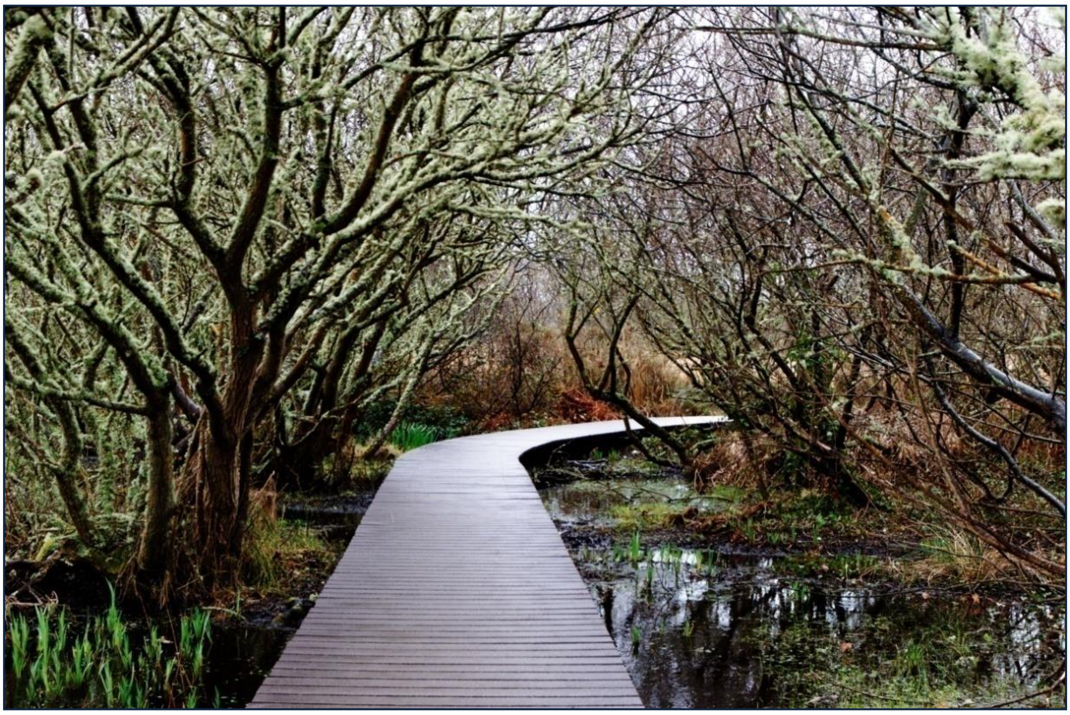
Lower Moors SSSI

Improved Hydrological Management: Scoping Study



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Abbreviations

AONB	Area of Outstanding Natural Beauty
CIoS	Council of the Isles of Scilly
IoSWT	Isles of Scilly Wildlife Trust
maOD	Metres above Ordnance Datum
SSSI	Site of Special Scientific Interest

Contents

1 Executive Summary

Lower Moors is a wetland site occupying 10.2 ha (Natural England, 2016c) of low-lying land in the west of the island of St. Mary's, within the archipelago of the Isles of Scilly. The wetland is designated as a Site of Special Scientific Interest, cited for its range of wetland habitats and rare species (Natural England, 1976). It also sits within the Isles of Scilly Area of Outstanding Natural Beauty (AONB). The site is owned by the Duchy of Cornwall and managed by the Isles of Scilly Wildlife Trust (IoSWT).

Flooding problems have been experienced in the industrial site, and to a lesser extent the waste site, both adjacent to the wetland. In January 2015 Rigare completed a detailed study of the groundwater of the site, including characterising the dominant sources of water and the mechanisms for water retention. Following a site visit in July 2015, Natural England reviewed the status of the wetland including ecological indicators, concluding that although the site was in an *unfavourable recovering* state, further elucidation of surface water regime and management was necessary to prevent further drying. Dawson (2015) surveyed vegetation on behalf of IoSWT, also reporting later in the year.

The Council of the Isles of Scilly (CIoS) wish to explore options for management practices that may reverse these issues, and have contracted Milestone Environmental to advise on the best ways of developing the understanding of surface water hydrology, building on the Rigare (2015) report. The current study aims to review the existing information available for the site, understand the likely critical surface water functioning, and recommend a programme of measures to develop this understanding in order to facilitate effective management in the future.

A site visit was completed on 4th March 2016 to confirm hydrological mechanisms operating and improve the understanding of the surface hydrology of the wider catchment, including the industrial and waste sites.

A hydrological conceptualisation has been developed, and key risks to the site are regarded as a) management of the site deriving from non-evidenced decisions (for example, the clearing of ditches on the proviso that that this would prevent flooding of the industrial site); b) conflicting management priorities; c) increased runoff rates from the industrial and/or waste sites; d) climate change and associated sea level rise increasing salt water intrusion; e) contamination from the runoff from the waste site or from agriculture; and f) over-abstraction of water for potable supply.

Recommendations are provided to facilitate effective surface water management in the future. These are as follows:

A. A **hydrological management plan** should be developed, to be agreed by all parties, to determine the desired water levels during different seasons and in different areas of the wetland, and reflecting the target ecology of the different wetland niche habitats. This should be informed by the current hydrological conceptualisation, and refined from the hydrological monitoring programme (see below);
B. A **detailed topographic survey** of both the ditches and the wider area is fundamental to the understanding of surface water mechanisms at the wetland site. This will enable determination of inflows, storage within the wetland and outflows;
C. A programme of **hydrological monitoring** should be initiated to elucidate storage and transfer mechanisms. If possible, this should include some points with data logging, rainfall data, and water quality parameters;
D. **Runoff calculations** should be completed for the industrial and waste areas to quantify the impact of increased hardstanding. This will enable mitigation options to be considered (e.g. drainage towards Porth Mellon beach); and
E. Experimental **use of the stop plank structure** at the wetland outlet during summer months, to investigate the efficacy of maintaining water levels within the wetland.

2 Introduction

Lower Moors is a small (10.2 ha) wetland lying immediately to the east of Hugh Town on the Island of St Mary's, within the Isles of Scilly archipelago. It is a protected site given its habitat and species composition, as outlined below (see Section 3.1). Development around the site margins continues to put pressure on the site, with the potential for changing the hydrology of the catchment.

2.1 Aims and Objectives

Rigare (2015) defined the dominant hydrological processes within the wetland, with a focus on the subsurface hydrology. The current study aims to extend this understanding, focussing on the surface water hydrology, and in addition investigating the developments on the upstream margins of the site. Further work to fully understand the hydrology of the catchment will allow the management to mitigate any negative impacts of development where possible.

The objectives of the current report are therefore to:

a) Review previous studies and current management;
b) Conduct a site visit to understand the wetland site and its hydrology, and to investigate key management problems;
c) Develop the conceptual understanding of the site's surface water hydrology; and
d) Recommend a programme of measures to develop the understanding of the wetland hydrology to a point that facilitates effective management for its sustainable continuation.

2.2 Report Structure

To achieve the above, the current report will firstly provide an introduction to the site (Section 3) including the physical characteristics; ownership and responsibilities; and management. Previous studies are then outlined in Section 4, followed by a summary of the site visit in Section 5. A conceptual hydrological model of the site is outlined in Section 6, with conclusions and recommendations made in Section 7.

3 Background

3.1 Site Introduction

The Lower Moors wetland site was designated a Site of Special Scientific Interest in 1976 (SSSI; Natural England, 1976) with the following key features noted: the range of wetland habitats at the site, dominated by reedbeds of *Phragmites australis* (Common Reed) with fringes of *Salix cinerea* (Grey Willow). The acidic waterlogged soils have numerous wetland species including *Dactylorhiza praetermissa* (Southern March Orchid). Other areas include wet meadows dominated by *Juncus effuses* (Soft Rush) and *Iris pseudacorus* (Yellow Iris). Open water areas in the centre of the site attract breeding waders including *Gallinago gallinago* (Snipe) and *Rallus aquaticus* (Water Rail).

Ownership of the site lies with the Duchy of Cornwall; management is undertaken by the Isles of Scilly Wildlife Trust (IoSWT), regulated by Natural England given its protected status. The Council of the Isles of Scilly (CIoS) manages the adjacent industrial and waste sites, including permitting development, and has a remit to manage flood risk here, together with the wider Isles of Scilly Area of Outstanding Natural Beauty (AONB).

The entire site lies at less than 5 maOD. Land use around the site varies markedly. The western boundary is the extent of Hugh Town, buffered only by the waste site. To the northeast, a small industrial estate drains towards the site, beyond which lies Porth Mellon beach. Small areas of pasture lie to the southern fringes, becoming more extensive to the east and northeast. The site boundary is shown in Figure 1, together with the industrial and waste sites. A view of the site from Hugh Town is shown in Figure 2.

The wetland has formed in the 'bowl'-shaped enclosure formed at the base of the surrounding hillslopes. The notable water sources into the wetland are summarised by Rigare (2015) as direct rainfall, surface runoff and shallow groundwater. The drainage from Lower Moors is naturally restricted by its landscape position and, despite its close proximity to the coast at Porth Mellon to the northwest, all of the site drains south to the sea at Old Town.

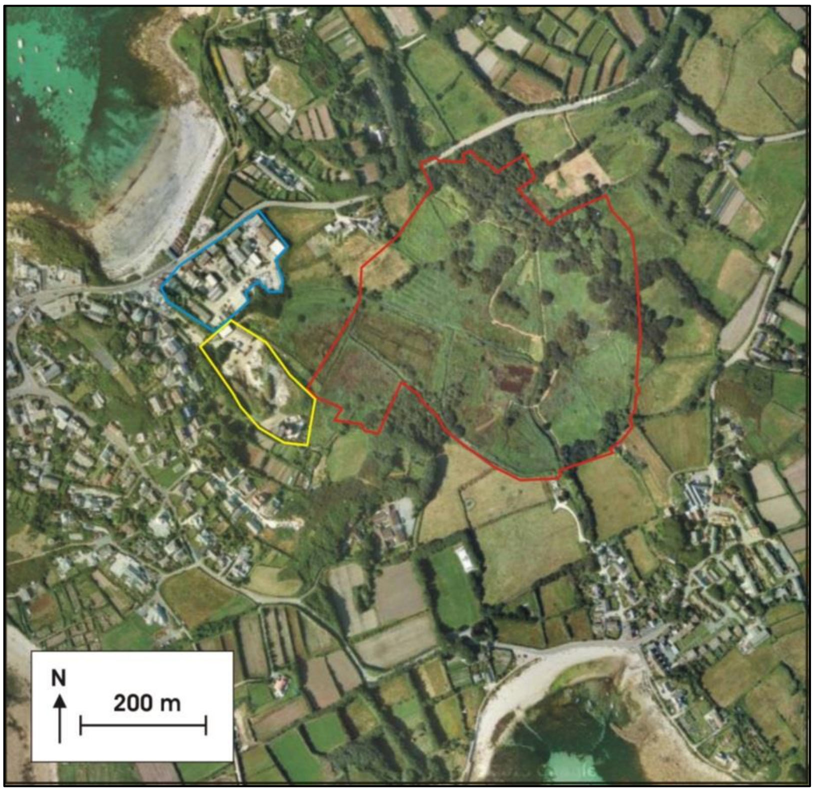

Figure 1 – Satellite image of the site, with site boundary marked in red, industrial site in blue and the waste site in yellow. Map data © 2016 Google; approximate site boundary taken from Natural England (2016)

Figure 2 – The northern extent of wetland site, looking east from Hugh Town

Like all wetlands, Lower Moors is dynamic and its character will naturally shift as conditions change and through natural ecological succession. The build-up of organic debris and accumulation of sediment causes the surface elevation of the wetland to increase. As this happens, the distance to the groundwater table increases and plant roots are increasingly exposed to rainfall rather than groundwater, which can limit the availability of nutrients. Further development of vegetation and increasing scrub coverage leads to increased evapotranspiration rates which could result in the drying out the site: usually only intervention through management will prevent this succession and eventual loss of the wetland.

3.2 Site Ownership and Responsibilities

The leasehold of the land is held by the Duchy of Cornwall, and the site is leased to and managed by IoSWT. The local unitary authority, CIoS, has responsibility for permitting development and flood management, and thus has a vested interest in effective management; the wetland also lies entirely within the AONB, for which CIoS are responsible. Natural England enforces the protection of designated sites, and thus gives consent for changing management activities.

3.3 Historic Management

Ditch re-profiling has occurred regularly through history since their development in 1889, most recently in 1998 (Natural England, 2015). The stop plank structure was installed in 2000 with the stated objective of increasing water levels in the site; the boards were stolen in the same year and never found (Natural England, 2015). There is documentary evidence of the structure being planned since the early 1980s (CIoS, 2016).

3.4 Current Management Objectives

The increasing rarity of wetland habitats and their contemporary societal appreciation leads to management that prevents change and encourages the persistence of the present or historical status. The IoSWT management strategy has not been seen, but relevant specific questions have been answered (D. Mason, IoSWT; personal communication).

Natural England (2015) state that "*a strategy to increase the wetness of the site which involves ditch blocking and the creation of new open water areas has been developed*". It is unclear if this is based on a sound understanding of the hydrology of the site, including the recent conceptual development by Rigare (2015).

The IoSWT management plan aims to remove 1.86 ha of willow coverage over a 10 year period, with this so far being ahead of schedule (D. Mason, IoSWT; personal communication). A four-way rotational reed-cutting programme is focussed to the east of the central ditch, as shown in Figure 3 (observed during the site visit).

Salt water intrusion is allowing development of *Juncus maritimus* (Sea Rush) in the southwestern area of the site. It is unknown whether this intrusion is flow backing up from the culvert outlet, or from saltwater upwelling from the area around the waste site and flowing across the wetland (see Section 5.7). Using herbicide is an option for management of this, for which a detailed hydrological understanding of the locality would be required for effective and targeted use.

Figure 3 – Active *Salix sp.* management on site

Under the Higher Level Stewardship of the site (under Natural England consent), IoSWT has a requirement to re-profile ditches, provide seasonal water level control and creation of open water and improving water quality. The Head Ranger (D. Mason, IoSWT; personal communication) plans to use this consent to:

- Block the drainage ditches to reduce flows and create more open water;
- Re-profile the ring ditches to capture and encourage flow towards the site (rather than bypassing it); and
- Reinstate the stop planks to control water levels (assumed to be at drier periods);

Critically, the impact of these actions is not certain, and a full hydrological understanding is needed to ensure the desired outcomes will be likely to be achieved.

IoSWT instigate grazing in small areas to the southwest and northeast of the site. Grazing prevents the establishment of woody plants, and thus higher evaporation rates, and prevents the deterioration of botanical richness (Natural England, 2004).

Several agencies are involved with the management of the site, as outlined in Section 3.2. The current report was commissioned by CIoS, who would like to explore the potential for improving the hydraulic conveyance of the ditches (possibly through increasing cross-sectional area) to alleviate flooding problems at the industrial site, and to a lesser extent at the waste site. Thus a detailed understanding of the hydrology of the site is required before evidence-based decisions can be made.

Natural England (2015) summarise:

> *"The current condition of the site is unfavourable recovering, and priorit[ies] for management at this site includes investigation into the water regime, especially water level management/sluice controls, grazing and cutting management and* Salix *control. Further* Salix *control required. Negative indicator species indicate drying of site as does the lack of positive indicator species."*

Flood risk poses a potential management dilemma at the site: upstream flood risk *may* be managed by clearing ditches to increase conveyance through the site to remove flood waters from the site. It is the wish of CIoS to minimise flood risk to the industrial and waste sites: surface water management within the wetland may improve this problem, but this is unproven.

Water quality is also a key issue for ongoing management. There is a lack of clarity as to whether the wetland is eutrophic (nutrient rich) or ombrotrophic, as discussed by Natural England (2004), which may have management implications. If the site is ombrotrophic, agricultural runoff with high nutrient loads has the potential to encourage a change in species composition. Furthermore, runoff from the waste site has potential to cause water quality problems. Historic documents show that previously the central ditch has been kept wet to ensure runoff from the west of the site drains to the outlet, so as not to spread to the west of the site and contaminate the drinking water abstraction point at Aunt Joaney's Well (see Figure 21, below).

4 Previous Studies

Investigations into the Lower Moors site have been completed previously. This section outlines those relevant to the current report.

4.1 Rigare, 2015

Rigare (2015) conceptualised the hydrology of the site, including defining the dominant hydrological processes, and notably the hydrogeology. The following summarises these findings:

- No streams flow into the site from the eastern high ground, but two dry valleys are likely to provide diffuse runoff towards the site during prolonged rainfall. Springs along this boundary discharge groundwater into the site;
- The wetland drains south from the northern boundary of the site;
- The surface water drainage flows entirely to the south, which is surprising given the close proximity to the coastal boundary at Porth Mellon system is dominated by a central ditch, running north to south and discharging through a culvert to beyond Old Town beach;
- A ring ditch almost entirely encircles the site, historically acted as a catchwater, collecting surface runoff from surrounding ground and directing it toward the culvert outlet. The ring ditch continues to function as such, visibly so in the eastern side of the site but is not complete in the western side;
- A network of minor ditches drain towards the central ditch;
- The geological structure is likely to comprise the following:
    - A granite bedrock underlying the following varied superficial deposits, unlikely to sustain notable groundwater flow;
    - Deposits of mixed 'ram' material of periglacial origin along the dry valleys and southern boundaries (and likely underneath the whole site). The locations of springs at the base of dry valleys indicate that that the ram deposits are permeable, and thus have a high sand and/or gravel composition, and in turn that they are likely to sustain a locally-significant discharge given that they also lie beneath the wetland site;
    - Blown sand at the northwestern and southern boundaries of the site;
    - Alluvial deposits across the majority of the wetland likely indicate historic saturation (reducing in nature), with their origin likely to be reworking of the ram and blown sand deposits;
    - Shallow surface peat deposits observed during a site visit indicate that continuous maintenance of near-surface water tables historically;
- During an August 2014 site visit, ditches within the upper areas of the site (north and northwestern) were dry, suggesting a hydraulic gradient generally from north to south; and
- The main ditch at the southern end of the scrapes contained >1 m of water depth, whilst towards the culvert outlet this was only 10-20 cm. Combined with very small flows, this suggests that the bed of the outlet channel slopes *upwards* towards the point of discharge, with a topographic high limiting outflow. This feature created the wetland characteristics of the site as a topogenous mire, as per the SSSI citation (Natural England, 1976). Note that if flow had been higher, a *downward* bedslope may have been inferred along this channel.

4.2 Natural England

Natural England has a responsibility (Natural England, 2016) to enforce the protection of designated areas such as SSSIs. Consents are required from Natural England for change in management regimes. The latest site assessment was completed in 2012 (Natural England, 2012), which recommended “water regime investigations” and continued management for site improvement.

The Natural England (2015) site visit summary, completed after the Rigare (2015) work states:

> *“Previous management has sought to increase the velocity of the water within the ditches in order to promote ecological diversity within the ditches themselves. However, the primary habitat, and the habitat for which the site was notified is the topogenous mire and this is the habitat that should be reinstated through the regrading of the raised ring ditch and the infilling of ditches which will allow water from the surrounding catchment to collect within the mire basin rather than being deflected from it.”*

Furthermore, the report states that the stop plank structure (located at the southern boundary of the site, historically to maintain ditch water levels: see Section 5.5) should be reinstated to prevent saline intrusion (assumed from the outlet culvert) “*if this is part of the site’s natural regime”*. Monitoring of the hydrological regime was also recommended if the flooding of the industrial site was a risk as a result of water levels in the Lower Moors backing up; or if water quality issues from the waste site runoff were considered a real risk.

Restoration plans include a diversion ditch, which is assumed to run from the waste site through the southwest of the wetland site to the culvert outlet, bypassing the ecologically sensitive areas.

Given that the site is a Higher Level Stewardship site, certain management regimes are required by Natural England, as discussed above in Section 3.4.

4.3 Dawson, 2015

Dawson (2015) surveyed the fauna of the ditches, inferring links to hydrological process operating. The primary conclusions of this work were that brackish water dominated species composition in the west of the site. The report recommended reducing shading from tree cover and ditch re-profiling to improve species composition, and ditch clearance to increase conveyance and thus alleviate flood risk, with biodiversity benefits being secondary.

Flood risk improvements may not be possible from ditch clearance, given that conveyance is likely to be limited by the topographic high point (Rigare, 2015) and the small capacity of the outflow culvert observed during the site visit (see Section 5.5).

A mention of brackish ecology is made regards the site by Dawson (2015), (although the specific location is unclear) suggesting that saline intrusion into the site from the culvert (e.g. at high tides) is may be a problem. This would verify observations of IoSWT (D. Mason, IoSWT; personal communication; see Section 3.4), although the source of saltwater intrusion remains unclear. Another potential conduit is saline groundwater upwelling, which has been anecdotally reported at the waste site springs (see Section 5).

4.4 Current Monitoring

A small network (thought to number approximately ten) of water level monitoring wells has been installed by SLR Consulting, and is monitored by RPS. The objective of the installations is unclear, and at the time of writing the authors are awaiting further details, together with the data collected thus far, reported to be monthly readings.

5 Site Visit

5.1 Introduction and General Observations

The site visit took place on a day with showers of hail and rain, and with 4.6 mm of rainfall having fallen in the previous three days (Wunderground, 2016); this followed a generally wet winter with sequential Atlantic storm systems prevailing. The field investigations fully concur with the findings of Rigare (2015). Despite the contrasting season in which the site visits for Rigare (2015) and the current study were undertaken, flows remained low in early March, with minimal or zero flow visible in the vast majority of inspected ditches, including the central ditch.

The small flows that were observed supported the position of Rigare (2015) previous reports and anecdotal evidence that a shallow hydraulic gradient exists within the ditch network. However, this cannot be quantified without an accurate topographic survey being completed.

5.2 Central Ditch

The upper end of the central ditch has an inflow from a small upstream catchment lying outwith the wetland to the north, adjacent to Porth Loo Lane, shown in Figure 4. This flows beneath the road at a culvert to the northeast boundary of the SSSI site. Flow velocity was too low to observe, but the cross sectional area appeared to be approximately as great as at any other point in the length of the central ditch.

Figure 4 – Channel upstream of the wetland

At the top of the site, tree cover is dense and surface splashing (occasionally open water) is prevalent across expanded areas, as shown in Figure 5, which is taken close to the site of Aunt Joaney's Well: it is assumed that excess runoff (i.e. that not taken for public water supply) transfers through this surface runoff towards the central ditch at times of saturation in winter months. The central ditch continues south through the wetland, largely adjacent to the main footpath running through the site, as shown in Figure 6.

Two dipwells (assumed to be water level monitoring installations) were observed on the site, both on the east of the central path and to the north of the site. The existing network was installed last year (H. Pearce, CIoS; personal communication). The data and details of the installations have been requested for further information.

Figure 5 – Surface splashing and increased tree cover at the top of the site

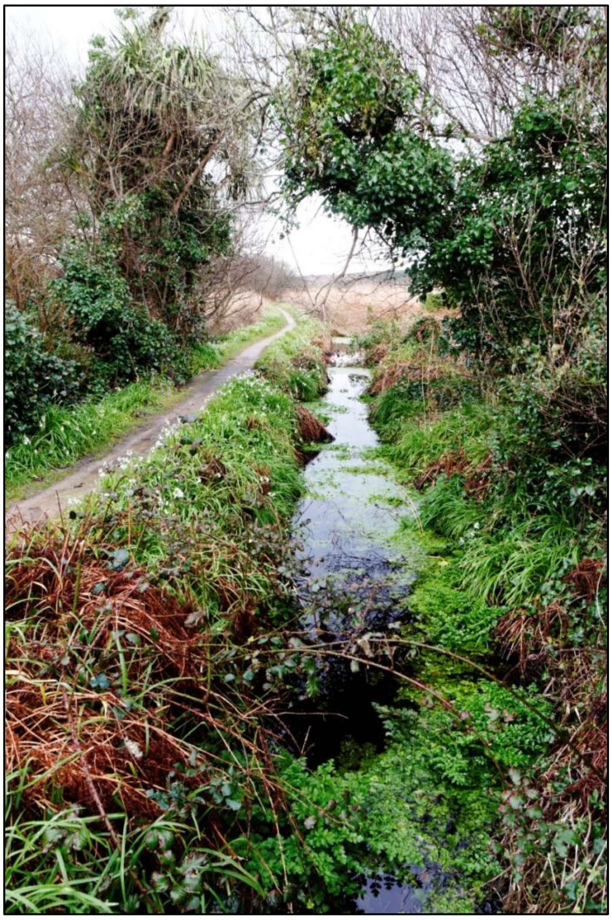

Figure 6 – Central ditch, approximately in the middle of Lower Moors, adjacent to the main footpath

5.3 Secondary Ditches

There are numerous ditches across the site. As discussed by Rigare (2015), most drain, albeit with very low hydraulic gradients, towards the central ditch.

This includes the ring ditch that acts as a catchwater, collecting runoff from higher ground from both the eastern and western higher ground. The ring ditch to the west is less intact, being somewhat disconnected on mapping which seems to be reflected on the ground. The eastern ring ditch connects to the main central ditch downstream of the stop board location (see Section 5.5), via a 150 mm pipe under the footpath; a very small flow was observed here (<1 l/s) as shown in Figure 7. Rigare (2015) also noted a "*very small flow*", and this it can be assumed that this is sustained by groundwater given its lack of seasonal variation.

In contrast to this, the consistent shallow surface flooding across the northern extent of the site confirms Rigare's (2015) assertion that a shallow hydraulic gradient drains the top half of the site, as evapotranspirative demands increase in summer months. This reflects the topography and the high density of *Salix sp.* in the northern areas.

The distributed network of minor ditches creates a complex route for water through the site. This is coupled with the very small flow observed in the ring ditch. Thus, the diffuse runoff from the eastern hillslopes, including that from the eastern springs manifesting at their base, takes an attenuated route through the site. It is assumed that a similarly diffuse route is taken by surface flow towards the central ditch in winter.

The ditch network from the western side of the site will include the runoff from the industrial site and the waste site. The condition of the ring ditch could not be inspected, but information from IoSWT suggests that it is not as intact as the eastern counterpart.

The hydraulic gradients in all of the ditches, including the central ditch, were very low. Flow was observed only on a very few number of occasions. Although no major rainfall event had occurred in the preceding two days, this was despite the generally wet prevailing conditions, and the late winter season meaning that water levels and flows would be expected to be at their peak for the year. The low conveyance of the system is of course the reason for the existence of the wetland landscape being present, but more seasonal variation may have been expected.

Figure 7 – Location of the eastern ring ditch flowing into the central ditch

5.4 Open Water

Areas of open water were observed in the centre of the site. These are thought to be artificial features created to enhance the attractiveness of the site for bird species, adjacent to the two bird hide structures. Although not thought to be deep (approximately 0.5 to 1.0 m), they vary in extent and depth seasonally, water levels appear to be substantially higher than in summer (as reported by Rigare, 2015), suggesting that the local groundwater level also varies. Natural England (2015) state that in late July 2015 the open water areas "*were in danger of drying out.*"

Figure 8 – Open water 'scrapes' in the centre of the wetland

5.5 Wetland Outlet

The wetland drains towards the south, with all ditches converging to the central ditch. Just upstream of where the eastern ring ditch joins, a substantial structure exists, mostly comprising concrete but with stop plank grooves (1,850 mm cross-channel width: Figure 9). CIoS documents, including those from the Nature Conservancy, suggest that the stop plank structure was installed in the early 1980s to maintain water levels in the central ditch, for the purpose of preventing contaminated water from the waste site – which at the time included an incinerator that burnt all of the Islands' waste – reaching the potable water abstraction point at Aunt Joaney's Well. It is unknown as to whether this would be successful, given the permeability of the substrate as highlighted by Rigare (2015). This is considered to be the southern extent of the site boundary.

Below this point, the central ditch continues beyond the site boundary further for approximately 80 m, where it is taken into a culvert (Figure 10) that runs beneath Trench Lane to be discharged to the sea at an unknown location. The culvert inlet is 450 mm in diameter, and has a trash screen. Its invert level was just below the water surface, suggesting that this is a controlling factor for the flow out of the site: a flow of ~ 5 l/s was observed.

It is considered that saltwater intrusion from the outlet is feasible, and a non-return valve was not observed on the culvert inlet (the culvert's outlet could not be located). However, *Juncus maritimus* (Sea Rush) has been observed by IoSWT (D. Mason, IoSWT; personal communication).

Figure 9 – Stop plank structure at the downstream point of the site boundary

Figure 10 – Culvert inlet (partially obscured by vegetation); tape measure extended to 1 m for scale

IoSWT have reported that some sedimentation has occurred in the central ditch, near to the new water treatment facility close to the wetland outlet. It was not possible to verify on site – this would be visible from the results of a topographic survey.

5.6 Industrial Site

The industrial site comprises numerous leased units housing varied light industrial operations, lying on the northern edge of the wetland site. Despite its proximity to Port Mellon beach (~15 m) in the north, the site drains towards the wetland and thus towards Old Town Bay. The drainage system of the industrial site is relatively modern (Figure 11) and thus likely to be efficient, conveying flows to the lower end of the hardstanding areas and to the adjacent channel rapidly. The hydraulic efficiency of this ditch, running behind the industrial site towards the wetland, is anecdotally poor, confirmed during the site visit (Figure 12). Thus it is thought that water backs up from this point towards the industrial area in storm events, flooding the site with its own runoff due to the lack of conveyance capacity through the wetlands downstream from here. Given the relatively extensive area of the wetland, and large vertical storage both within the soil profile and in surface splashing, it is unlikely that water from the wetland is transferred to the industrial site.

Figure 11 – Drainage from the industrial site

Figure 12 – Drainage ditch running along the southern edge of the industrial site

5.7 Waste Site

The waste site lies on the eastern boundary, unmistakable given the legacy stockpiling of waste (Figure 13).

Figure 13 – Waste site (viewed from Telegraph Road the eastern end of the industrial estate)

A new waste strategy is being implemented, with support from a £3m Defra grant. This work aims to transform the site from a legacy dumping area posing a risk to the ecology of the local area, to a processing plant exporting processed material to the mainland.

A new hardstanding area to the northwest of the waste site (Figure 14) is part of the site refurbishment, and work has begun on a surface water interceptor tank (Figure 15) to store runoff from this area.

Figure 14 – New hardstanding area, northeastern part of the waste site

Figure 15 – Works for new interceptor tank, northeastern area of the waste site

The centre of the site is dominated by substantial legacy waste piles. The southern end of the site is the location of the recently-decommissioned incinerator: this was previously used to burn all of the waste from the Islands. Two springs emerge at this southwest of this area, with flow visibly running across the hardstanding (Figure 16). The water here is anecdotally from salt water intrusion, supported with ecological investigations from the wetland site by Dawson (2015). This area has some surface flooding, the source of which is unknown: this could be rising groundwater or surface runoff sitting on impermeable ground.

Figure 16 – Spring at the southern end of the site (behind hardcore)

Figure 17 – Surface flooding at the southern end of the site

As with the industrial site, the southern portion of the waste site appears to have an efficient drainage network, discharging directly into the northeastern extent of the wetland drainage ditches, as shown in Figure 18.

Figure 18 – Drainage from the southern area of the waste site

It is unclear whether the works being implemented will prevent contaminated runoff from reaching the site, as it is considered that there is a legacy of contamination within the soil profile. This is beyond the scope of the current report.

5.8 Transition of Ecology

Although the ecological makeup of the wetland is beyond the scope of the current report, the ecology and hydrology of wetland communities are intricately linked and each provides insights into the mechanics of the other. Tree cover is visibly more dense in the northern half of the site, most notably *Salix sp*., as shown in Figure 19, adjacent to the board walk section of the main north-south path. Further south, approximately at the southern edge of the open water area, there is a sharp delineation to *Phragmites sp.* which can be clearly seen in Figure 20. It is likely that this is related to a change in dominant hydrological processes, such as the transition from seasonally inundated area in the northern half of the site to continual inundation in the south.

Figure 19 – Shrub and tree cover in the north of the site

Figure 20 – *Phragmites sp.* dominated areas to the south of the site, with transition to *Salix sp*. behind (looking northeast)

6 Conceptual Hydrological Model

6.1 Inflows

The flow into the top of the site is unknown, but is likely to be stable, along with the spring-fed baseflows along the eastern edge of the site. Given the abundance of brackish indicator species in the west of the site (Dawson, 2015), it is likely that salt water intrusion from groundwater occurs in the northwest: this may be more seasonally variable. Rainfall distribution through the year will tend to be weighted to winter in terms of total depths.

6.2 Outflows

As noted by Rigare (2015), evapotranspirative loss is the key seasonally-changeable factor (via site management) of the hydrological regime, given that it is driven by the site vegetation. Indeed, evaporative demand can be expected to be similar in magnitude to the hydraulic surface water outflow in the summer months.

Management of vegetation that has high evaporative losses should continue. This will help redress the balance in the critical summer months when evaporative losses are at their maxima, leaving the wetland with higher water levels. In wet periods, this strategy will not have an impact, as evaporative losses are lower in winter when water levels are typically higher.

The abstraction for potable water at Aunt Joaney's Well will have a quantifiable impact on water stores in the wetland, having most effect in the summer months. Although no evidence has been observed that this is significantly degrading the wetland site (i.e. that it is not sustainable), this impact should be observable through an effective monitoring programme.

6.3 Stores

Water is stored in open water scrapes, linear ditches, within the soil profile and deeper groundwater. Although the groundwater will be mostly stable through the changing seasons, other water levels vary visibly, dropping in summer months. The key disparity through a north-south transect of the site is likely to be the result of the shallow topographic gradient leading to the water levels dropping below ground through slow drainage and high evapotranspiration in summer, as elucidated by Rigare (2015).

6.4 Impacts of Management

The use of stop planks at the site boundary control structure may retain some water from the wetter months and keep the northern half of the site inundated or saturated for longer, possibly resulting in more widespread (and deeper) flooding in the south. Note however that the original SSSI citation (NE, 1976) highlighted the range of habitats being positive; this action may result in less variation across the site and thus removing some of the biodiversity. This may or may not be effective, given the transmissivity of substrates, as a higher driving head initiated by the boards may push water through the substrates more readily.

6.5 Map of Hydrological Movements

Figure 21 shows the major surface water transfers within the Lower Moors wetland. The upstream inflow from land across from Telegraph road is shown in **orange** to the north. The central ditch (**red**: north to south) conveys this water and that collected from lateral surface drains to the site outlet, where it meets with the ring ditches (also **red**). Beyond the stop plank structure at the southern site boundary, water flows downstream in an open ditch (**orange** arrow) before being culverted (**orange dashed** arrow) to Old Town Bay. The inferred runoff pathways from the industrial site (**blue**) and waste site (yellow) are also shown. The potable water supply abstraction point, Aunt Joaney's Well, is shown with a **purple** marker.

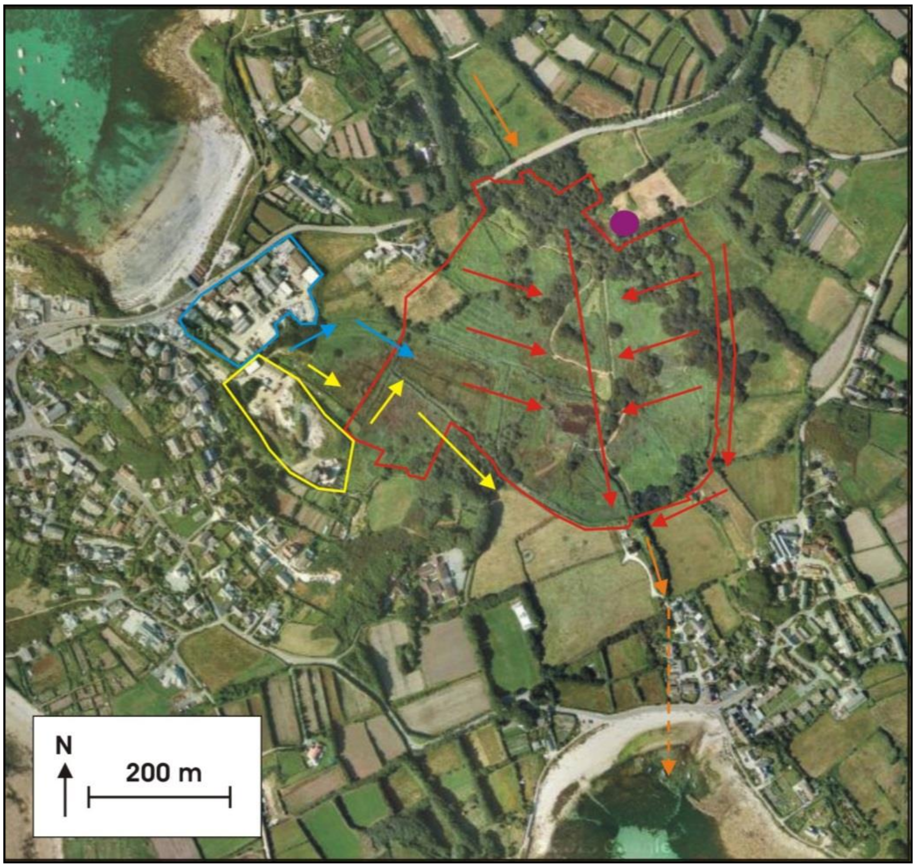

Figure 21 – Map showing the key surface water transfers in the wetland with site boundary marked in red, industrial site in blue and the waste site in yellow. See text for further discussion. Map data © 2016 Google; approximate site boundary taken from Natural England (2016).

6.6 Dynamic Conceptual Model

Given the above discussion, the hydrological dynamics of the two areas is shown visually below: Figure 22 shows how water levels are thought to vary relative to the surface topography in both areas. This should be taken along with understanding of the Rigare (2015) conceptualisation of the surface and groundwater hydrology of the site, shown in long section in Figure 23.

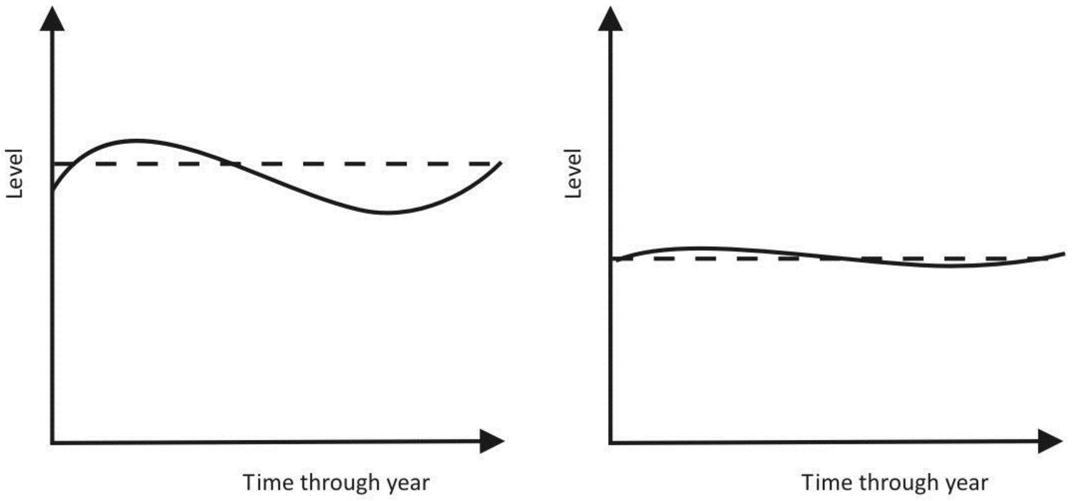

Figure 22 – Dynamic conceptual hydrological model of the two areas of the wetland: the northern area wetland to the left with a higher topography and more seasonally-variable water level regime; to the right the southern area of wetland with lower surface elevation and more stable water level

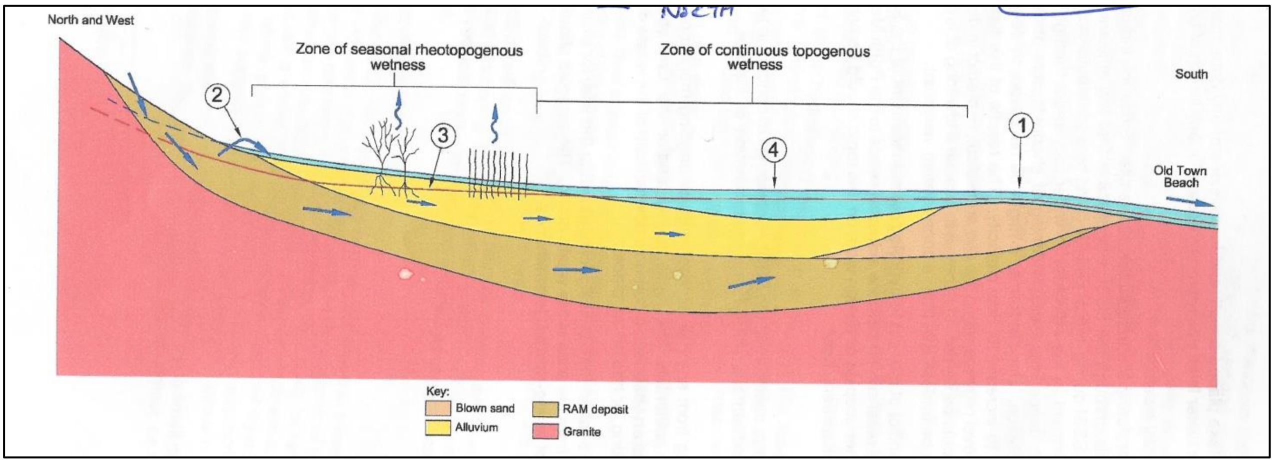

Figure 23 – Long section of site hydrology (Rigare, 2015)

7 Conclusions and Recommendations

7.1 Conclusions

A review has been conducted of existing understanding of the Lower Moors site, and peripheral development areas, together with known management strategies. A site visit has been completed to understand the critical surface hydrology issues. A hydrological conceptualisation has been developed. Much of this conceptualisation is inferred, and a detailed knowledge of the wetland system, its inflows, stores, transfers and outflows can only be understood through targeted detailed monitoring. Recommendations can now be made in that regard.

Key risks to the site are considered to be:

1. Management of the site deriving from non-evidenced decisions, for example, the clearing of ditches on the proviso that that this would prevent flooding of the industrial site. Decisions should be made with clear evidence of likely impact;
2. Conflicting management priorities: clear and multi-agency approved management plans are required;
3. Increased runoff rates from the industrial and/or waste sites;
4. Climate change and associated sea level rise increasing salt water intrusion, thus transitioning the ecological niches present towards a more brackish environment;
5. Contamination from the runoff from the waste site or from agriculture; and
6. Over-abstraction of water for potable supply.

Active management is required in part by the increasing pressures of marginal development. The management can only be effective if responsive to a robust understanding of the hydrological mechanisms taking place.

Specific interpretation of the key marginal pressures is considered in turn initially below. Following this, the wetland itself is discussed, and finally detailed recommendations are made.

7.1.1 Industrial Site

The drainage system of the industrial site is relatively modern and thus likely to be efficient, conveying flows to the lower end of the hardstanding areas and to the adjacent channel rapidly. The hydraulic efficiency of this ditch, running behind the industrial site towards the wetland, is anecdotally poor, confirmed superficially via the site visit. It is thought likely that water backs up from the drainage ditch towards the industrial area in storm events, flooding the site with its own runoff as this runoff has no outlet. Importantly, it is unlikely that water from the wetland is transferred to the industrial site. One option would be to clear the drainage ditch adjacent to the industrial site; issues with this include:

- Given the low capacity of the outlet structure (at the southern end of the wetland), and the fact that during storm events the wetland will be saturated also, effective conveyance increases would be minimal;
- Clearance here may provide some storage that could alleviate flooding risk for low return period (i.e. small magnitude) events, potentially preventing the industrial site from flooding;
- Any increase in storage capacity would only be available in summer months when water levels in the northern section of the wetland are lower and so when this drainage ditch is not full; in winter this area is saturated and the ditches are likely to be full, and thus not able to provide storage;
- This option is also likely to be uneconomic, as the cost of disposing of waste sediment is prohibitive on the mainland: space is clearly even more limited on the archipelago. Any spoil deposited on the wetland site from ditches will remove above-surface storage, potentially offsetting any benefits gained and simply displacing potential floodwater stores.

Ditch clearance within the wetland to the point where flooding risk at the industrial area was tangibly decreased would likely fundamentally change the nature of the drainage channels, as a flood pathway would need to be created to the wetland outlet; thus this is not considered an appropriate management option.

A survey of channels, the industrial site, together with a detailed understanding of the industrial site's drainage system will increase the understanding and management options of this localised issue.

It is recommended that further hardstanding development is prevented, as this would further prevent infiltration and percolation of water through the substrates, and in turn further increase runoff rates. Runoff rates pre- and post-development should be fully evaluated to quantify the impact of the existing development, with mitigation measures implemented as appropriate to alleviate the impact on the wetland. This should be done for existing developments in addition to those proposed in the future.

Given the close proximity of the site to the sea (~200 m) and the agreeable topography, it is recommended that solutions are sought for managing runoff from the site, either through on-site storage or potentially using pumped or otherwise artificial discharge to the sea at Porth Mellon. This would remove any negative impact the site already has on the hydrology of the wetland through decreasing runoff lag times. Although potentially economically unfeasible in the short term, this should be kept in mind for longer timescales should funding become available.

7.1.2 Waste Site

The flooding issue here is driven by the same mechanisms as per the industrial site: a lack of hydraulic capacity through the wetland, but again any flooding is likely from its own runoff.

In the case of the waste site, the severity of the impacts is lower given the nature of the land use. Effective management options are more limited, as pumped discharge to Porth Mellon to the north is likely to be less feasible than for the industrial site given both the greater distance and greater topographic head difference. However, the greater abundance of land within the site boundary facilitates greater potential runoff storage.

As with the industrial site, it is recommended that pre- and post-development runoff calculations are made to quantify the problem and thus highlight potential mitigation measures.

The water quality risk posed by the waste site remains at present, but a waste strategy is being implemented at the site that should minimise the direct runoff from the waste site flowing to the wetland. This is a very positive step, and represents a significant investment. Plans include interceptor tanks to store runoff, bunding to prevent diffuse site runoff, and legacy waste stockpiles being processed to remove hazardous material. It is unclear what technical work has been completed in preparation for these works: it is assumed herein that the works are based on sound understanding of the flow pathways here. Perhaps most importantly, the incinerator that for many years burnt all of the waste from the archipelago, has already been decommissioned, removing a substantial source of water quality risk. Despite this, legacy contaminants are considered likely to remain in substrates on the site for many years; thus rapid implementation of the aforementioned strategy is critical. Water quality risk management is beyond the scope of the current work, although inherently linked to water flow through the site. Thus effective surface water management of the site should be completed as a matter of urgency.

7.1.3 Wetland Site

There appears to be a marked delineation in the wetland, with ditch water levels in the south being markedly stable, contrasted with significant seasonal variation in the north. The hydrology is conceptualised to be dominated by consistent groundwater and rainfall inflow providing a baseflow through the substrate and perhaps the ditch network, coupled with seasonally varying evapotranspirative demand. Although initiated by topographic differences, the high evapotranspiration rates within the northern half of the site compound this differential, enhancing lowering of water levels in summer. The constricted outflow and low hydraulic gradient ensure that the wetland remains largely wet.

There is no evidence that wetland ditch clearance would reduce flooding problems observed at the industrial or waste sites: the low hydraulic gradients would prevent substantially increased flow conveyance. Conversely, substantial ditch clearance would likely initiate the gradual draining and degradation of the wetland. Further complications arise from water quality issues from the waste site and its interaction with the wetland.

Management decisions for all areas (the industrial site, the waste site and the wetland itself) should be made with a robust understanding of the likely hydrological implications and subsequent ecological reaction. It is the author's experience that an iterative process of management options often exists, whereby options arise from an increased hydro-ecological understanding as changes are made and the site's response is observed through monitoring.

7.2 Recommendations

The recommended course of action regards surface water hydrology should be as follows, given in order of priority:

A. Hydrological management plan

A hydrological management plan should be developed, to be agreed by all parties, with the following key points in mind:

- This should be developed to determine the desired water levels during different seasons and in different areas of the wetland, reflecting the target ecology of the different wetland niche habitats;
- It should be informed by current hydrological conceptualisation, and refined from the hydrological monitoring programme (see below);
- It will follow assessment of various management options proposed, again using evidence collected from the hydrological monitoring programme (see below). These management options include:
    - Regrading of the raised ring ditch (Natural England, 2015);
    - Infilling of ditches which will allow water from the surrounding catchment to collect within the mire basin (Natural England, 2015);
    - Installation of a diversion ditch (assumed to take potentially-polluted water from the waste site to the culvert outlet without compromising the wetland site: Natural England 2015) ;
    - Re-profiling of other ditches (Dawson, 2015);
    - Experimental re-instatement of the stop planks (see below);
    - Continued management to reduce evapotranspiration;
    - Management of the saltwater inflows;
    - Management of water quality issues from Waste Site;
    - Any other management deemed likely to improve the hydro-ecology of the site. This may include the use of herbicide to remove *Juncus maritimus*; and
    - Installation of drainage systems from the industrial and waste sites, and pumped discharges to the sea at Porth Mellon.

B. Topographic survey

A detailed topographic survey of both the ditches and the wider area is fundamental to the understanding of any wetland site. From this, calculations can be made to estimate:

- Flow hydraulics through the ditches at given hydraulic gradients within the wetland and adjacent marginal areas;
- Culvert outlet flow at different water levels;
- Inflow from the upstream channel at a given hydraulic head; and
- Potential for storage of runoff from the industrial and waste sites.

Environment Agency LiDAR coverage should be investigated. Data should be sub-centimetre accuracy, to ensure that low flows are understood across shallow topographic gradients found at Lower Moors.

A full brief for the detailed survey should be developed by a qualified surface water hydrologist, but should include as a minimum:

- Appropriately high accuracy and precision level measurements;
- Long sections of the flow pathways through the wetland, critically determining hydraulic gradients, for the central ditch, ring ditches, minor drainage ditches specifically including those taking flows from the industrial and waste sites;
- Ditch cross sectional profiles;

- Surface topography at an appropriate spatial resolution; and
- Surface topography of the industrial and waste sites.

C. Hydrological monitoring

Monitoring is needed, as soon as practicable, to ensure management decisions are made on a sound knowledge base. As stated by Rigare (2015), this would refine the conceptual understanding of the hydrology of the site, and inform appropriate hydrological management of the site.

A brief for hydrological monitoring can now be efficiently developed. This would include:

- Transects of surface water dipwells from north to south at critical locations, to include the full extent of the wetland, to identify water flow gradients and seasonal changes;
- Transects of surface water dipwells from west to east at critical locations, to include the full extent of the wetland. Critically, this should specifically include the areas of suspected salt water intrusion, as identified by *Juncus maritimus* occurrence, and the abstraction at Aunt Joaney's Well;
- Level monitoring in the central ditch, critically at the top, centre and stop plank downstream locations of the site;
- Level monitoring of the central open water features;
- Level monitoring of the minor ditches as they intersect the above transects. This will inform the management plan of soil water response from ditch water level changes;
- Deeper groundwater level monitoring is considered **not** to be necessary given the likely cost. The groundwater flows are thought to be sufficiently well characterised, and the critical gap in knowledge is surface water flow mechanisms;
- Flow monitoring at the culvert outlet, via level monitoring and theoretical rating to derive flow if most efficient;
- Data logging in critical locations:
    - Resources are unlikely to facilitate comprehensive logging at all monitoring locations;
    - Logging at key locations will provide a high temporal resolution dataset that can be extrapolated across the site from manual measurement sites;
    - The logging of rainfall would facilitate both characterisation of response of wetland water levels (ditch network and soil profile) to rainfall events, and accurate calibration of any future hydraulic model that would assess the flooding mechanisms. Rainfall data may be available from the airport;
- The length of monitoring period will be determined by data quality and the density of the network as resources allow. A minimum monitoring period of 24 months should be used, to allow observation of both seasonal and annual variations in condition and hydrological behaviour. If possible an element of logging should continue to provide a long term dataset to monitor change, including that induced from sea level rise and associated salt water intrusion; and
- Hydrological monitoring should be combined with a full expert ecological survey of the site at varied times of the year, given the interaction between hydrology and ecology, e.g. potential saltwater intrusion. Although this may be a natural phenomenon, and almost certainly will not be manageable, it may inform future management plans. The measurement of basic water quality parameters (to be specified separately) should be used to identify saltwater intrusion mechanisms. If structured intelligently, this would also identify the impact of the waste site runoff, and any associated contaminant problems.

D. Peripheral area runoff quantification

In order to understand the interaction of wetland surface water with the adjacent industrial and waste sites, runoff calculations should be completed for these areas to quantify the impact of increased hardstanding (both historically and in the future). This, together with an increased understanding of the storage capacity of the wetland site (resulting from the topographic survey) and its capacity to convey high flows out to Old Town Bay via the culvert outlet will allow potential mitigation measures to be assessed.

In the interim, further hardstanding development of the industrial area should be prevented. It is appreciated here that this may not be possible for the waste site given the ongoing development of the site given wider objectives. Indeed, work to limit runoff from the waste site, given water quality issues here, should be completed promptly. It is unclear what technical work has been completed in preparation for these works: it is assumed herein that the works are based on sound technical understanding.

E. Experimental use of stop planks

Placing stop planks at the downstream end of the site *may* maintain water levels in summer months across the whole site. This management option would be cost-effective given existence of structure (although boards would need to be sourced – and secured), and should be trialled.

As Rigare (2015) states, the permeable substrates mean that flow will likely bypass any water retention structures on longer timescales; however this approach certainly will not initiate draining of the site, and decreasing the hydraulic capacity of the drainage channels in this way is likely to be more akin to the natural state of the site.

The boards should be in place only in the summer months, with the aim of creating a hydraulic gradient along the length of the central ditch within wetland to maintain levels in the north of the site. It must be appreciated that *if* this is successful, storage capacity in the northern areas of the site would *not* be available for flood storage. Note that close monitoring of prevailing meteorological conditions and resultant surface water levels should be monitored continuously during this experimental period, given the potential for causing upstream flooding. Stop boards should be removed or adjusted if site water levels rise beyond the target water levels to prevent upstream flooding.

Ideally, an automatic sluice would be used as opposed to manually-installed planks. However, this is unlikely to be economically feasible, at least in the short term. Hydrological monitoring would allow a full evaluation of the relative benefits of this to be completed at a later date.

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