	38568	17289	0	0	0	99633	0	0	0	0
April 2015-March 2016	61344	26949	24480	0	0	0	14328	51000	0	0	0	0
Mean	27270	28232	34740	12397	0	0	15264	66812	5920	0	0	0
Minimum	0	14904	20976	0	0	0	0	17176	0	0	0	0
Maximum	62160	54264	46704	33120	0	0	66600	107352	35520	0	0	0

NB figures for 2014/15 are not available by month. Highlighted in yellow are the months, which will require additional water at King Sedgemoor in order to create and maintain good conditions for breeding waders. For peat preservation it might be necessary to maintain pumping through Aug, Sep, Oct but as this is not undertaken at West Sedgemoor (where peat preservation is not the intended management operation) the quantities cannot be accurately modelled using this method.

The theoretical maximum amount of water required in the spring is ca. 300,00 m^3, with monthly maximum requirement of ca. 96,000; 84,000; 72,000 and 51,000 m^3 in April, May, June and July, respectively, based on cumulative ditch length (see table 11 in appendix).

Actual volumes required are likely to be less than this, but theoretical maxima are useful when determining whether solar pumping technology is appropriate for the task.

The maximum predicted total volumes required in a single year can be seen in the last row.

The figures and tables above have so far only considered the site as a whole. As Map 3 above shows, the RWLA is divided into three discrete areas, each with their own water level targets. The following table shows the predicted requirements for each of the three units individually. The nature of the figures from West Sedgemoor means that it is not possible to separate requirements for different water levels in different compartments and the figures given here are therefore averages across all three areas.

Table 6 Predicted mean volumes (m^3) in each month for each individual unit in the RWLA for ditch length only (for full figures see table 12 in appendix).

	East vol required	Middle vol required	West vol required
April mean	12127	13114	16927
May mean	12554	13577	17524
June mean	15449	16707	21564
July mean	5513	5962	7695

4 Solar pumps

Pump power requirements.

The power (in W) required by any pump can be calculated by the following formula:

Volume required/ days in month/ mean sunshine hours/ 3.6 *vertical lift* 10 (acceleration under gravity)

As mechanical pumps are not 100% efficient, the final figure must be divided by the pump's efficiency.

Using the figures calculated for April, this would mean:

96121/30/5.2/3.6*0.75*10= 1283.66W

1283.66/50% = 2567.33W (assuming 50% pump efficiency)

The RSPB has purchased several solar-powered pumps for projects in Kent and Essex from the Dutch company Aqua Delta. According to the company's factsheet of these pumps, the t400D, the maximum output of these units is 40 m^3 per hour, but the recommended maximum for the Kent and Essex project is between 20m^3 and 25m^3 per hour.

This system would require ca. 10 such pumps to move the maximum volume of water required in the month of June, even at the maximum output of 40m^3/ hour and 15 in April (see tables 12 in the appendix).

For the mean average values, the number of pumps required are ca. 8 in June and 10 in April.

A very rough cost estimate for the provision and installation of one unit in Kent and Essex was provided as £10,000.

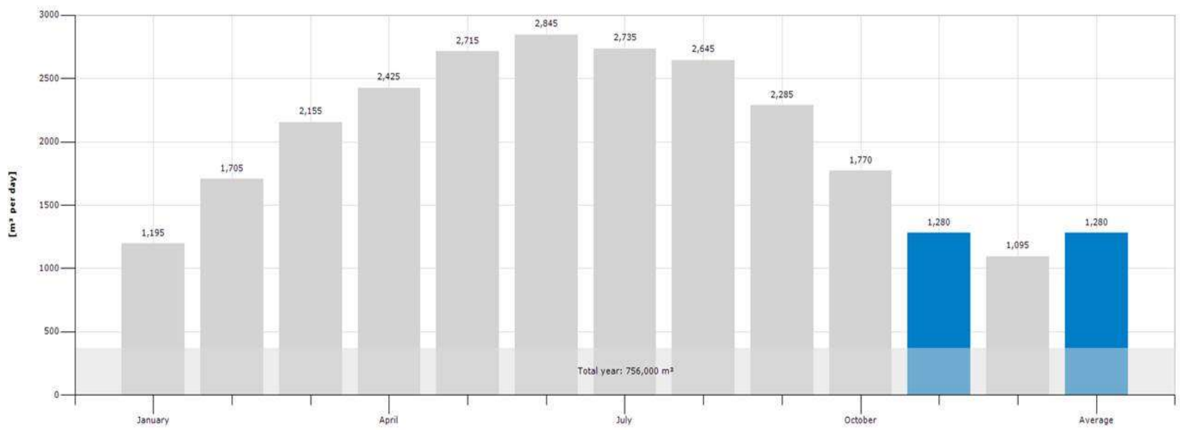
The sheer number of such pumps makes this option unfeasible.

Speaking to the company's representative, Aqua Delta also manufacture a larger pump, the t400D2, which, according to their representative can move twice the volume of water as the t400D. Therefore, to meet the theoretical maximum volume required in April, 8 such units would be required. 5 such units are required to meet the predicted volumes required in June.

5 units could provide ca. 62,400m^3 in April; 74,400m^3 in May; 72,000 m^3 in June and 83,080m^3 in July. Comparisons between predicted required volumes and capacity of 5 units working at 80m^3 per hour every day for the average predicted hours of sunlight for that month are shown in table 13 in the appendix.

The German company Lorentz manufactures solar powered pumps, and their UK sales company has provided the following chart for predicted output for one of the more powerful units produced, the PSk2-40 model using ~75kWp of PV.

Figure 2 Lorentz PSK2-40 predicted monthly output



Based on this chart, this unit is capable of moving 72,750 m³, 84,165 m³, 85,350 m³ and 84,785 m³ in April, May, June and July if run every day of the month, a total of 324,321 m³.

Table 14 in the appendix shows the comparison of predicted water requirements and theoretical output of the Lorentz PSk2-40.

Table 7 Showing the calculated mean and theoretical maximum water requirements per month (m³), based on cumulative ditch length and compares them with the capabilities of the Aqua Delta t400D2 (5 units) and the Lorentz PSk2-40 (1 unit).

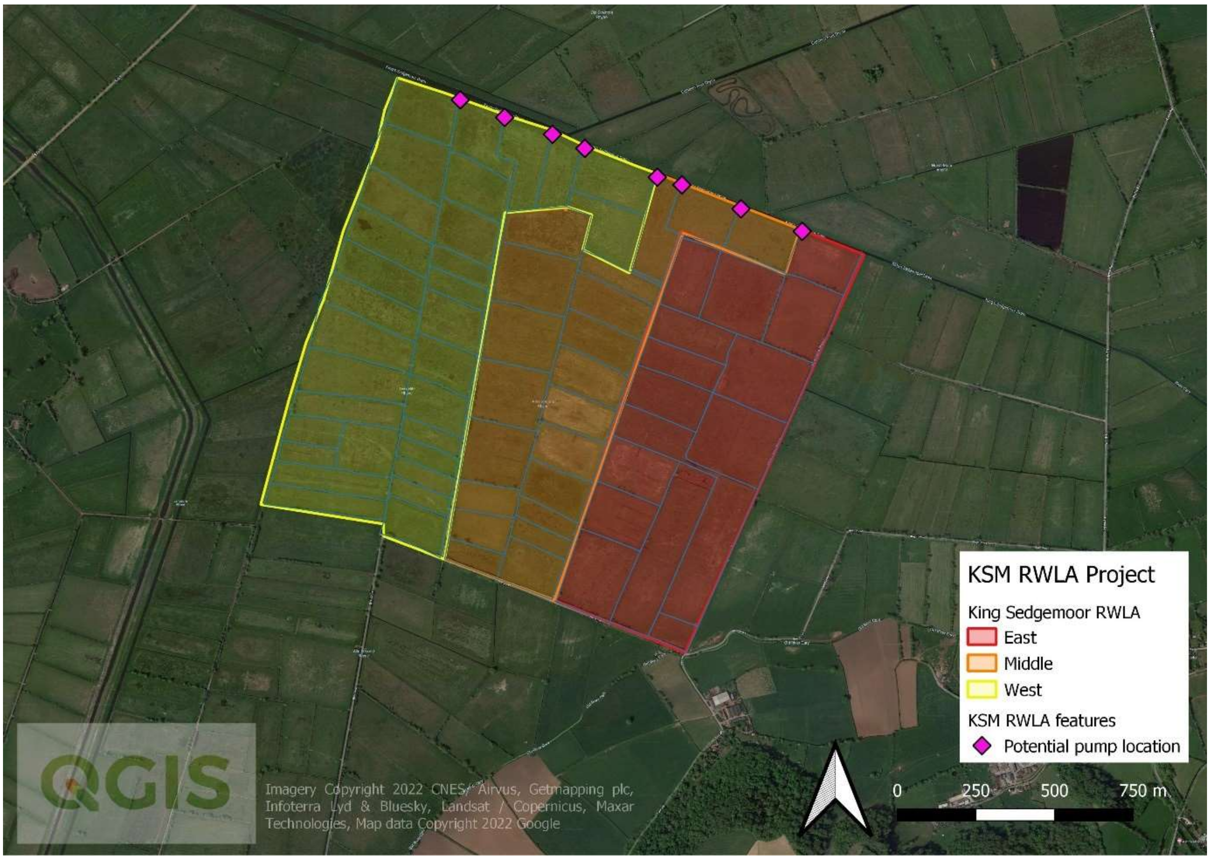
Month	April	May	June	July
Mean requirement	42169	43656	53720	19170
Max requirement	96121	83911	72220	51215
AD t400D2 capability (5 units)	62400	74400	72000	83080
Lorentz PSk2-40 (1 unit)	72750	84165	85350	84785
Difference AD capability & mean requirement	20231	30744	18280	63910
Difference AD capability & max requirement	-33721	-9511	-220	31865
Difference Lorentz capability & mean requirement	30581	40509	31630	65170
Difference Lorentz capability & max requirement	-23121	254	13130	33570

NB The Aqua Delta t400D is not included here as it is not deemed to be capable of moving the required volumes of water.

The highlighted lines are the capabilities of the two pumps, figures in red show where the calculated water requirements exceed the pump's capabilities.

According to the figures in Table 7, the Lorentz system should be able to cover the vast majority of the requirements, apart from predicted maximum requirements in April, while five AD t400D2 pumps have significant shortfalls when considering the theoretical maxima in April and May, as well as a small shortfall in June. Addition of a sixth pump would address the shortages in May and June and reduce the shortfall in April to around 20,000 m³.

Map 5 Potential locations for pumps along the King Sedgemoor Drain.



Map 5 above shows points at which ditches from the RWLA intersect with King Sedgemoor Drain. It should be possible to site a pump at each of these to lift water from the Kind Sedgemoor Drain over the water control features at the end of the smaller ditches and rhynes and into the RWLA.

Which of these locations is most suitable for siting the pumps will depend on the requirements of each compartment and the flow of water through the higher compartments to the lower ones. The land slopes gently downward from the east to west.

If only one pump were to be installed, this would have to be installed at the eastern-most point in map 5, which is the only location for a pump supplying the eastern compartment.

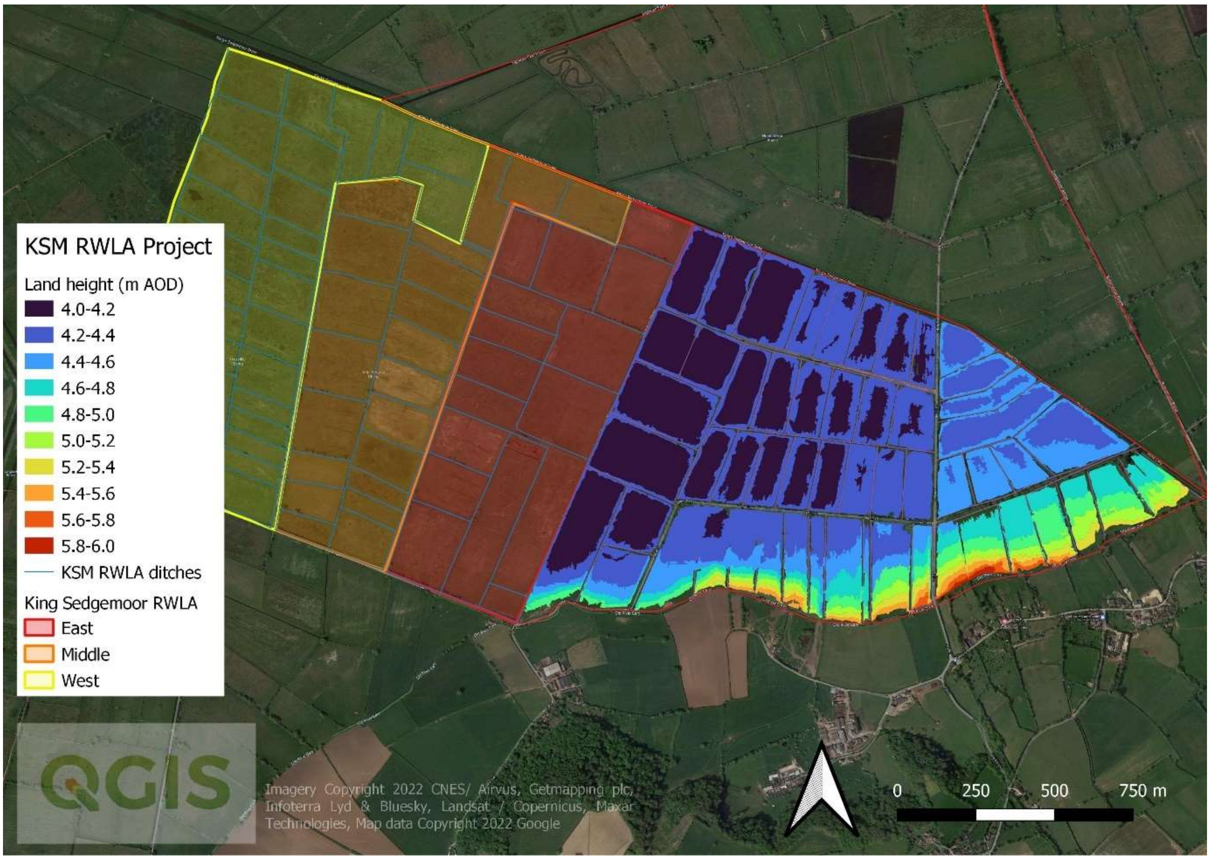
Table 8 Cumulative ditch length in each compartment and expressed as a percentage of the overall ditch length and the calculated mean volume of water required for each month for each compartment.

Site	East	Middle	West
Ditch length(m)	8443.68	9131.25	11785.84
% of total length	28.75837	31.10017	40.14145
Mean volume required April m^3	12554.76	13577.09	17524.15
Mean volume required May m^3	15449	16707.01	21563.99
Mean volume required June m^3	5512.98	5961.903	7695.117
Mean volume required July m^3	12554.76	13577.09	17524.15

A single AD t400D2 can move 12,480 m^3 in April, 14,880 m^3 in May, 14,400 m^3 in June and 16,616 m^3 in July. As there is only one location to supply the eastern compartment, there would be a shortfall of 75 m^3 in April, while the pump is capable of providing sufficient water in the other months, based on figures for mean requirements. If theoretical maxima are considered, the AD t400D2 can not provide sufficient water for the eastern compartment.

5 Water retention on adjacent land

Map 6 KSM RWLA and land to the east considered for winter water retention.



NB The land heights in the unit to the east of the RWLA are based on LIDAR data in 0.2m increments. Small areas and ditches have not been mapped here.

Map 7 Ditches in the potential water retention area to the east of the RWLA.

The following calculations are based on the polygons in map 6, where the field levels have been averaged between the lowest and highest contours. E.g., a polygon lying between the 4.0 and 4.2m contours has been assigned a value of 4.1m AOD.

The available water in the fields has been calculated by subtracting this mean field level from the theoretical penning level multiplied by the area of the polygon.

To this, the total length of the ditches, multiplied by an estimated average width of 1.3m, multiplied by the difference between penning level and target water level (4.05m) has been added to give the theoretical total water volume available at the chosen penning level.

Table 9 Available water volumes at different theoretical penning levels.

Penning level (m AOD)	Volume fields (m^3)	Volume ditches (m^3)	Total volume (m^3)
4.0	0	0	0
4.1	0	1083	1083
4.15	23455	2166	25621
4.2	46910	3249	50159
4.3	93820	5415	99235

Retained winter rainwater will only be available in early spring before evaporation, transpiration and movement through the soil continuously reduces the amount of water available. As such, only the water requirements for April have been considered here.

The maximum calculated water requirement for the month of April is 96121 m³. To meet this requirement with penned winter rainwater alone would require a penning level of ca. 4.3 metres.

The figures in table 10 show that the Lorentz pumping system would be able to provide the majority of the required water with a shortfall of 23371 m³, which could be supplemented with penned winter rainwater. This would require a penning level of 4.15 metres, which would provide an additional 25621 m³.

Installation of 5 Aqua Delta t400D2 units has a predicted shortfall of 33127m³ for calculated maximum requirements in April, 9511m³ in May and 220m³ in June.

As Table 9 shows, a penning level of 4.15 metres would not be sufficient to meet the predicted shortfall in April and would require a penning level of 4.2 metres, which would compensate for the shortfall in April, but water loss through evaporation and evapo-transpiration would almost certainly mean that there would remain a shortage of water in May.

6 Conclusions

Based on the RWLA water requirements at West Sedgemoor and the figures provided by the two solar pump manufacturers, the technology to move the required volumes of water exists.

This is, however, only true when the mean average is considered. For the calculated maxima, pumping alone will lead to significant shortfall in the month of April when using both scenarios of a single Lorentz pump or five Aqua Delta pumps, and, depending on exactly which and how many pumps are used, shortages in May and June, as well.

In this case, water retention on adjacent land can supplement the water available and can be used to make up any shortfall, if the installation of additional/ larger pumps is not feasible.

In most years, water retention on adjacent land should not be required and cannot provide the water required throughout the spring on its own. However, it would of course, not be possible to predict if the upcoming spring was going to necessitate the storage or otherwise of water within the reservoir area.

While creation of a shallow reservoir such as this is not essential to meet the water level targets, retention of water in these areas would also align well with management for the restoration of peat.

Aqua Delta have provided indicative prices for the installation of six t400D2 pumping units (note that the calculations above are based on five units and addition of a sixth would increase predicted output by 20%). The cost for the installation of these would come to € 69.640,78 + VAT (£58877.90 at an exchange rate of €1.18 = £1) and the addition of a smart system would raise that to € 75.530,62 + VAT (£63857.47).

No prices have been provided at this time by the company that handles sales of the Lorentz pumps, so it is not known what the cost implications are for provision and installation of this system.

As climate change is predicted to further increase water shortages in spring and the difference between water requirements and the ability of the pumps to meet this is relatively small at present, thought must be put into how the needs of the RWLA can be met in future.

This report has mainly considered supplying water to RWLAs in order to provide habitat for breeding waders. In order meet the aim of peat retention/ restoration, it will be necessary to provide water through the summer and autumn months before the water is once again supplied by rainfall. As the pumps at WSM are not used for this purpose, it not known what water volumes will be required to prevent the drying of the peat through summer and autumn. The volumes calculated for July can give an indication of the volumes that may be required. The rate of water loss later in the year is likely to decrease as sunlight hours are reduced and rates of evapo-transpiration slow with the end of the vegetation growing season.

The installation of either pumping system and monitoring their use over the season would provide the data required to allow informed decisions to be made over what type of pumping systems are applicable for different situations.

Installation of additional pumps is no doubt feasible but must be considered as a short to medium term option at best.

More sustainable, long-term solutions to counter the drying of peatland will almost certainly be necessary and must include, among others, reassessments of the Main River EA-operated drains that bisect these large expanses of peat along with the IDB operation of viewed rhynes and, as these contribute significnatly to water losses from the peat resource in these areas.

In summary:

- Some form of management intervention is required to ensure RWLAs deliver for breeding and wintering waders
- The technology to use solar powered pumps to move required water volumes does exist
- The Dutch company Aqua Delta manufactures pumps which would require a series of pumps to provide the required water volumes
- The German company Lorentz manufactures larger pumps, one unit of which can theoretically move the required water volumes (pending confirmation and pricing from the company)
- Lorentz also manufacture smaller pumps, which could be used in a series (pending further information from the company)
- A small-scale trial using a single pump in the highest (eastern-most) compartment is recommended to determine pump performance. Depending on pricing, this could be the large Lorentz pump, a smaller model by the same company or one Aqua Delta pump.
- Assuming a successful trial, more pumps can be added for the lower compartments, if required
- The trial can also monitor pump performance throughout the year to determine efficacy in preserving or restoring peat
- Any abstraction will require input from and potentially a licence from EA
- The findings of this study and/ or a successful trial can be applied to other RWLAs or areas under consideration for raised water level management
- As climate change is predicted to exacerbate water shortages in these areas, other options must be considered, including review of current drainage management
- Water retention on adjacent land is not essential to maintain target levels in most years but may be required in years of extreme low rainfall to supplement the water pumped.
- Such retention would also meet any targets for peat retention and restoration, and could be potentially be funded through a blend of ELMS Landscape Recovery and private CO2 reduction trading

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Appendix

Table 10. The volume of water required at West Sedgemoor per hectare and per metre of ditch length and the theoretical volumes required at Kings Sedgemoor using the same metrics, for the total area of ca. 211 hectares and a cumulative ditch length of 29360.77 metres.

Year	Volume (m^3) required / ha WSM	Total Volume (m^3) required KSM (area)	Volume required (m^3) /m Ditch length WSM	Total volume (m^3) required KSM (ditch length)
April 2014-March 2015	445.1159	93931.5	3.844653	112882
April 2015-March 2016	1085.982	229171.5	9.380081	275406.4
April 2016-March 2017	1149.207	242513.8	9.926187	291440.5
April 2017-March 2018	1704.732	359744.4	14.72448	432322.2
April 2018-March 2019	1747.317	368731.1	15.09231	443121.9
April 2019-March 2020	485.9451	102547.5	4.197312	123236.3
April 2020-March 2021	872	184015.5	7.531831	221140.3
Mean		225807.9		271364.2
Minimum		93931.5		112882
Maximum		368731.1		443121.9

Table 11. Based on the figures in Table 10, the mean, minimum and maximum volumes (m³) required each month of the year at King Sedgemoor. Autumn figures have been omitted here.

Totals month	Apr	May	Jun	Jul	Aug	Mar	Totals required spring
Mean volume required ha KSM	35090	36327	44701	15952	0	0	132072
Mean volume required m KSM	42169	43656	53720	19170	0	0	158717
Min volume required ha KSM	0	19177	26990	0	0	0	46168
Min volume required m KSM	0	23046	32436	0	0	0	55483
Sum of monthly max volumes required ha KSM	79984	69824	60096	42617	0	0	252522
Sum of monthly max volumes required m KSM	96121	83911	72220	51215	0	0	303468
Max volume in a single year m KSM	96121	55111	48468	20597	0	0	220299

Table 12. Expected daily output of the Aqua Delta t400D per month and monthly total at maximum output.

Month	Mean hours of sunshine/ day (Met office)	Mean water yield/ day @ 20m³/ hour	Mean water yield/ day @ 25m³/ hour	Mean water yield/ day @ 30m³/ hour	Mean water yield/ day @ 35m³/ hour	Mean water yield/ day @ 40m³/ hour	Mean water yield/ month @ 40m³/ hour
Jan	1.6	32	40	48	56	64	1984
Feb	2.5	50	62.5	75	87.5	100	2800
Mar	3.4	68	85	102	119	136	4216
Apr	5.2	104	130	156	182	208	6240
May	6	120	150	180	210	240	7440
Jun	6	120	150	180	210	240	7200
Jul	6.7	134	167.5	201	234.5	268	8308
Aug	6.1	122	152.5	183	213.5	244	7564
Sep	4.5	90	112.5	135	157.5	180	5400
Oct	3.6	72	90	108	126	144	4464
Nov	2.1	42	52.5	63	73.5	84	2520
Dec	1.6	32	40	48	56	64	1984

Table 13 Predicted required water volumes and water volumes moved by 5 t400D2 units. Figures in red show where the required water exceeds that of the pumps' capabilities.

Totals month	Required April	AD t400D2 capability for April (5 units)	Difference between capability and requirements	Required May	AD t400D2 capability for May (5 units)	Difference between capability and requirements	Required June	AD t400D2 capability for June (5 units)	Difference between capability and requirements	Required July	AD t400D2 capability for July (5 units)	Difference between capability and requirements
Mean volume required ha KSM	35090	62,400	27090	36327	74,400	38327	44701	72,000	27299	15952	83,080	67128
Mean volume required m KSM	42169	62,400	20231	43656	74,400	30744	53720	72,000	18280	19170	83,080	63910
Min volume required ha KSM	0	62,400	62400	19177	74,400	55223	26990	72,000	45010	0	83,080	83080
Min volume required m KSM	0	62,400	62400	23046	74,400	51354	32436	72,000	39564	0	83,080	83080
Max volume required ha KSM	79984	62,400	-17984	69824	74,400	4576	60096	72,000	11,904	42617	83,080	40463
Max volume required m KSM	96121	62,400	-33721	83911	74,400	-9511	72220	72,000	-220	51215	83,080	31865

Table 14. Comparison of predicted water requirements and theoretical output of the Lorentz PSk2-40. Figures highlighted in red show where the pump output is less than the predicted requirements.

Totals month	Required April	Lorentz pump capability April	Lorentz pump capability difference	Required May	Lorentz pump capability May	Lorentz pump capability difference	Required June	Lorentz pump capability June	Lorentz pump capability difference	July	Lorentz pump capability July	Lorentz pump capability difference
Mean volume required ha KSM	35090	72,750	37660	36327	84,165	47837	44701	85,350	40648	15952	84785	68832
Mean volume required m KSM	42169	72,750	30580	43656	84,165	40508	53720	85,350	31630	19170	84785	65614
Min volume required ha KSM	0	72,750	72750	19177	84,165	64987	26990	85,350	58359	0	84785	84785
Min volume required m KSM	0	72,750	72750	23046	84,165	61118	32436	85,350	52914	0	84785	84785
Max volume required ha KSM	79984	72,750	-7234	69824	84,165	14340	60096	85,350	25254	42617	84785	42167
Max volume required m KSM	96121	72,750	-23371	83911	84,165	253	72220	85,350	13129	51215	84785	33569