LIFE TECHNICAL MANUAL – REVIEW OF BEST PRACTICE MEASURES

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Introduction

Best practice in raised bog restoration is documented and presented in Irish Wildlife Manual No. 99 (Mackin et al, 2017). This document was prepared following consultation with a broad range of organisations, groups and individuals involved in peatland restoration across Ireland to document best practice knowledge at the time of publication. The document aimed to assist those involved in undertaking restoration projects by providing a simple guide to implementing common restoration measures, thus ensuring a consistent approach is applied, and common pitfalls are avoided. Application of standard approaches aimed to assist with maximising successful restoration of damaged raised bogs and reduce the number of simple errors that can prevent the full potential of restoration measures from being realised.

In the original document, it was noted that as more comprehensive restoration projects are completed, further lessons will be learned, and best practices will evolve and be developed further. Since the publication of this report in 2017, the EU LIFE-funded Living Bog Project (LIFE14 NAT/IE/000032) has successfully completed restoration on over 3,000 ha across 12 project sites between 2018-2021, making it the largest raised bog restoration project completed in Ireland to date. This project utilised the best-practice methods outlined by Mackin et al (2017) to inform the design of the measures and ensure best practice was followed. However, through the experience developed during the implementation of restoration measures in a range of variable settings, several improvements to existing methodologies were noted and adopted by the project. In addition, several innovative methods were trialled by the project which had not previously been deployed on Irish peatlands. The project investigated the effectiveness of these measures at raising the water level to promote the return of the suitable hydrological conditions for Active Raised Bog (ARB) or Peat Forming Habitat (PFH) to develop.

This report aims to document and provide a means to disseminate the best practice techniques utilised in the Living Bog Project to a wider audience, particularly other raised bog owners and conservation practitioners in Ireland and throughout the EU who may be interested in raised bog habitat improvement, restoration and protection. It is also intended that this report will be published as an addendum to the existing Irish Wildlife Manual (Mackin et al., 2017) to ensure that the lessons learned through the Living Bog project can be applied to future peatland restoration projects in Ireland. The long-term objective of the National Raised Bog Special Areas of Conservation Management Plan 2017-2022 (NPWS, 2017) is to restore at least 3,600 ha of active raised bog throughout the designated network of Special Areas of Conservation (SACs) and Natural Heritage Areas (NHAs). Since 2020 NPWS has initiated an accelerated programme of raised bog restoration and are also supporting wider community-led restoration initiatives through the Peatlands Community Engagement Scheme (PCES) across both designated and non-designated bogs.

Given the widespread restoration programme, it is anticipated that this guide will ensure that any of these ongoing or future projects make use of the latest best practice guidance and lessons learned through the Living Bog Project. It is acknowledged that during future projects, additional lessons will be learned and new methodologies will continually be adopted hence an ongoing review of the overall best practice document should be undertaken on a regular basis.

The following techniques are considered in this document:

1. Peat dams on high bog and cutover
2. Plastic dams on high bog and cutover (Z profile)
3. Plastic dams on high bog and cutover (Multilock)
4. Plastic sandwich dam
5. Partial dam blocking
6. Lilliput dams
7. Marginal Bunding
8. Weir Installation
9. Contour / Cell bunding
10. Land reprofiling
11. Conifer Removal on high & cutover bog

Measure:	Peat dams on high bog and cutover

Peat dams are dams typically installed on intact bog drains using wide-tracked excavators. These dams are typically constructed from peat excavated from borrow pits near the drains. The aim is to bring the water table up to the bog surface and maintain it near the ground surface throughout the year. This is to restore suitable hydrological conditions to allow active raised bog (ARB) to develop on the high bog. On cutover bog, these dams also aim to reduce vertical loss of water from the high bog and provide suitable hydrological conditions for peat-forming vegetation to develop. Even in areas where ARB cannot be restored, drains should be blocked as this can help reduce the rate of flow of the bog and provide wider benefits including a reduction in carbon emissions.

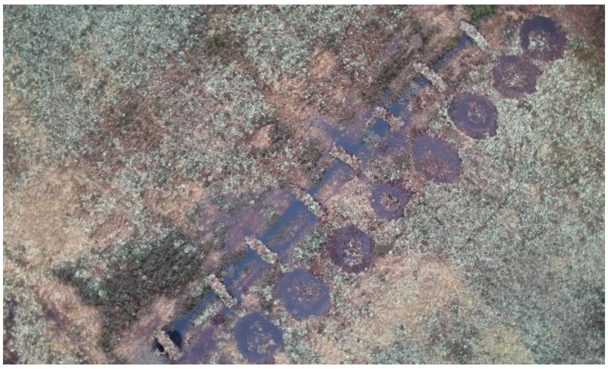
Examples where this has been used/done on the Living Bog Project:

- Ardagullion Bog SAC
- Carrowbehy/Caher Bog SAC
- Carrownagappul Bog SAC
- Clara Bog SAC
- Ferbane Bog SAC
- Garriskil Bog SAC
- Killyconny Bog (Cloghbally) SAC
- Kilsallagh Bog SAC
- Mongan Bog SAC
- Moyclare Bog SAC
- Raheenmore Bog SAC
- Sharavogue Bog SAC

Installation method:

Peat dams are installed using a specially adapted tracked machine (bearing pressure no more than 1.6 lb/inch^2) following the approach outlined by McDonagh (1996):

- Place a dam every 10cm fall in elevation with a minimum of three and a maximum of ten dams per 100m (topographic survey carried out in advance of drain blocking to identify and mark locations for dams).
- Identify a suitable location for machine checks, refuelling, and storage in advance of undertaking works.
- Determine appropriate machine tracking routes (avoiding sensitive areas e.g., sub-central ecotope) and plan drain-blocking to minimise the number of machine passes. This is a particular issue when refuelling so prior planning is essential.
- Start drain-blocking at the top/ highest elevation point of the drain to prevent flooding of the immediate area upstream, thus decreasing the likelihood of the excavator getting stuck.
- Remove scraw (place close-by for replacement later) and clear peat from both sides of the drain.
- Cut a key in the drain, ensuring that this is wider than the actual drain (c. 75cm on either side).
- Remove scraw from the area behind the machine to be used as a borrow pit.
- Dig out peat from the borrow pit and place it into the drain compacting as additional layers are added. Only use the deeper, more compacted peat to build the dam as this provides a more effective seal in the drain.
- Build the dam at least 75cm above the surface of the bog to allow for subsequent shrinkage of the peat as it dries and extend the sides by at least 75cm into the bog.
- Place and compact scraw on top and sides of the dam to stabilise the dam and prevent erosion.
- Re-profile and backfill borrow pit with the peat removed from the sides of the drain to form the key and any peat from the borrow pit. The final profile of the borrow pit should resemble a shallow bowl that is no more than 25cm in depth.
- Replace and compact any remaining scraw into the borrow pit.



Effectiveness:

Has been proven very effective on many bogs. Success in restoring ARB will depend on the surface slope, flow patterns and extent of vertical losses of water through the peat to depth. The build quality of the dam will also have a significant influence on the success of restoring ARB. Poorly constructed dams may fail or fail to maintain a high water level. If there are significant water flows in the drain, erosion of the dams may occur. In cases such as this consideration should be given to the potential installation of plastic piles to reinforce and protect the peat dams.

Maintenance:

Maintenance requirements are low provided dams are installed correctly and in suitable drains (i.e., no significant flows or mineral substrate exposed), most damage will typically occur within the first year of installation during times of high flow, this may require a survey to check dam integrity and identify locations where dams require replacement or where reinforcement is required.

Lessons learned:

- Machine blocking is more effective, faster and cheaper than hand-blocking.
- Machine must be adapted to work on the high bog e.g., longer, and wider tracks to reduce bearing pressure. Preference is for machines with plastic tracks which reduce damage to the vegetated surface.
- Highly skilled driver required and prior planning is essential to ensure the job can be completed safely (e.g., avoidance of sensitive areas).
- Requires checks during the first winter to ensure the integrity of the dam is maintained and the first summer to ensure that they are fully watertight.
- May not be suitable for very wide and deep drains where a bespoke solution is needed.

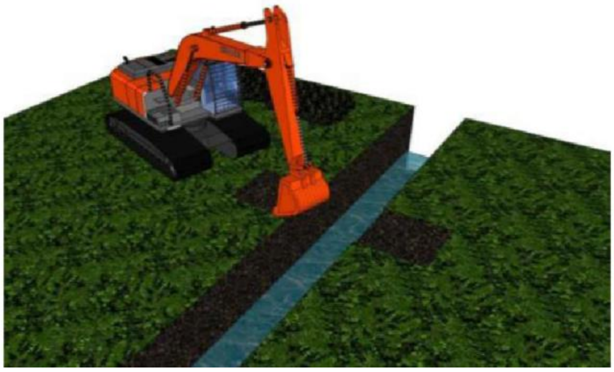
Costs:

Varies with drain dimensions – on The Living Bog project, dams were categorised into small (<1.5m), medium (1.5m – 2.5m) and large (>2.5m) dams and estimated at c. €30, €50 and €80 per dam respectfully, this includes the lifetime cost of the specially adapted machine, labour and fuel.

Risks / optimum time of year for operations:

Potential impacts on the water table in surrounding areas must be assessed, particularly for drain blocking on cutover areas. Prior planning should be done via the development of a restoration plan. The optimum time of year for operations is in the summer months when water levels are lowest making working conditions more favourable. However, work can be carried out throughout the year provided ground conditions are suitable. Potential for impacts on sensitive habitats and species (e.g., ground-nesting birds) requires consideration and some vegetation clearance may be required, especially on cutover areas. Adequate planning is required to ensure any vegetation disturbance occurs outside of the bird nesting season (1st March to the 31st August).

Installation Schematic:



1. Remove scraw from either side of the drain at the proposed location of the peat dam. Place material close by for replacement later.
2. Cut a key in the drain and ensure that it is 0.75m wider than the actual drain on both sides. The key should extend the full depth of the drain plus an additional 0.75m below the invert of the drain. The removed material should be placed behind the machine for replacement later.

3. Remove scraw from the area behind the machine to be used as a borrow pit. If more peat than usual is required to fill the drain, make sure to widen the borrow hole not deepen it as the best peat for damming is nearest ground level due to fibre content.
4. Dig out peat from borrow pit and place into drain compacting in layers of 3-4 buckets per layer depending on the size of drain and machine used. Compact the peat using the bucket before laying more peat from the borrow hole.

5. Build the dam 75cm above the ground level of the bog to allow subsequent shrinkage of the peat as it dries.
6. Take the scraw removed in step 1 and place it on either side of the dam. Then use the scraw removed from the top of the borrow hole to cover the rest of the dam. Backfill the borrow hole with the peat extracted from the drain in step 2. Press down on the sides of the peat borrow hole with the bucket to smooth the slope into the hole.

Reference:

McDonagh, E. (1996). Drain Blocking by machine on Raised Bogs. National Parks and Wildlife Service, Dublin

Measure:	**Plastic dams on high bog and cutover (Z profile)**

Description:

Plastic dams are typically installed by hand on high bog or cutovers, especially where peat dams may erode. On the high bog, they are used in areas where machine access is not possible or where relatively few dams are required meaning the costs of a machine are not justifiable. The aim is to bring the water table up to the bog surface and maintain it near the ground surface throughout the year. This is to restore suitable hydrological conditions to allow active raised bog (ARB) to develop on high bog. On cutover bog, these dams aim to reduce vertical loss of water from the high bog and provide suitable hydrological conditions for peat-forming vegetation to develop. Even in areas where ARB cannot be restored, drains should be blocked as this can help to reduce the rate of flow off the bog.

Examples where this has been used/done on the Living Bog Project:

- Carrowbehy/Caher Bog SAC
- Carrownagappul Bog SAC
- Kilsallagh Bog SAC
- Moyclare Bog SAC
- Sharavogue Bog SAC

Installation **method:**

Plastic dams are typically installed by hand using lengths of interlocking plastic piles. These can be supplied in varying lengths and if necessary cut to size depending on the depth of the drain. It is important that the piles are long enough to extend sufficiently below the base of the drain in order to be secure and minimise water flow under the base of the dam. This may vary depending on the characteristics of the drain. Plastic dams should be installed in drains every 10cm fall in elevation (McDonagh, 1996). The installation process is outlined below:

- Push the first plastic pile into the centre of the drain, ensuring it remains vertical.
- Drive the pile into the peat further until it is held firm using a large rubber mallet (if necessary protect the top of the plastic using a timber batten).
- Once the centre pile is in a secure position guide adjacent piles into position, pushing into the peat and using the rubber mallet to drive into a firm position.
- The dam should extend beyond the width of the drain into the bog, typically by a minimum of 75cm to prevent water from flowing around the dam and eroding the sides of the drain.
- Once all piles have been positioned and are secure they should be driven to a final position, starting from the centre until all piles are approximately 30cm above the level of the surface.
- This plastic should extend at least 75cm below the base of the drain if the peat is very firm. If the peat is weak the plastic should be driven in further until the plastic is held secure.
- If significant flow is expected which could cause erosion around the dam, create a notch for water to overflow by driving the centre pile(s) slightly further

Effectiveness:

Has been proven very effective at many bogs where it has been used and installed correctly. Very ineffective if plastic is not installed deep enough into the drain or does not extend far enough laterally into the bog. In some areas where significant water level fluctuations occur a gap may open up between the peat and plastic allowing increasing water losses over time.

Maintenance:

Maintenance requirements are low provided dams are installed correctly. Most damage will typically occur within the first year of installation during times of high flow. This may require a survey to check dam integrity and identify locations where dams require replacement or where reinforcement is required.

Lessons **Learned:**

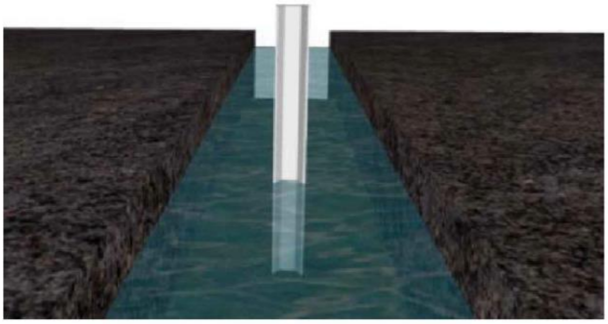
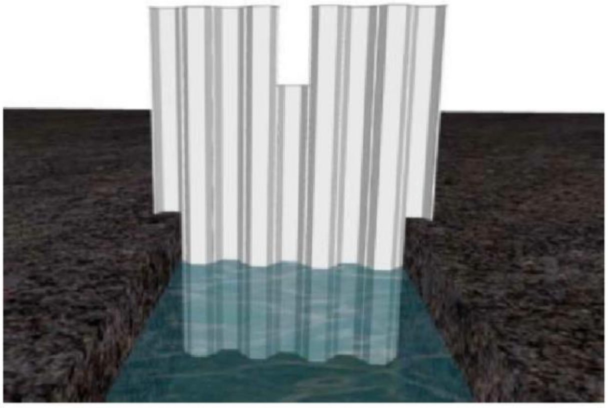
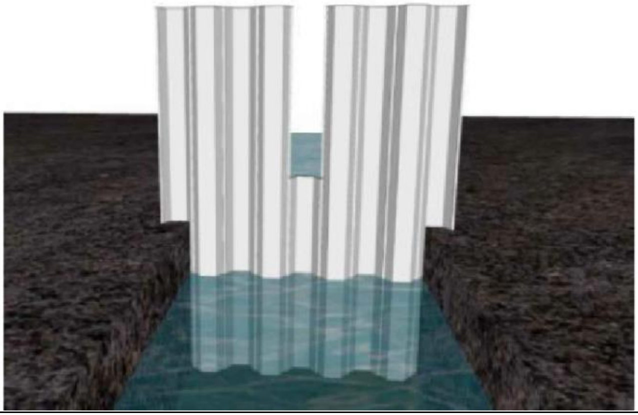
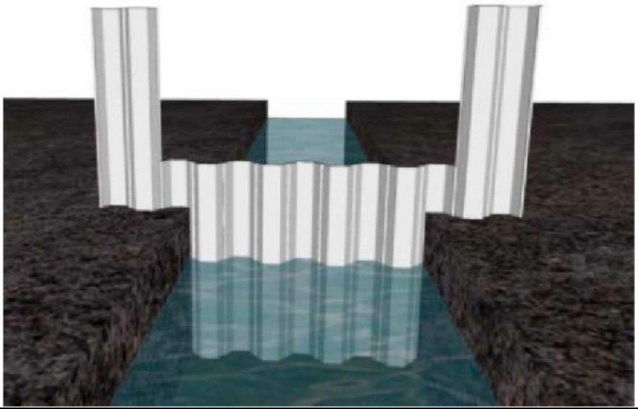
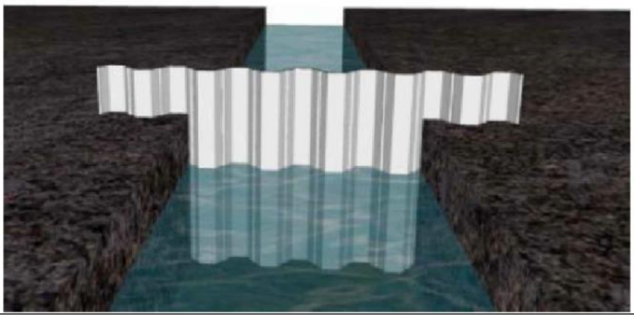
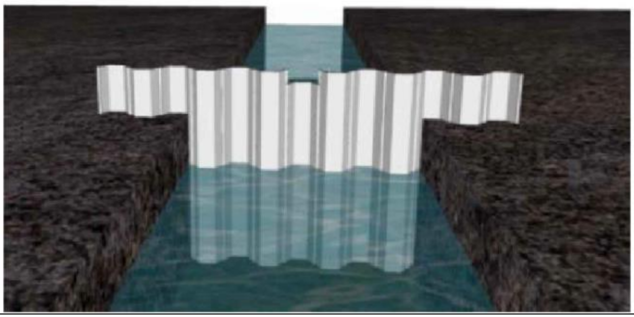
- Plastic dams can fail if they are not installed correctly or can be ineffective in some situations e.g. where cracks are present in the peat.
- Plastic dams can provide effective reinforcement for peat dams in areas where significant flow can be anticipated such as steeply sloping high bog margins or on the cutover. The design of these hybrid dams will vary depending on the specific conditions of the site.
- More expensive than peat dams but can be more economical if machinery access is not feasible or if very few dams are required.
- Requires checks to ensure the integrity of the dam is maintained.

Costs:

Varies with drain dimensions and type of plastic pile used – typical high bog drain using multi-lock piles c. 1m deep estimated to cost c. €350 to block including materials and labour.

Risks/ optimum time of year for operations:

Potential impacts on the water table in surrounding areas must be assessed, particularly for drain blocking on cutover areas. The optimum time of year for operations is in the summer months when water levels are lowest making working conditions more favourable. However, work can be carried out throughout the year provided conditions are suitable. Potential for impacts on sensitive habitats and species (e.g., ground-nesting birds) requires consideration and some vegetation clearance may be required, especially on cutover areas. Adequate planning is required to ensure any vegetation disturbance occurs outside of the bird nesting season (1st March to the 31st August).

Installation Schematic:	
	
1. Push the first pile into the centre of the drain and drive using slow short bursts of pressure from the excavator bucket or a rubber mallet until secure. (If necessary, protect the top of the plastic using a timber batten.) Please ensure that the pile remains vertical and is embedded 75cm below the invert of the drain.	2. Guide adjacent piles into position, again use a machine bucket or rubber mallet to drive into a firm vertical position ensuring they are embedded at least 75cm below the base of the drain until the plastic is held secure.
	
3. Drive piles into the final position starting with the centre pile until all piles are approximately 30cm above the level of the surface.	4. The dam should extend beyond the width of the drain into the bog, typically by a minimum of 75cm to prevent water from flowing around the dam and eroding the sides of the drain. Drive all piles to the final position.
	
5. Where drains are greater than 1.5m and the weight of the water could cause failure reinforcement should be added in the form of 10cm diameter vertical timber posts inserted into plastic piles (where Multi-lock is used) and support timbers fixed immediately behind the dam.	6. If significant flow is expected which could cause erosion around the dam, create a notch for water to overflow by driving the centre pile(s) slightly further until it is below the level of the adjacent bog surface.

Reference:

Best Practice in Raised Bog Restoration in Ireland (Mackin et al., 2017)

McDonagh, E. (1996). Drain Blocking by machine on Raised Bogs. National Parks and Wildlife Service, Dublin.

The Plastic Piling Company. Website, available at: http://www.plasticpiling.co.uk/

Measure:	Plastic dams on high bog and cutover (Multilock)

Description:

Multi-lock plastic dams offer great strength than z-profile plastic piles and are primarily used in areas where high flows are experienced, meaning peat dams or z-profile dams would not be sufficient due to the risk of erosion. The aim is to bring the water table up to the bog surface and maintain it near the ground surface throughout the year. This is to restore suitable hydrological conditions to allow active raised bog (ARB) to develop on the high bog. On cutover bog, these dams aim to reduce vertical loss of water from the high bog and provide suitable hydrological conditions for peat-forming vegetation to develop. Even in areas where ARB cannot be restored, drains should be blocked as this can help to reduce the rate of flow of the bog and provide wider benefits including a reduction in carbon emissions.

Examples where this has been used/done on the Living Bog Project:

- Carrowbehy/Caher Bog SAC
- Carrownagappul Bog SAC
- Kilsallagh Bog SAC
- Moyclare Bog SAC
- Sharavogue Bog SAC

Installation **method:**

Multilock dams are typically installed by machines using lengths of interlocking plastic piles. The sheet piles can come in various profiles, however, the multi-lock pile with the hexagon cross-section was found to be the strongest and most suitable design. These can be supplied in varying lengths and if necessary, cut to size depending on the depth of the drain. The piles must be long enough to extend sufficiently below the base of the drain (approx. 75cm) to be secure and minimise water flow under the base of the dam. This may vary depending on the characteristics of the drain. Plastic dams should be installed in drains every 10cm fall in elevation (McDonagh, 1996). The installation process is outlined below:

- Push the first plastic pile into the centre of the drain, ensuring it remains vertical.
- Drive the pile into the peat further until it is held firm using a large rubber mallet or the bucket or an excavator (if necessary, protect the top of the plastic using a timber batten).
- Once the centre pile is in a secure position guide adjacent piles into position, pushing into the peat.
- The dam should extend beyond the width of the drain into the bog, typically by a minimum of 75cm to prevent water from flowing around the dam and eroding the sides of the drain.
- Once all piles have been positioned and secure, they should be driven to a final position, starting from the centre until all piles are approximately 30cm above the level of the surface.
- This plastic should extend at least 75cm below the base of the drain if the peat is very firm. If the peat is weak the plastic should be driven in further until the plastic is held secure.
- If significant flow which could cause erosion around the dam is expected, create a notch for water to overflow by driving the centre pile(s) slightly further until it is below the level of the adjacent bog surface.

Effectiveness:

Has been proven very effective at many bogs where it has been used and installed correctly. Very ineffective if plastic is not installed deep enough into the drain or does not extend far enough laterally into the bog. In some areas where significant water level fluctuations occur a gap may open up between the peat and plastic allowing increasing water losses over time.

Maintenance:

Maintenance requirements are low provided dams are installed correctly. Most damage will typically occur within the first year of installation during times of high flow. This may require a survey to check dam integrity and identify locations where dams require replacement or where reinforcement is required. Where bypass is occurring, additional sheet piles may be added to increase the width of the dam and increase its effectiveness.

Lessons **Learned:**

- Plastic dams can fail if they are not installed correctly or can be ineffective in some situations e.g., where cracks are present in the peat.
- Plastic dams can provide effective reinforcement for peat dams in areas where significant flow can be anticipated such as steeply sloping high bog margins or on the cutover. The design of these hybrid dams will vary depending on the specific conditions of the site.
- More expensive than peat dams and z-profile plastic dams but can be more economical if machinery access is not feasible or if few dams are required.
- Roots can cause issues when installing, where roots are encountered the ground should be probed first to determine if the install location is suitable.
- Requires checks to ensure the integrity of the dam is maintained.
- Centre pile should be located lower than the rest to allow for overflow. If this isn’t completed it can increase the risk of erosion.

Costs:

Varies with drain dimensions and type of plastic pile used – typical high bog drain using multi-lock piles c. 1m deep estimated to cost c. €350 to block including materials and labour.

Risks/ optimum time of year for operations:

Potential impacts on the water table in surrounding areas must be assessed, particularly for drain blocking on cutover areas. The optimum time of year for operations is in the summer months when water levels are lowest making working conditions more favourable. However, work can be carried out throughout the year provided conditions are suitable. Potential for impacts on sensitive habitats and species (e.g., ground-nesting birds) requires consideration and some vegetation clearance may be required, especially on cutover areas. Adequate planning is required to ensure any vegetation disturbance occurs outside of the bird nesting season (1st March to the 31st August).

Measure:	**Plastic sandwich dam**

Description:

Sandwich dams are a hybrid combination utilising both peat and plastic dams and offer greater strength than a dam constructed using either material alone. They are used where peat and plastic dams are not suitable to block the drain due to the large flow observed or the channel dimensions. They aim to bring the water table up to the bogs ground surface and maintain it within 10cm of the surface all year round. These dams aim to reduce vertical loss of water from the high bog and provide suitable hydrological conditions for peat-forming vegetation to develop. These dams combine the benefits of plastic dams and peat dams, creating a robust dam that has negligible horizontal flow loss if constructed correctly. They offer a viable solution to problems such as peat dam erosion.

Examples where this has been used/done on the Living Bog Project:

- Carrownagappul Bog SAC
- Kilsallagh Bog SAC

Installation method:

Sandwich dams are installed using a specially adapted tracked machine to install lengths of interlocking plastic piles in two parallel rows 0.75m apart and infilled with peat between. It is important that the piles are long enough to extend sufficiently below the base of the drain in order to secure and minimise water flow under the dam. This may vary depending on the characteristics of the drain. The installation process is outlined below:

- Determine appropriate machine tracking routes, material drop of points and plan drain-blocking to minimise the number of machine passes.
- Identify a suitable location for machine checks, refuelling, and storage in advance of undertaking works.

Peat extraction process

- Remove scraw (place close-by for replacement later) and clear peat from both sides of the drain.
- Cut a key in the drain, ensuring that this is wider than the actual drain (c. 75cm on either side).
- Remove scraw from the area behind the machine to be used as a borrow pit.

Plastic dam process

- Using the tracked machine push the first plastic pile into the centre of the drain (downstream side), ensuring it remains vertical.
- Drive the pile into the peat further ensuring it is embedded at least 75cm below the base of the drain until the plastic is held secure
- Once the centre pile is in a secure position guide adjacent piles into position, pushing into the peat until pile is located in a firm position.
- The plastic should extend beyond the width of the drain into the bog c. 75cm.
- Once all piles have been positioned and are secure, they should be driven to a final position, starting from the centre until all piles are approximately 30cm above the level of the surface.
- Timber telegraph poles are then slotted into position on the downward side of the sheeting, providing support both vertically and horizontally.
- The second span of piling is installed using the same process (downstream side).

- A second support line of forestry poles are placed against this second sheet piling.

Peat dam process

- Dig out peat from the borrow pit and place it into the drain compacting as additional layers are added. Only use the deeper, more compacted peat to build the dam.
- Build the dam at least 75cm above the surface of the bog to allow for subsequent shrinkage of the peat as it dries and extend the sides at least 75cm into the bog

Final Steps

- Place and compact scraw on top and sides of the dam to stabilise the dam and prevent erosion.
- Re-profile and backfill borrow pit with the peat removed from the sides of the drain to form the key and any peat from the borrow pit.
- Replace and compact any remaining scraw into the borrow pit.

Effectiveness:

These sandwich dams are very effective in drains with large catchments areas feeding into them and receiving substantial flow. They can be ineffective if not installed deep enough into the drain or if the dam does not extend far enough laterally into the bog. They are an expensive damming technique so should only be selectively used in the most suitable locations based on topographic analysis of the contributing catchment area.

Maintenance:

Maintenance requirements are low provided dams are installed correctly. Most damage will typically occur within the first year of installation during times of high flow. This may require a survey to check dam integrity and identify locations where dams require replacement or where reinforcement is required. Where bypass is occurring, additional sheet piles may be added to increase the width of the dam and increase its effectiveness. Where excess flow is observed an overflow notch should be included to limit lateral erosion around the side of the dams.

Lessons Learned:

- The machine must be adapted to work on the high bog/cutover bog e.g., longer and wider tracks to reduce bearing pressure.
- More expensive than both peat and plastic dams but can be more economical if placed in a suitable strategic location.
- Highly skilled machine driver required with adequate supervision.
- Requires checks during the first winter to ensure the integrity of the dam is maintained and the first summer to ensure that they are fully watertight.
- The interlocking plastic piles can fail if they are not installed correctly or can be ineffective in some situations e.g., where cracks are present in the peat.
- Roots can cause issues during installation. Where roots are likely the ground should be probed first to determine if the install location is suitable.
- Water should be able to spill out onto adjacent cutover, where this isn't applicable, the centre pile should be located lower than the rest to allow for overflow. If this isn't completed it can increase the risk of erosion.

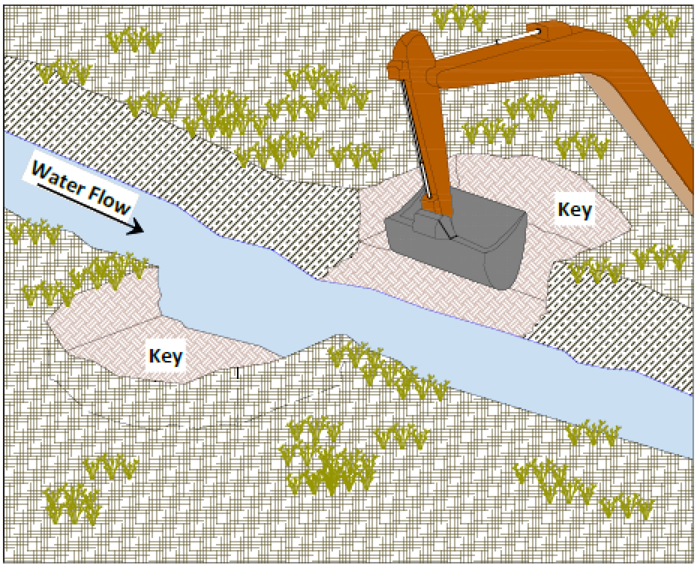
Costs:

Based on peat dam cost plus the plastic dam cost, estimated the cost per dam to be approximately €1,000-2,000 per sandwich dam. This figure includes the lifetime cost of the specially adapted machine labour and fuel. This will vary depending on the width and depth of the drain and the quality of the plastic piling used with multi-lock plastic piling being the most expensive but offer the highest reinforcement.

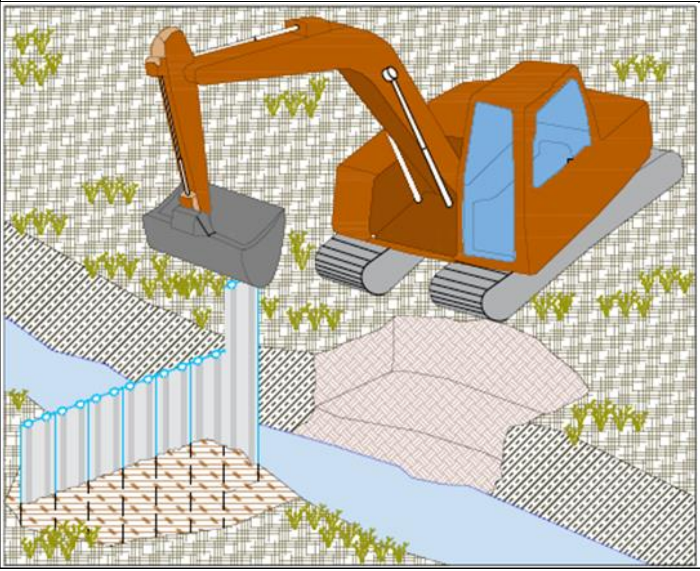
Risks/ optimum time of year for operations:

Potential impacts on the water table, as well as risk of backwater effects in drains, must be assessed, particularly for drain blocking on cutover areas. The optimum time of year for operations is in the summer months when water levels are lowest making working conditions more favourable. However, work can be carried out throughout the year provided conditions are suitable. Potential for impacts on sensitive habitats and species (e.g., ground-nesting birds) requires consideration and some vegetation clearance may be required, especially on cutover areas. Adequate planning is required to ensure any vegetation disturbance occurs outside of the bird nesting season (1st March to the 31st August).

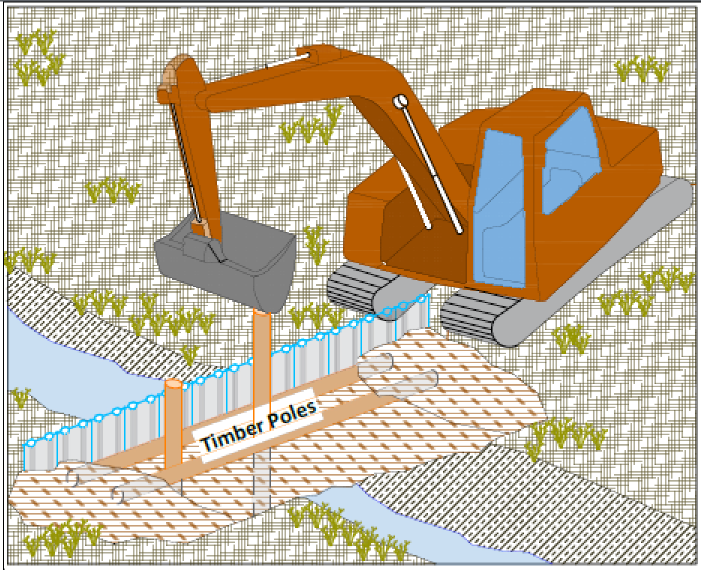
Installation Schematic:



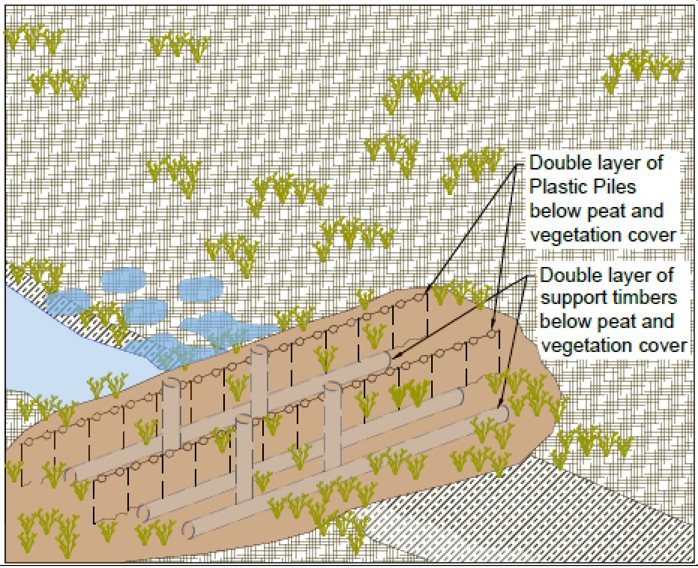
1. The excavator is used to prepare the area by carefully removing vegetation for replacement and digging keys into the drainage channel. The area behind the machine is prepared as a borrow pit to use for infilling the drain with compacted peat.



2. Guide piles into position, using the machine bucket to drive into a firm vertical position ensuring they are embedded at least 75cm below the base of the drain until the plastic is held secure. Remove scraw from the area behind the machine to be used as a borrow pit on the uphill side, remove turf and degraded peat. Place this material close by to be used as a cover later. Extract 'clay-like peat and use this to fill the drain edge and base keys in compacted 300mm layers. Compact the peat firmly using the excavator bucket before laying more peat from the borrow hole bringing the peat to ground level.



3. Timber telegraph poles are then slotted into position on the downward side of the sheeting, providing support both vertically and horizontally. The second span of Piling is then placed downhill of the forestry poles and driven home. A second support line of forestry poles are placed against 2nd span of piles and embedded in the compacted peat. Vertical support poles are driven into the honeycomb structure of the central plastic piles acting as reinforcement. Drive piles into the final position until all piles are approximately 30cm above the level of the surface.



4. The space between the two spans of piling and also the back and front of the dam is backfilled with peat from the borrow pit, burying the forestry poles and providing a seal around the structure. The acidic nature of the peat will help to slow down the rate of decay in the timber whilst the sphagnum moss takes hold and infills the drain. The dam should extend beyond the width of the drain into the bog, typically by a minimum of 75cm to prevent water from flowing around the dam and eroding the sides of the drain. Take the scraw removed in steps 1 & 2 and place it on the compacted peat mound. Then use the scraw removed from the top of the borrow hole to cover the rest of the trench. Backfill and cover the borrow hole with the degraded peat extracted from the drain and remaining scraw.

Measure:	Lilliput dams / bunding

Description:

Lilliput bunds are typically constructed on cutover areas between two high bog outcrops, that exist due to historic cutting referred to as lilliput cutting. This is where a long-arm machine excavated peat leaving a shallow trench behind. Standard Peat/Plastic/Sandwich dams would not be effective in these areas given the span of the trench which is typically between 5-20m. The aim is to bring the water table up to the bog surface and maintain it near the ground surface throughout the year. They are most suited to locations where the cutover is extremely flat, there is contributing flow from the nearby high bog and peat conditions are suitable to prevent significant infiltration. Water depth behind a marginal bund should not exceed 25cm as above this depth *Sphagnum* growth is inhibited and the risk of wave action and erosion increases. Weirs/outlets must be included to enable water from the cutover to discharge into downstream cells or adjacent marginal drains when water levels rise above the 25cm level. This measure may also be useful in reducing subsidence on the high bog by reducing losses of water to depth.

Examples where this has been used/done on the Living Bog Project:

- Carrownagappul Bog SAC

Installation method:

Lilliput bunds are typically constructed from highly humified peat:

- Peat should be excavated from a suitable area within the site.
- A 1.5m deep x 0.5m wide trench should be excavated along with the proposed location of the embankment (using a suitably adapted tracked machine). (Note: it is essential that before excavation of peat or a trench an assessment is carried out to ensure that removal of peat or digging into mineral soils will not have adverse hydrological impacts on peatland habitats or any other qualifying interests of the site.)
- The trench should then be infilled with highly humified peat and compacted in layers until fully infilled.
- The lilliput bund should be keyed into the high bog outcrops on either end of the bund (c. 75cm on either side).
- Locations of overflow weirs should be identified, and weirs/overflow pipes put into place.
- Compacted peat should continue to be placed, on either side of the liner until it is fully covered. The embankment should be approximately 1.5m wide.
- Further layers of compacted peat should be placed on top until it is a minimum of 0.75m above the ground surface.
- A layer of scraw should be placed on the top and sides of the embankment to prevent erosion.

Effectiveness:

Has been proven to be very effective at Carrownagappul Bog SAC. The construction of a lilliput bund has resulted in a significant improvement in the hydrology of these areas and the development of peat-forming habitats. This measure is ineffective in areas where there is significant infiltration through the peat as water cannot be retained. If there are significant water flows in the trench, erosion of the dams may occur. In cases such as this consideration should be given to the potential installation of plastic piles to reinforce and protect the peat dams. Weirs/overflow pipes are required to ensure appropriate water levels are maintained levels (<25cm).

Maintenance:

Lilliput bunds require ongoing maintenance to ensure that weirs are operating correctly and that the structural integrity of the bund has not been compromised. Typically, a survey is required during and following heavy rainfall events following installation to identify locations where weirs are operating ineffectively. These surveys should be carried out regularly immediately after construction but can be reduced to an annual survey if no issues are identified following significant rainfall events.

Lessons Learned:

- Machine must be adapted to work on the high bog e.g., longer, and wider tracks to reduce bearing pressure.
- Highly skilled driver required, and prior planning is essential to ensure the job can be completed safely.
- Requires checks during the first winter to ensure the integrity of the dam is maintained and the first summer to ensure that they are fully watertight.
- Adequate outlet weirs or overflow pipes are required to ensure water levels do not rise too high. These should ensure that when water levels reach a maximum of 25cm that water is discharged into a downstream cell or drain.
- The marginal drain downstream of the bund should be of adequate capacity to accept flows from cutover areas. This may require an assessment of conveyance capacity and possible drainage management measures.

Cost:

Estimated costs of €25-€30 per linear metre based on costs at Carrownagappul Bog SAC. This includes the lifetime cost of the specially adapted machine, labour and fuel Costs may be significantly more expensive if peat has to be sourced from another site.

Risks/ optimum time of year for operations:

The optimum time of year for operations is the summer months when water levels are lowest meaning the dam can be constructed without experiencing significant flows. Potential for impacts on sensitive habitats and species (e.g., ground-nesting birds) requires consideration and some vegetation clearance may be required, especially on cutover areas. Adequate planning is required to ensure any vegetation disturbance occurs outside of the bird nesting season (1st March to the 31st August).

Measure:	Marginal Bunding

Description:

Marginal bunds are constructed on the cutover area surrounding the high bog. The aim is to bring the water table up to the bog surface and maintain it near the ground surface throughout the year They are most suited to locations where the cutover is extremely flat, there is contributing flow from the nearby high bog, peat conditions are suitable to prevent significant infiltration and there is an adequate marginal drain in place behind the proposed dam location. Water depth behind a marginal bund should not exceed 25cm as above this depth Sphagnum growth is inhibited. Due to uneven topography behind the dam, this technique typically leads to a range of wet areas within depressions and close to the dam, as well as some drier areas on areas of higher ground. Weirs/outlets must be included to enable water from the cutover to discharge into adjacent marginal drains when water levels rise. This measure may also be useful in reducing subsidence on the high bog by reducing losses of water to depth.

Examples where this has been used/done on the Living Bog Project:

- Ardagullion Bog SAC

Installation method:

Marginal bunds are typically constructed from highly humified peat:

- Peat should (ideally) be excavated from a suitable area within the site or if this is not possible, imported from another bog and left to drain in a suitable dry location on-site.
- A 1.5m deep x 0.5m wide trench should be excavated along the proposed location of the embankment (using a suitably adapted tracked machine). (Note: it is essential that before excavation of peat or a trench an assessment is carried out to ensure that removal of peat or digging into mineral soils will not have adverse hydrological impacts on peatland habitats or any other qualifying interests of the site.)
- The trench should then be infilled with highly humified peat and compacted in layers until fully infilled.
- Locations of overflow weirs should be identified and prefabricated weirs put into place.
- Compacted peat should continue to be placed, on either side of the liner until it is fully covered. The embankment should be approximately 1.5m wide.
- Further layers of compacted peat should be placed on top until it is a minimum of 1.0m above the ground surface.
- A layer of scraw should be placed on the top and sides of the embankment to prevent erosion.

Effectiveness:

Has been proven very effective at Ardagullion Bog SAC, expanding on the effective results observed at Killyconny Bog SAC, where it was trialled earlier in 2008. The construction of a marginal bund has resulted in the significant development of peat-forming habitats on cutover areas. Weirs are required to ensure appropriate water levels are maintained levels (<25cm). Existing topography will define if this measure should be used with large flat areas required, if the topography is more varied, cell bunding should be used.

Maintenance:

Marginal bunds require ongoing maintenance to ensure that weirs are operating correctly and that the structural integrity of the dam has not been compromised. Costs may be high initially but reduce significantly over time. Typically, a survey is required during and following heavy rainfall events following installation to identify locations where weirs are operating ineffectively. These surveys should be carried out regularly immediately after construction but can be reduced to an annual survey if no issues are identified following significant rainfall events.

Lessons Learned:

- Machine must be adapted to work on the high bog e.g., longer, and wider tracks to reduce bearing pressure.
- Highly skilled driver required and prior planning is essential to ensure the job can be completed safely.
- Requires checks during the first winter to ensure the integrity of the dam is maintained and the first summer to ensure that they are fully watertight.
- Adequate outlet weirs, (preferably pre-fabricated), are required to ensure water levels do not rise too high. These should ensure that when water levels reach a maximum of 0.25m that water is discharged into a drain behind the dam. Weirs should be designed to ensure erosion of the dam is prevented and that water flows into the adjacent drain without causing erosion.
- The marginal drain behind the dam should be of adequate capacity to accept flows from cutover areas. This may require an assessment of conveyance capacity and possible drainage management measures.
- Not suitable in areas of shallow peat.

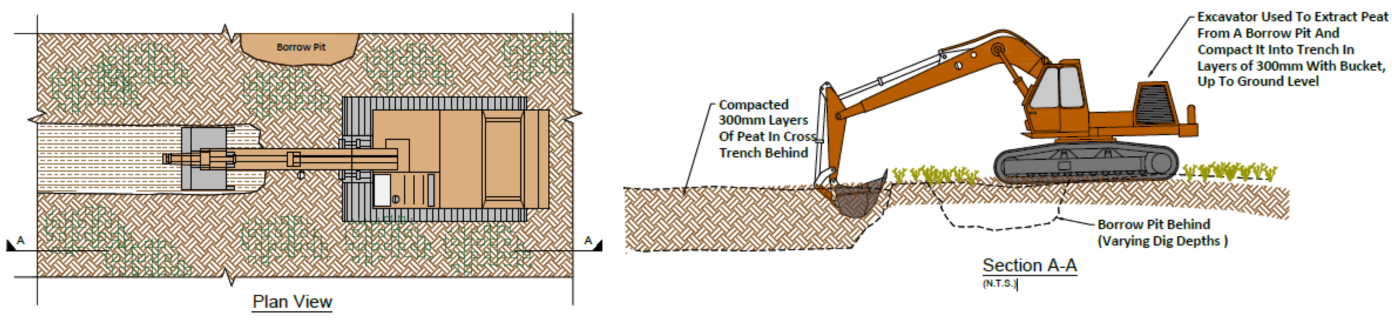
Costs:

Varies with the overall length of bunding designed. Estimated costs of €20-€35 per linear metre based on costs at Ardagullion Bog SAC. This includes the lifetime cost of the specially adapted machine, labour and fuel. Costs may be significantly more expensive if peat has to be sourced from another site.

Risks/ optimum time of year for operations:

Potential impacts on the water table in surrounding areas must be assessed, particularly for drain blocking on cutover areas. The optimum time of year for operations is the summer months when water levels are lowest meaning the dam can be constructed without experiencing significant flows. Potential for impacts on sensitive habitats and species (e.g., ground-nesting birds) requires consideration and some vegetation clearance may be required, especially on cutover areas. Adequate planning is required to ensure any vegetation disturbance occurs outside of the bird nesting season (1st March to the 31st August).

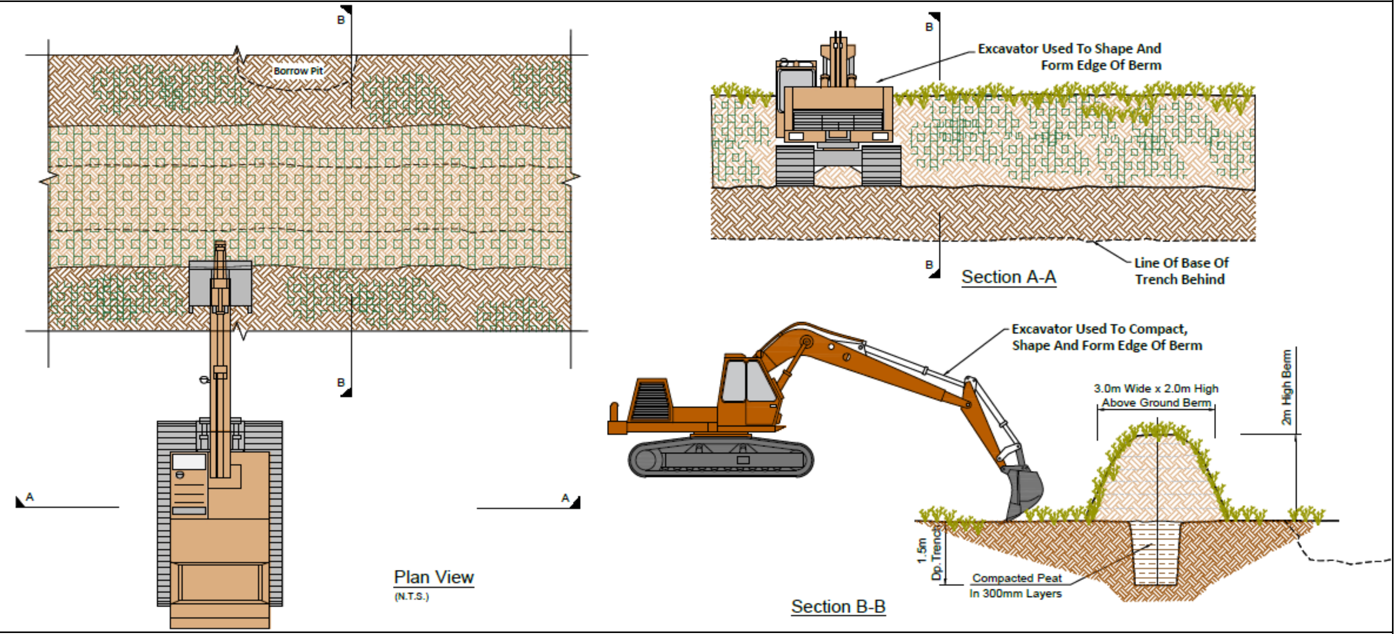
Installation Schematic:



Phase 1

An excavator is used to dig a trench approx. 1.2m wide (4ft wide excavator bucket) and up to 1.5m deep where ground conditions allow, along the proposed location of the marginal bund.

If good 'clay like' ombrotrophic peat exists in the trench the peat is turned over and compressed back into the trench. The area behind the machine is used as a borrow pit. The peat should always be taken from downstream of the dam, if taken from upstream it will create a shallow pool of standing water close to the dam face. Remove degraded peat and place this material close by to be used as cover later. 'Clay' like peat is extracted from the pit and compacted in 300mm layers using the excavator bucket. The peat is firmly compacted using the machine bucket before laying more peat from the borrow pit until the ground level is reached.



Phase 2

The excavator is used to complete the bund by taking peat from the borrow pit. The peat material in the bund is compacted in layers of 300mm. The excavator bucket is used to form and shape the edges of the compacted bund before placing vegetation on top of the bare peat to prevent erosion. The borrow pit is backfilled with the degraded peat extracted from the trench and surface of the borrow pit.

Reference:

Schouten, M., Streefkerk, J. & Zandstra, R. (1994). General Proposals for Technical Measures for the Conservation and Restoration of the Raised Bogs Clara and Raheenmore, National Parks & Wildlife Service - Dublin, Geological Survey of Ireland - Dublin, Department of Nature Conservation, Environmental Protection and Wildlife Management - The Hague, National Forestry Service of the Netherlands – Driebergen

Measure:	Weir installation

Description:

Prefabricated were used on several Living Bog Project sites, with the aim of creating an effective, long-lasting overspill weir for the marginal/barrier dams on site. The overspill notch was cut after installation, based on a design water level generated from the topography of the cutover upstream of the weir. Although these weirs can be constructed using an array of materials, on the Living Bog Project, prefabricated steel structures were utilised as they provided a longer-term solution compared to timber weirs and are less suspectable to displacement associated which can be an issue with plastic sheet pile weirs. The weirs ensure the water level remains in the correct range for bog vegetation to become established and allow excess water to discharge into downstream water courses.

Examples where this has been used/done on the Living Bog Project:

• Carrowbehy Bog SAC	• Killyconny Bog (Cloghbally) SAC

Method:

Weirs are typically installed using a specially adapted tracked machine (bearing pressure no more than 1.6 lb/inch²) to manoeuvre and install the large steel structures. The area where the weir is to be installed should be cleared of any existing vegetation, it is important to ensure no roots or stumps are located close to the location as this will impede the installation.

- The steel weir is lifted by the excavator into position and a banksman ensures the weir is orientated correctly before the weir is lowered into position.
- A timber batten is placed on top of the structure to ensure it is not damaged during installation. The excavator places the arm of the machine on top of the timber batten and exerts a force onto the structure pushing it into the peat.
- It may be necessary to alternate the excavator arm to different areas of the weir so it is lowered at a consistent level.
- Once the bae of peat is reached, a spirit level is used and minor corrections are made to the weir to ensure the final install position is level.
- Survey equipment is then used to mark the design level on the central metal plate, this is the level at which the water level should be maintained on the upstream cutover.
- The peat surrounding the central plate is excavated by hand and a cut-off saw is used to cut the sides of the central metal sheet to the desired level
- The machine arm then bends the central metal sheet towards the downstream side, ensuring allowing the water to flow through the weir.
- Additional peat is compacted around the weir by hand to ensure no bypass can occur

Effectiveness:

Has been proven very effective at Ardagullion Bog SAC and Killyconny Bog SAC. The weir ensured a stable water level upstream of the bund to promote the return of peat-forming habitats. The timber weir installed at Killyconny in 2008 had started to show signs of failure, which may have compromised the positive impacts observed behind the barrier dam. By replacing it with a more secure and long-lasting steel fabricated weir the long-term benefits of the observed restoration have been ensured.

Maintenance:

Maintenance requirements are low provided weirs are installed correctly. Most damage will typically occur within the first year of installation during times of high flow. This may require a survey to check weir functionality to ensure the peat surrounding the weir maintains its integrity and that the weir has not become blocked with debris. Stones or concert paving stones can be placed on the downstream section of the weir to limit the erosion of the peat caused by the outfall.

Lessons Learned:

- Catchment analysis should be conducted prior to design to ensure that the weir notch is large enough to accommodate large flows during flood periods.
- In Carrowbehy Bog, a weir was placed into a 2.5m trapezoidal channel which had a large catchment area and received a large volume of water. This weir failed as it warped under the pressure of the water. This weir could have been reinforced with timber reinforcement, using timber immediately behind the dam.
- Clearing the weir of any vegetation that may have got stuck at the opening is required, however, this is mainly an issue in the first 6 months post-restoration and becomes less problematic as the upstream peatland stabilises following restoration.
- In order for the detailed design to be effective, peat depth in the area should be measured via peat probing to ensure the stell weir is installed to the base of the peat (ideally in contact with the underlying substrate).

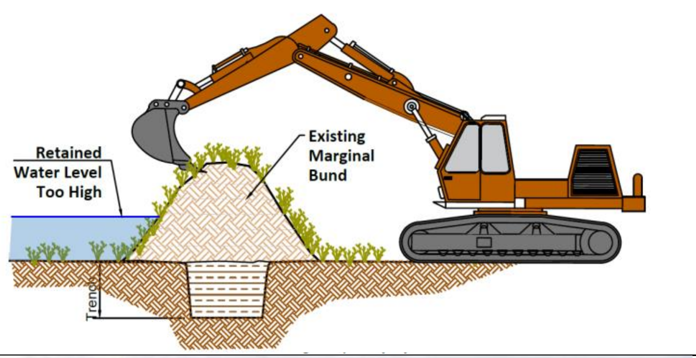
Costs:

Varies with the size of the upstream catchment, however on both Ardagullion SAC and Killconny SAC, the prefabricated steel weir cost approximately €5,000 per unit. The installation process cost €1,000 per unit. this includes the lifetime cost of the specially adapted machine, labour and fuel.

Risks/ optimum time of year for operations:

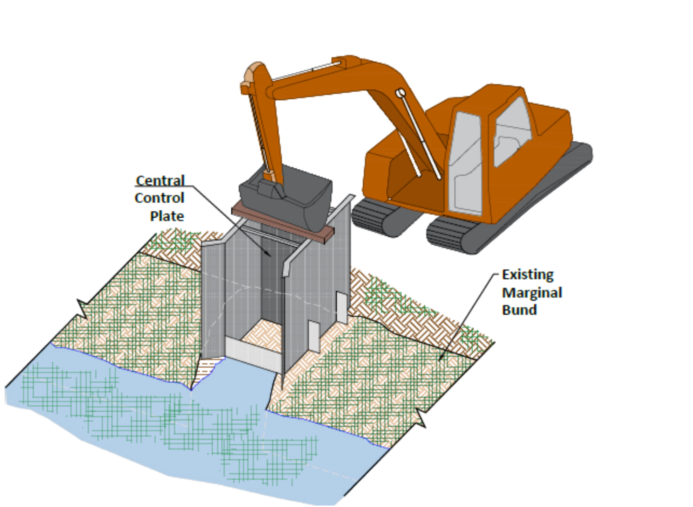
The major risk is that the barrier dam fails during the installation which would release large quantities of water. This is why the weirs should be incorporated into the dam as its being constructed. To lower the risk of a breach during installation, the LIFE project installed temporary pipes to lower the water table in other sections of the barrier dam that were removed when the weirs were in place. The optimum time of year for operations is in the summer months when water levels are lowest making working conditions more favourable. However, work can be carried out throughout the year provided ground conditions are suitable. Potential for impacts on sensitive habitats and species (e.g., ground-nesting birds) requires consideration and some vegetation clearance may be required, especially on cutover areas. Adequate planning is required to ensure any vegetation disturbance occurs outside of the bird nesting season (1st March to the 31st August).

Schematics:

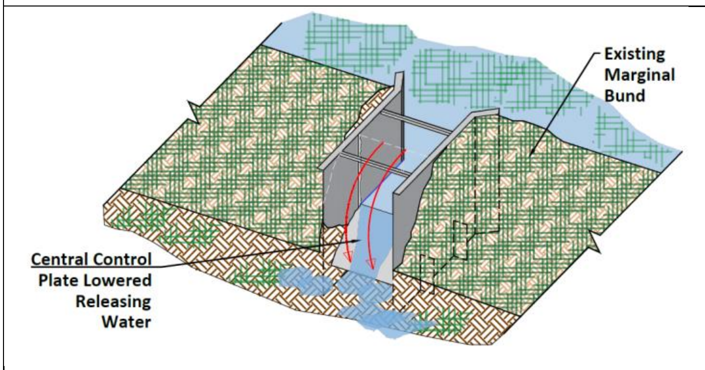


Phase 1 : An Excavator is used to prepare a 1.2m wide section of the existing marginal bund (4ft.wide excavator bucket) removing any scraw and roots that might obstruct the installation of the weir structure.

Phase 2: The arm of the excavator is then used to lower the galvanised weir structure in position spanning the width of the bund.



Phase 3: A timber beam is laid across the top of the weir and used to spread the pressure of the load as the bucket of the excavator is used to push the weir down through the bund and embed it into the trench below. The central control plate of the weir is then cut down along its 2 vertical edges to a pre-determined level.



Phase 4: The central control plate of the weir is then cut down along its 2 vertical edges to a pre-determined level. The plate is bent down letting the water traverse across the bund over the lowered steel plate where it acts as a barrier to the peat underneath.

References:

https://www.nature.scot/sites/default/files/2019-03/Guidance-Peatland-Action-installing-peat-dams.pdf

Measure:	**Cell bunding**

Description:

Cell bunding is typically installed in cutover areas using wide-tracked excavators. These cells are typically constructed from peat by a specially adapted tracked machine (bearing pressure no more than 1.6 lb/inch^2). The bunds are generally located along contour lines with a bund typically placed at every 50cm falls in elevation to form a series of interlocking cells. The cells aim to regulate water levels in areas where acrotelm is absent, by retaining a shallow depth of water (ideally <10-20cm) above the surface, which ensures these areas remain resilient to dry periods during summer months. This ensures that suitable hydrological conditions exist to allow peat-forming vegetation to develop.

Examples where this has been used/done on the Living Bog Project:

- Carrownagappul Bog SAC
- Killyconny Bog SAC
- Clara Bog SAC

Method:

The process of construction contour/cell bunding is detailed below:

- Remove scraw and dig a trench approx. 1.2m wide (4ft. wide excavator bucket) and a minimum of 1.5m deep along the proposed location of the Bund. Trenches up to 2.0m deep are dug where cracks and peat pipes are identified. Place scraw and degraded peat material close by for replacement later.
- If good ‘clay like’ ombrotrophic peat exists in the trench; turn this peat over and compress it back into the trench.
- Remove scraw from the area behind the machine to be used as a borrow pit on the uphill side, remove turf and degraded peat. Place this material close by to be used as a cover later. Extract 'clay’-like peat and use this to fill the trench in compacted 300mm layers. Compact the peat firmly using the excavator bucket before laying more peat from the borrow hole.
- Trench bunds are built 600mm higher than the surrounding ground to allow for settlement and shrinkage as the peat dries out and should also extend beyond trench width.
- Take the scraw removed in step 1 and place it on the compacted peat mound. Then use the scraw removed from the top of the borrow hole to cover the rest of the trench. Backfill the borrow hole with the degraded peat extracted from the trench in step 1 and the remaining material from step 3.

Effectiveness:

Was proven as very effective on Killyconny Bog SAC, Clara Bog SAC and Carrownagappul Bog SAC. The construction of the cells has resulted in the significant development of peat-forming habitats on cutover areas where it was installed. This measure is ineffective in areas where there is significant infiltration through the peat as water cannot be retained or in steeply sloping areas. Weirs/pipes are required to ensure appropriate water levels are maintained levels (<25cm). Measure may be ineffective where steep vertical gradients exist, and prior hydrological investigation should be completed prior to construction to determine if the methodology is suitable.

Maintenance:

Cell bunds require ongoing maintenance to ensure that weirs/pipes are operating correctly and that the structural integrity of the dam has not been compromised. Costs may be high initially, particularly if there are failures due to erosion but reduce significantly over time as the bund stabilises. Typically, a survey is required during and following heavy rainfall events after installation to identify locations where overflows are operating ineffectively. These surveys should be carried out regularly immediately after construction but can be reduced to an annual survey if no issues are identified following significant rainfall events.

Lessons Learned:

- Machine must be adapted to work on the high bog e.g., longer, and wider tracks to reduce bearing pressure.
- Highly skilled driver required and prior planning is essential to ensure the job can be completed safely.
- Adequate outlets (weirs or pipes) are required to ensure water levels do not rise too high. Weirs should be designed to ensure erosion of the dam is prevented and that water flows into the adjacent drain without causing erosion.
- 5m long “finger bunds” extending perpendicular to each bund are required at 30-40m intervals to prevent flow along the front of each bund as well as reducing the impact of wave action.
- The marginal drain behind the dam should be of adequate capacity to accept flows from cutover areas. This may require an assessment of conveyance capacity and possible drainage management measures.
- Bunding cells should not typically be larger than 70m X 70m, to reduce the impact of wave action which prevents *Sphagnum* formation (larger cells may be feasible where the topography creates a mosaic of water depths).
- Not suitable in areas of shallow peat, areas where steep vertical gradients exist or where the topography is very steep.

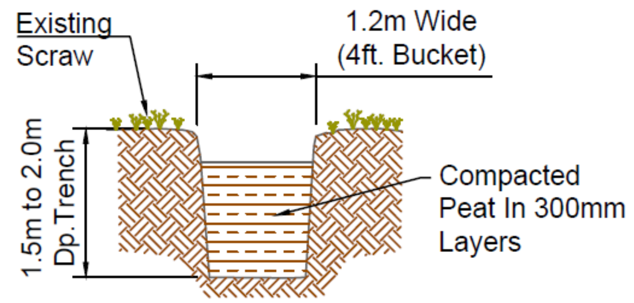
Costs:

Estimated costs of €15-€30 per linear metre based on costs at Carrownagappul Bog SAC and Clara Bog SAC.

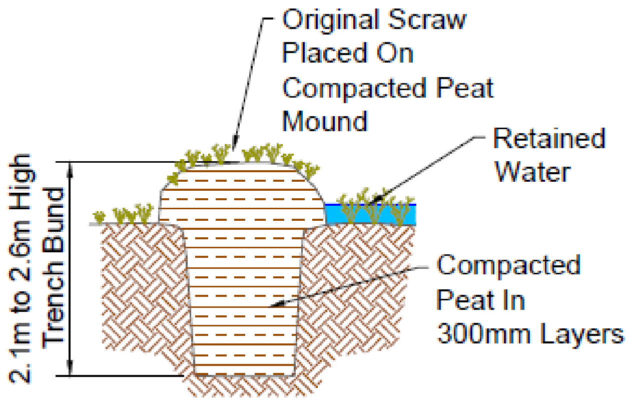
Risks/ optimum time of year for operations:

Largest risk with cell bunding is bund failure, this can be reduced by ensuring adequate overflows are installed, which can be estimated by determining the upstream catchment size. Potential impacts on the water table in surrounding areas must be assessed, particularly for drain blocking on cutover areas. The optimum time of year for operations is the summer months when water levels are lowest meaning the bund can be constructed without experiencing significant flows. Potential for impacts on sensitive habitats and species (e.g., ground-nesting birds) requires consideration and some vegetation clearance may be required, especially on cutover areas. Adequate planning is required to ensure any vegetation disturbance occurs outside of the bird nesting season (1st March to the 31st August).

Installation Schematics:



1. Remove scraw and dig a trench approx. 1.2m wide (4ft. wide excavator bucket) and a minimum of 1.5m deep along the proposed location of the Bund. Trenches up to 2.0m deep are dug where cracks and peat pipes are identified. Place scraw and degraded peat material close by for replacement later.
2. If good 'clay like' ombrotrophic peat exists in the trench; turn this peat over and compress it back into the trench.
3. Remove scraw from the area behind the machine to be used as a borrow pit on the uphill side, remove turf and degraded peat. Place this material close by to be used as a cover later. Extract 'clay'-like peat and use this to fill the trench in compacted 300mm layers. Compact the peat firmly using the excavator bucket before laying more peat from the borrow hole.



4. Trench bunds are built 600mm higher than the surrounding ground to allow for settlement and shrinkage as the peat dries out and should also extend beyond trench width.
5. Take the scraw removed in step 1 and place it on the compacted peat mound. Then use the scraw removed from the top of the borrow hole to cover the rest of the trench. Backfill the borrow hole with the degraded peat extracted from the trench in step 1 and the remaining material from step 3.

Measure:	Land reprofiling

Description:

Land reprofiling is the measure of levelling out the existing area and making the surface topography more uniform across the bog. Most commonly carried out on cutaway bog or previously milled areas of high bog. This alteration of topography allows for more gradual slopes, thus reducing horizontal hydraulic gradient aiding in the rewetting of the bog. Topographic gradient is recognised as a key contributing factor determining hydrological and therefore ecological conditions on a raised bog, by influencing the rate of runoff. Land reprofiling is carried out by a bulldozer with wide tracks and/or a retrofitted snowplough. On the Living Bog Project, once the ground had been reprofiled, cell bunding was constructed in the area to increase water retention.

Examples where this has been used/done on the Living Bog Project:

- Clara Bog SAC

Method:

Reprofiling of peat is carried out using a specially adapted tracked machine (bearing pressure no more than 1.6 lb/inch^2) this machine is generally an adapted bulldozer/ snowplough. The process of reprofiling the bog is detailed below:

- The selected area to be re-profiled should be an area relatively free of vegetation and tree stumps.
- The re-profiling of the area should begin starting in one section and levelling the peat in one row (extend of the dozer).
- The excess peat dozed up should be piled up at the ends of the rows to be spread later on into drains or areas where it may be required.
- Deep face banks or marginal drains should be infilled as a priority with the excess peat, a study of the impacts on adjacent land may be required.
- When levelling the peat, shorter cuts should be made to prevent peat from spilling over the sides of the dozer blade, increasing efficiency and reducing the number of trips required tracking up and down the bog.
- Spot levels are recorded using survey equipment to ensure the reprofiled ground is correctly levelled to the design.
- Once the land has been reprofiled, cell bunding may be used to control water levels.

Effectiveness:

This method has been seen to be successful on Clara Bog SAC, rewetting an area that was extremely dry with high bog remnants with limited restoration potential. Post restoration water levels rose close to the surface over a large area, promoting the growth of *Sphagnum* mosses. It must be noted that cell bunding contributed largely to the success witnessed at Clara bog and a combination of the two methods should be utilised where possible. Measure may be ineffective where steep vertical gradients exist, and prior hydrological investigation should be completed prior to construction to determine if the methodology is suitable.

Maintenance:

Maintenance requirements are low provided levelling is completed correctly. There is the potential that the freshly disturbed peat will subside over time, this may require a survey to check that the topography has not altered to a degree that the surface slope cannot sustain ARB/PFH. Where this has occurred additional levelling or cell bunding may be required.

Lessons Learned:

- Machine must be adapted to work on the cutover bog e.g., longer, and wider tracks to reduce bearing pressure.
- Highly skilled driver required and prior planning is essential to ensure the job can be completed safely.
- Supervision is required while the land is being reprofiled and take spot measurements of the ground surface to ensure that the correct surface topography has been created.
- Not suitable in areas of shallow peat, peat probing prior to completion of construction can assess the suitability of the method.
- Method requires careful consideration in areas sensitive to water quality changes, as reprofiling increases the risk of peat silt mobilisation into downstream watercourses (bunding can assist in reducing the risk, as peat silt typically settles out of deposition prior to discharge).

Cost:

The cost is site-dependent, largely depending on the size of the area to be reprofiled and working conditions (existing slopes/camber, presence of tree stumps, very wet conditions). Costs increase significantly as the slope increases, due to a requirement to move more peat to level the surface. Estimated costs of €500 per ha based on costs at Clara Bog SAC (costs of cell bunding are additional)

Risks/ optimum time of year for operations:

The key risk of impacts from reprofiling is the risk of water quality impacts by creating a large source of potentially mobile peat silt. Consideration of this issue is important at an early stage. The optimum time of year for operations is in the summer months when water levels are lowest making working conditions more favourable. However, work can be carried out throughout the year provided conditions are suitable. Soil moisture is a very important factor in earth moving since it impacts the soil's weight and handling properties. As soil weight affects the dozers' ability to push and grade the material. Therefore, drier periods of the year will have less weight due to the decreased water table, resulting in a quicker and cheaper process. Vegetation clearance of the area may be required, planning may be required to remove this outside of the bird nesting season (1st March to 31st August).

Measure:	Conifer Removal on high & cutover bog

Description:

Plantations of conifers are removed from raised bogs to increase the water table within the peat. Water tables are lowered in areas where conifers are planted due to the drainage network present as well as the impact of interception and increased rates of evapotranspiration. This measure is typically combined with drain-blocking and/or furrow blocking to increase the water table to appropriate levels. In some areas, it can be combined with measures such as bunding.

Examples where this has been used/done on the Living Bog Project:

- Carrownagappul Bog SAC
- Killyconny Bog (Cloghbally) SAC

Method:

The most common approach to conifer removal is clear-felling using a specialist harvester machine that fells the trees in preparation for being sent to a sawmill. This machine cuts the trees at the base of the trunk, removes all branches and cuts to specified lengths. The waste material including branches and uncommercial lengths of timber are placed under the machine to create a brash mat to distribute the weight of the machine and reduce the bearing pressure on the bog surface. The timber lengths are then removed by a forwarder which also travels on the brash mat. Collection of the brash mat into rows (windrowing) is carried out following clear-felling to aid the establishment of *Sphagnum* species on the ground surface. Several further alternatives are available depending on the particular circumstances on each bog e.g., halo-thinning, ring barking, use of an all-terrain vehicle, fell to waste using a specialist track machine or chainsaw, or complete tree removal with cables/winches. The most appropriate solution will depend on the purpose of conifer removal including the potential for peat-forming habitats to develop, risk of damage to the bog surface and commercial viability (area and yield class) of the crop. In general, clear-felling using a harvesting machine should only be carried out if a crop is commercially viable and surface conditions are dry and there is a low risk of damage to raised bog habitats. Where working conditions on the raised bog surface are not suitable for machinery, or there is a small crop of conifers, the use of a chainsaw may be the most appropriate solution. Examples of several scenarios are outlined in the examples box below to highlight the issues that should be considered.

Effectiveness:

This measure has been proven effective at Carrownagappul Bog where it has been carried out, with water levels rising closer to the ground surface. The residual conifer crop material (brash) left on site can provide a source of nutrients that influences the plant communities that initially develop. Over time it is expected that these will develop into ombrotrophic bog communities. The effectiveness of the measure may reduce over time if seedlings are allowed to re-establish in the area, increasing the evapotranspiration rates and reducing the water table depth again. In such cases, additional measures such as cell bunding or contour bunding should be utilised to ensure the water table remains high.

Maintenance:

It is essential that there is a control programme for the regrowth of trees and shrubs following conifer removal on a raised bog. The programme should be designed for the specific scenario encountered but should reflect the conditions on the site and the potential for peat-forming conditions to develop e.g., an intensive programme of regeneration control should be carried out in areas where peat-forming habitats are expected to develop.

Lessons Learned:

- Costs can vary significantly between different sites due to specific conditions.
- Specialist fell to waste machine has proven very successful.
- It can prove difficult to sell marginal commercial crops on high bogs which may increase the costs of restoration.
- Replanting obligations need to be addressed.

Costs:

- Costs based on the work completed at Carrownagappul Bog SAC, suggest the cost for fell to waste by specialist machinery was €1,200-€1,500 per hectare.
- Commercial conifer harvesting is cost neutral as the revenue generated from the sale of timber offsets the harvesting and extraction costs.
- Fell to waste by chainsaw, which was completed across the project sites to facilitate access to areas to complete drain blocking, cost approximately €900-€1,200 per hectare.

Risks/ optimum time of year for operations:

The key risk from this activity is the use of inappropriate machinery in unsuitable areas (e.g., the use of forwarders in wet conditions, resulting in significant disturbance to the peat surface). In addition, water quality risks associated with both peat silt and nutrients need careful consideration. The optimum time for felling is during the summer months to minimise damage to raised bog surface and to optimise conditions for timber harvesting.

Measure:	Stump flipping

Description:

After felling conifer plantations, the land that remains may not have the suitable topographic conditions to support peat-forming habitats due to the remaining stumps and furrows. The stumps and planting ridges offer a raised area, with a low water table, for non-bog flora such as conifers and birch to establish. Once these begin to grow they contribute to lowering the water table in the area once again. Stump flipping is a process of carefully prying the root plate of a stump off the bog surface and turning it upside down in the adjacent furrow using a toothed excavator bucket. Stump flipping can be combined with other measures such as land reprofiling and contour/cell bunding to produce effective results and provide suitable hydrological conditions for peat-forming vegetation to develop.

Examples where this has been used/done on the Living Bog Project:

- Carrownagappul Bog SAC

Method:

This process is carried out by a specially adapted tracked machine (bearing pressure no more than 1.6 lb/inch^2) often a wide tracked excavator.

- Once conifer felling has been completed a tracked machine can begin.
- The machine beings to dig under the stumps breaking roots or pulling the roots of the trees out. A toothed bucket helped grip the stump and made it easier to extract the root plate from the ground.
- The stumps are flipped into adjacent furrow drains and the planting ridge is levelled with the excavator.
- This process kills the tree and discourages the process of stump sprouting.
- Smaller stumps (<15cm dia) and older stumps that have rotted significantly may be removed by simply tracking over them using an excavator, a walkover survey should be conducted first to determine the condition of the stumps present on site.

Effectiveness:

Has proven effective on Carrownagappul bog SAC, where a large area of afforested high bog was clear-felled followed by a process of stump flipping. This has resulted in water levels rising closer to the ground surface. Success in restoring ARB/PFH will depend on the surface slope, flow patterns and extent of vertical losses of water through the peat to depth. The effectiveness of the measure may reduce over time if seedlings are allowed to re-establish in the area, increasing the evapotranspiration rates and reducing the water table depth again. In such cases, additional measures such as cell bunding or contour bunding should be utilised to ensure the water table remains high throughout the year and maintain the correct conditions for bog species.

Maintenance:

It is essential that there is a control programme for the regrowth of trees and shrubs following conifer removal on a raised bog. The programme should be designed for the specific scenario encountered but should reflect the conditions on the site and the potential for peat-forming conditions to develop e.g. intensive programme of regeneration control should be carried out in areas where peat-forming habitats are expected to develop.

Lessons Learned:

- Machine must be adapted to work on the high bog e.g., longer, and wider tracks to reduce bearing pressure.
- Highly skilled driver required and prior planning is essential to ensure the job can be completed safely.
- Can be difficult for the machine to operate in the area. If stumps are fresh and large they can cause damage to the machine, appropriate machine paths may need to be planned.
- With large levels of disturbances associated with stump flipping, appropriate silt control measures must be in place to protect downstream water bodies.
- Costs can vary significantly between different sites due to specific conditions.

Costs:

- Costs based on the work completed at Carrownagappul Bog SAC, suggest the cost was €1,200-€1,500 per hectare

Risks/ optimum time of year for operations:

The optimum time for felling is during the summer months to minimise damage to raised bog surface and to optimise conditions for timber harvesting. However, operations may have to be conducted outside during the bird nesting season (1st March to 31st August).

References: Campbell, D., Robson, P., Andersen, R., Anderson, R., Chapman, S., Cowie, N., Gregg, R., Hermans, R., Payne, R., Perks, M. and West, V. (2019). *Peatlands and forestry*. [online] Available at: https://www.iucn-uk-peatlandprogramme.org/sites/default/files/2020-01/CoI%20Forestry%20and%20Peatlands_reduced%20size.pdf.