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Self-regulating tide gate: a new design for habitat creation

Project: SC070031

Flood and Coastal Erosion Risk Management Research and Development Programme

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Miranda Kavanagh

Director of Evidence

Executive summary

The process of draining coastal land, defending it from the sea and incorporating flapped outfalls has taken place for more than 300 years, resulting in massive loss of inter-tidal habitat. Losses continue today and are currently estimated at 100 hectares per annum. In addition, traditional flapped outfalls are a significant obstruction to fish, especially migratory species, preventing access to spawning and feeding areas.

Climate change and sea level rise are exacerbating the problem. EU directives and UK policies require the Environment Agency and other operating authorities to redress habitat losses. Managed realignment (MR) projects are one solution, but regulated tidal exchange (RTE) can also be a useful technique. This involves allowing controlled tidal inundation of land behind existing defences in a way that creates or restores habitat without increasing flood risk. It has been widely adopted overseas, but only used at a small number of sites in the UK, despite the associated cost advantages. A demonstration site at Goosemoor, on the Clyst estuary near Exeter, has provided much useful evidence for the value of RTE.

Self-regulating tide gates (SRT) have been extensively used for RTE projects for at least 20 years, particularly on the eastern seaboard of the United States. Proprietary SRTs are available in the UK but have previously had to be imported from the USA or Australasia. They are frequently also subject to patent restrictions. These constraints have cost, technical support and sustainability implications which has led to the Environment Agency pursuing a project to develop its own design that could be produced locally and for which more support would be available. The objective of the project was to develop a generic design for a structure to permit and control tidal flows through defences and allow controlled inundation of currently defended land. The design should allow the creation of inter-tidal habitats behind existing defences whilst maintaining a specified level of protection. A further objective was to pilot the use of the design at one or more locations across England and Wales.

The Environment Agency has, through its Flood Risk Science R&D Programme, funded the development of a new design of SRT that will be available without restrictions. Key criteria for the generic design were that it:

- is fail-safe and can be applied to existing outfalls;
- can be produced at reasonable cost by UK manufacturers;
- can operate automatically without the need for any power source;
- requires a minimum of attendance and maintenance;
- is applicable to a range of tidal and fluvial locations;
- will facilitate fish passage.

The project has resulted in an innovative float-operated rotary valve that is adaptable to a wide range of situations and adjustable to refine its operation once installed. Two prototypes have been installed at Seaton in Devon and Lymington in Hampshire to demonstrate the successful use of the SRT in different applications. This report will elaborate on the design and operation of the new tide gate and draw attention to the benefits of its adoption. It is also intended as a reference for determining whether the use of a SRT may be appropriate at any site under consideration.

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Helen Clayton (Project Manager, Jacobs / Environment Agency) – Lymington Project Manager

Fraser Rush (Nature Reserves Officer, East Devon District Council) – Seaton Project Manager

The team from Stoneman Engineering, who helped to develop, fabricate and install the gates at Seaton and Lymington.

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1.0 Introduction

1.1 Project background

Coastal and wetland habitats have a long history of loss to development and reclamation. This is now compounded by losses resulting from coastal squeeze as sea levels rise against existing hard defences. The Government has set challenging targets (for the comprehensive spending review (CSR) period 2007-10) to create 800 hectares of new biodiversity action plan (BAP) habitat, with at least 300 hectares being inter-tidal habitats like salt marsh and mudflat. These targets will be reviewed for the next CSR period and may increase. In addition, legal obligations under the Habitats Regulations require that direct and indirect losses resulting from our flood risk management activities are mitigated.

Much attention has been focused on high profile managed realignment (MR) projects like Alkborough on the Humber and Wallasea in Essex. Large sites like this are not easy to find and require huge investment in time and funding. It may not be possible to meet the targets through MR alone and regulated tidal exchange (RTE) provides an additional method of creating or improving inter-tidal habitats. RTE can also help the development of sustainable coastal defences and assist in preparation for later removal of defences.

RTE allows water to enter areas behind existing coastal or estuarine defences, while retaining close control over the depth or extent of inundation to avoid unacceptable increases in flood risk. Often considered under the umbrella term of managed realignment, RTE is more accurately considered as a distinct category of coastal intervention. It includes a range of techniques to allow water through defences other than full breaching or removal of existing defences. These techniques include the use of sluice gates, spillways, culverts, or pipes to control tidal inundation. It has been argued that these mechanisms can be interpreted as MR where the active defence line is actually moved to landward. However, it is distinct from MR because a high degree of control is retained, the tidal range is restricted and the old defence line tends to require continued maintenance. RTE has also been used as a precursor to bank or breach MR in order to allow the ground behind seawalls to rise through sedimentation in controlled circumstances.

Regulated tidal exchange has been extensively used elsewhere, in particular in the USA, but there are still only a few sites in the UK. A demonstration site, owned and managed by the RSPB at Topsham in Devon, has provided much useful evidence on how such sites may develop and their biodiversity benefits.

Regulated tidal exchange: an inter-tidal habitat creation technique, a report by the RSPB and Environment Agency, was published in 2003. It provides useful background to this document, and is presented as Appendix B. It is also available from the RSPB website at http://www.rspb.org.uk/Images/RTE_tcm9-261368.pdf

1.2 Self-regulating tide gates

One way of achieving regulated tidal exchange is by the use of SRT. These can replace or supplement conventional flapped outfalls and typically involve the use of some sort of float to open a valve, which then closes again to prevent design water levels being exceeded on the landward side of defences.

SRT designs available to date have been of overseas origin, with little or no technical or other support available in the UK. The need to import gates increases their cost, difficulties with post construction support and carbon footprint. Examples of these overseas SRT are illustrated in figure 1-1.

Figure 1-1 Two examples of SRT designed overseas. Note floats have been removed from arms in first example.

The Environment Agency recognised the value of the technique, but felt that it was possible to produce its own design that would avoid patent restrictions, could be produced by suitable local fabricators, and would allow a greater level of technical support, all contributing to a greater level of uptake. Funding was provided through the Agency's flood risk science research programme.

The objectives of the project were to:

- develop a generic design for a structure to permit and control tidal flows through defences, allowing controlled inundation of currently defended land whilst maintaining a specified level of protection;
- construct and install at least one of the new structures to demonstrate successful use of the design.

1.3 Project summary

A two year research and development project has culminated in the production of a generic design for a rotary SRT and the development, construction and installation of two prototypes (at Seaton in Devon and Lymington in Hampshire), which demonstrate different applications of the design.

This report is intended to be of use to asset owners and managers (including Environment Agency staff, local authority staff, land owners and other such interested parties), environmental bodies (such as the RSPB, the National Trust and Natural England) and Internal Drainage Boards to:

- assist potential users through the design process;
- help them identify whether a site lends itself to a RTE/SRT approach;
- to disseminate the experience gained from the production of the two prototypes.

2.0 Design, development and installation of prototype

2.1 Prototype gate design criteria

The following criteria were laid out for the design and development of the prototype gate which must:

- be adaptable to a range of sizes;
- be safely operated and maintained;
- be fail-safe;
- be able to be installed on existing outfalls;
- be produced at reasonable cost by UK manufacturers;
- operate automatically without the need for any power source or telemetry;
- require a minimum of attendance and maintenance;
- be able to be applied to a range of tidal and fluvial locations;
- facilitate fish passage;
- not have an adverse effect on ecology or sediment transfer.

2.2 Prototype gate design and development

The Environment Agency team decided early in the process to work directly with a chosen fabrication contractor, rather than to engage engineering consultants. Competitive bids were invited from three interested contractors and the contract was awarded to Stoneman Engineering from Willand in Devon.

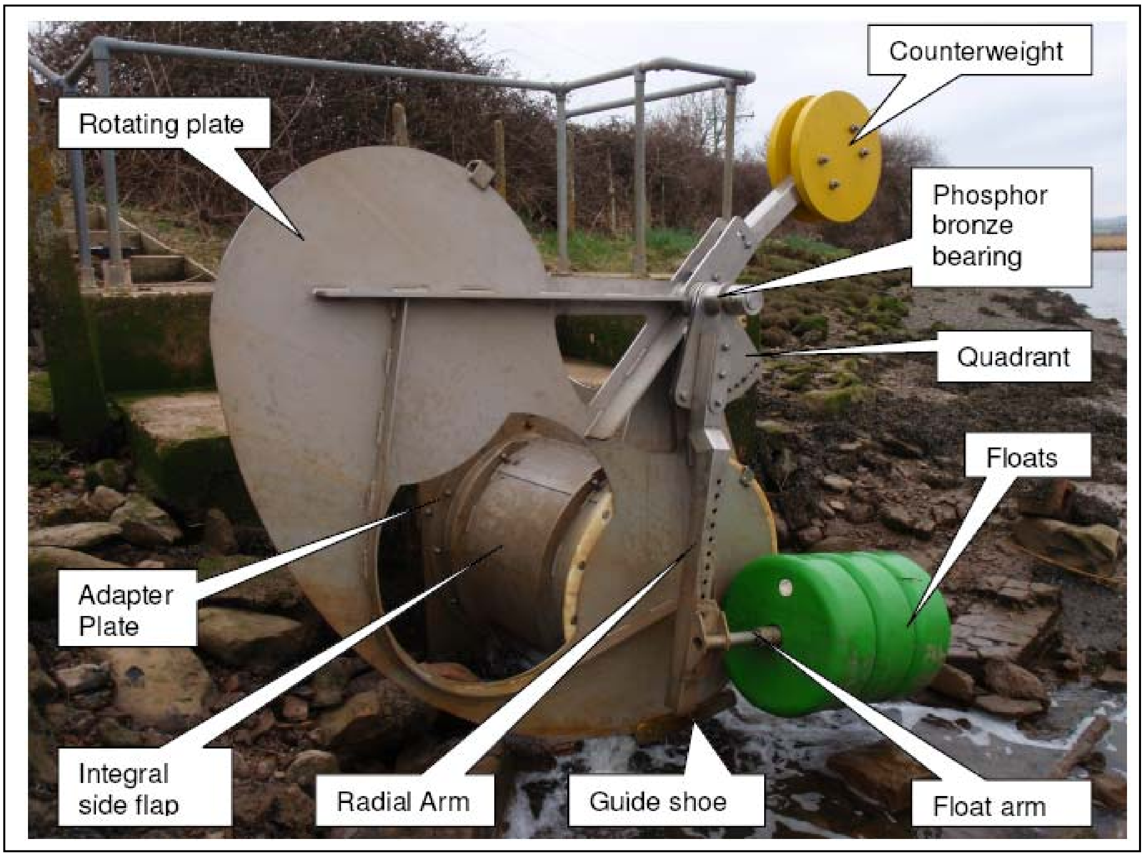


Figure 2-1 Photograph of the Seaton gate showing key elements

It was important that the chosen contractor had design and drafting capabilities. Meetings were held to develop the design and a number of possible solutions were examined. A preferred option was selected and a series of sketches were produced showing the behaviour of the valve at a range of high and low water levels. The key components of the gates are illustrated in figure 2-1.

The resulting design can be summarised as follows: A plate containing an aperture is mounted on the seaward end of a pipe. The plate pivots on a shaft and is caused to rotate across the face of a pipe by a flotation device. Inland flow through the pipe can only occur when the aperture is aligned with the pipe.

With two different design variants, the design is highly adjustable and adaptable to a wide range of situations. The two different variants are known as ‘stop-go-stop’ and ‘go-stop’, the major difference being the shape of the rotating plate. In the stop-go-stop variant the gate is closed at low water levels, before opening part way through the tidal cycle and then closing again at a pre-determined level as the tide rises further. In contrast, the go-stop version remains open at low level and closes as the tide rises. The two alternative variants of the basic design are shown in figure 2-2 below.

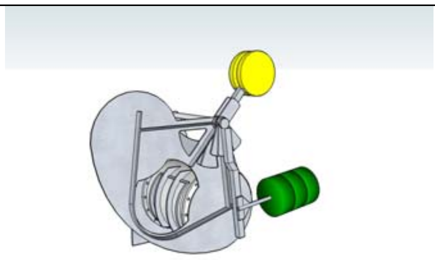
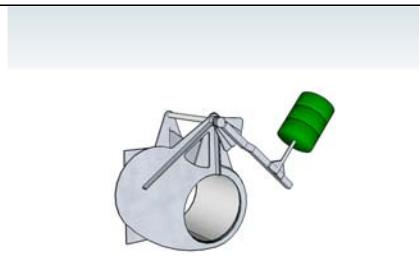
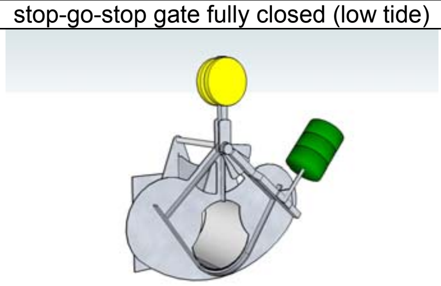
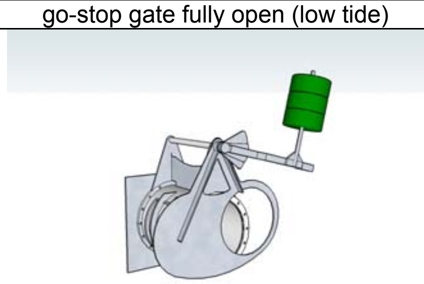
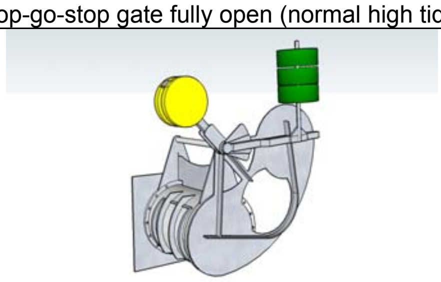
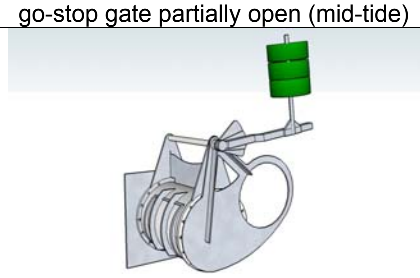
	
stop-go-stop gate fully closed (low tide)	go-stop gate fully open (low tide)
	
stop-go-stop gate fully open (normal high tide)	go-stop gate partially open (mid-tide)
	
stop-go-stop gate fully closed (extreme high tide)	go-stop gate fully closed (high tide)

Figure 2-2 Stop-go-stop (left) and go-stop variants of SRT: showing movement through tide cycle.

The go-stop variant maximises the amount of water that can enter a site; water flows through the gate as soon as the tide is above the invert level.

The stop-go-stop version enables a greater degree of control as the levels at which water both starts and ceases to enter can be varied. This provides control over the frequency of tidal exchange, a key parameter in determining the ecological outcomes.

Inter-tidal areas subject to more than about 450 inundations per annum will tend to become mudflat, while those subject to between 80 and 450 inundations per annum will tend to become saltmarsh. The species variety of a salt marsh will vary depending on the number of inundations.

2.3 How the gate operates

The new design consists of a flat plate, which rotates across a nylon sealing face on the front of a stainless steel tube bolted to the culvert. An aperture in the plate is aligned with the culvert by a foam filled polyethylene float attached to the plate by a radial arm; together with the adjustment of these features, the aperture in the plate will determine the period of opening of the gate.

The main adjustments controlling the operation, illustrated in figure 2-3, are as follows:

- The float arm (on which the floats are mounted) can be moved along the radial arm, altering the point at which the gate begins to rotate;
- The floats can be moved up and down the float arm, altering the point at which the gate closes at high water;
- The radial arm can be rotated on the quadrant, which changes the period of opening in relation to the tidal cycle.

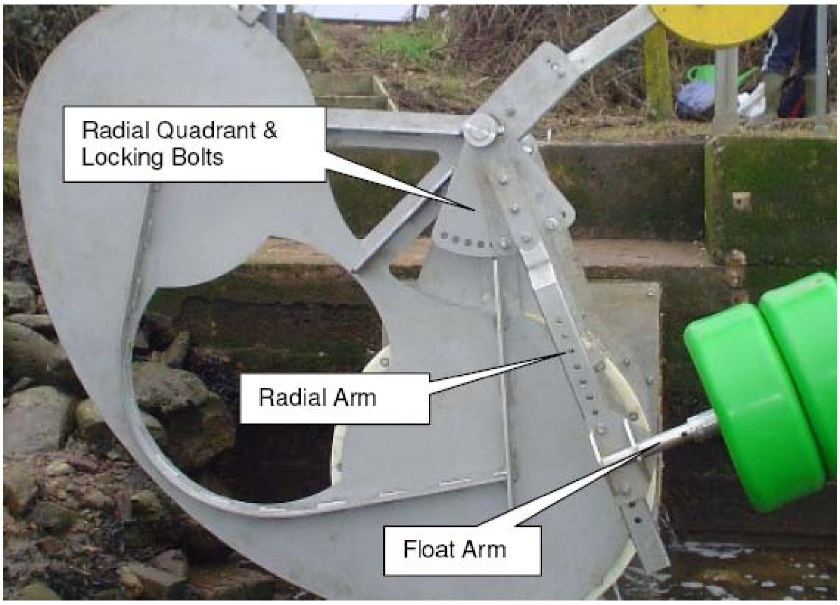


Figure 2-3 Photograph of the Seaton gate methods of adjustment

For most inter-tidal habitat creation applications the 'go-stop' gate will be appropriate, as this will maximise the total volume of water able to pass through the gate during a tidal cycle. This gate will typically have the aperture aligned with the culvert during low tide periods, gradually closing as the tide rises. The gate should be set to completely close at the point when the tide reaches the maximum allowable level for water behind the defences; this may happen at the highest point of each tidal cycle or may only happen at extreme high water levels such as spring tides or in storm conditions. Closing the gate fully at this level means that even if the tide remains high for an extended period, water will not continue to enter the defended area and cause flooding.

The stop-go-stop gate, as noted above, provides a greater degree of control over the frequency and duration of opening. It can, for example, be adjusted to remain closed until tide levels have risen to a pre-determined level so that the salinity of inflows or the number of inundations can be regulated.

The gate is fabricated from 316 stainless steel, with the parts laser cut. The Seaton prototype is 900mm diameter, but it is possible to use the design for a range of opening sizes between 300mm and 1,200mm diameter. A flap valve is fitted to the side of the tube to allow water to discharge from behind at low tide when the gate is closed. At some sites, such as Seaton (see section 4), this may be critical as additional inland waterways may use the route as a drain where the flap facilitates this.

The flexibility of the steel used for the gate may be of concern depending on the size of the aperture/culvert it is being attached to. This can be addressed by using thicker steel or stiffening webs. However, the additional weight and/or risk of accumulation of debris will need to be carefully considered before taking this step. It may be better to fix two gates in some circumstances.

The whole assembly for a 900mm valve weighs around 550kg and can include a demountable gantry to facilitate the installation of the various parts. Opening rotation operates due to three floats, two of which are foam-filled and the third being part-filled with water. The foam-filled floats are used to ensure that, in the event of them being punctured, buoyancy is maintained; the part-filled float works with the counterweights to provide additional closing force. The counterweights are positioned slightly to the right (that is, rotated clockwise) to move the centre of gravity.

The arrangement, when used with a stop-go-stop gate, also acts as a fail-safe ensuring that the valve closes should the floats be lost or become substantially damaged. This fail-safe is not present when using the stop-go gate and therefore additional structures should be considered to safeguard against failure and to prevent inundation of the land behind the flood defence.

Adjustability is built into the design with the ability to vary the position of the aperture in the rotating gate so that it is closed at low tide (thus excluding fresh water) and only opens once the saline wedge has reached the gate to achieve the required salinity.

2.3.1 Fish passage

One of the key criteria was that the SRT should be 'fish-friendly'. This has been achieved through the low invert/threshold of the tube, which optimises the amount of time where there is parallel, steady flow through the culvert which is ideal for fish passage. In addition, the SRT also provides unobstructed passage when the gate is open. This is a great improvement over traditional flap valves where there is risk of trapping fish and turbulent flow due to the increased velocities.

The Environment Agency is currently working on retrofitting SRTs to existing large flood gates to encourage greater fish passage at these locations.

2.3.2 Commercial issues

The rotary SRT was designed by the Environment Agency and Stoneman Engineering and fabricated and installed by Stoneman Engineering. The Environment Agency has applied to patent the design to prevent commercial exploitation of the design by others in the UK. However the aim is for the design to be widely used by the Environment Agency, the RSPB, Natural England, Internal Drainage Boards and land owners for the creation of new wetland habitat with the SRTs being produced locally under licence by suitably experienced fabricators.

3.0 Case studies

3.1 Seaton – original installation

Seaton was the original site selected for the trial of the SRT discussed in the main body of this document.

This site was chosen as it was part of the wider Axe Wetlands Project, a collaborative partnership between East Devon Council and the Environment Agency. The site manager was already considering using a SRT to create a saline lagoon. Another benefit of this site was that it was within easy travelling distance of the Environment Agency offices in Exeter and the contractor at Willand. Finally, it was felt that other constraints, such as obtaining planning permission, could be achieved within the project timetable.

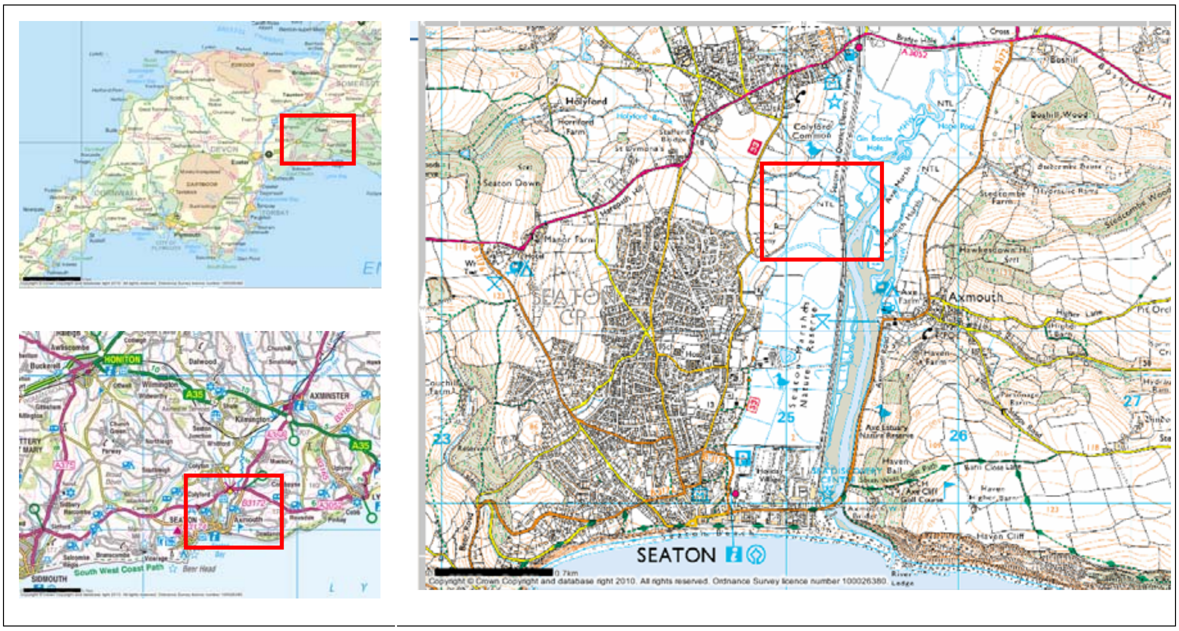


Figure 3-1 Seaton site location

As part of their land acquisition strategy for the Axe Wetlands Project, East Devon District Council purchased the fields including Black Hole Marsh in 2008. Once opened, the site will have extensive public access, including hides and boardwalks. In addition the Stop Line Way, a strategic cycle route, runs along the edge of the site. On the estuary side of the wetlands, the Seaton Tramway runs along the crest of the embankment. While this provides great views across the wetlands, it also means there is restricted access to the SRT itself.

Significant ground works were required at Black Hole Marsh to modify land levels to maximise shallow flooding of the site. Additional structures were also required to allow a watercourse to continue to drain to the estuary.

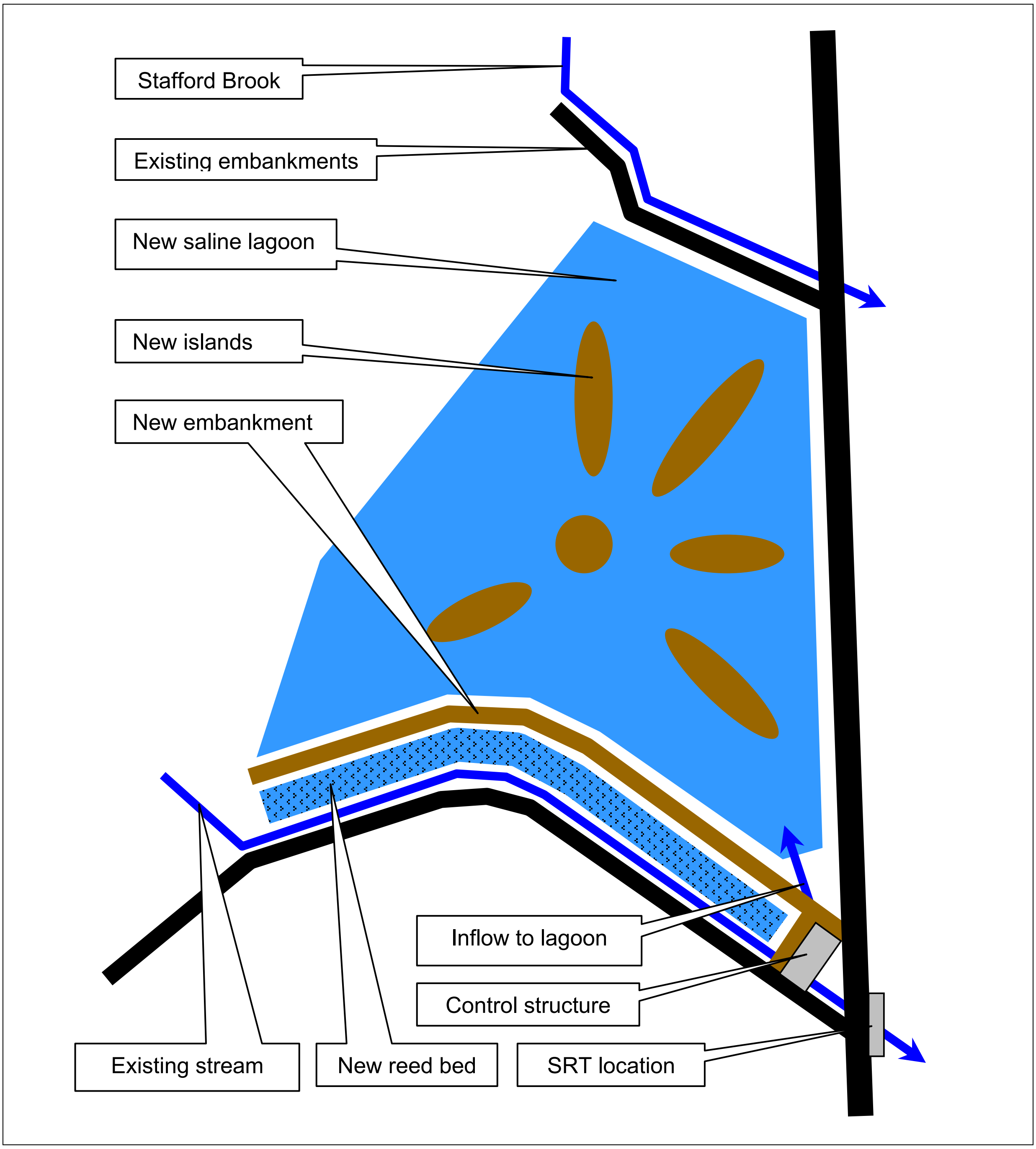


Figure 3-2 Seaton site layout

The site had an existing thick rubber flap valve installed which allowed the water upstream to drain out of the marsh at low tide in the estuary; this was removed and replaced with the prototype SRT.

Due to the location of the installation and ground conditions, it was impossible to transport and install the valve in one piece. As it is likely to be required at many remote sites, the SRT was designed to be fabricated as component parts that can be installed with a minimum of lifting equipment. The parts and the tools required were transported to the site on a flat-bed carriage pulled by a tram on the Seaton Tramway.

To ensure that the lagoon can retain a level of saline water and that this water does not drain back into the estuary at low tides, stop-logs were installed upstream of the SRT in an existing chamber. If the level of water retained in the lagoon needs altering in the future, stop-logs can either be added or removed to raise or lower the water level in the lagoon.

In order to maximise the range of habitats and species present within the Axe wetlands complex, there was a desire to create a saline lagoon at Black Hole Marsh. One of the key characteristics of this habitat is that the salinity remains high (typically between 15 and 40 parts per thousand). It was therefore important to avoid excessive intake of fresh water into the lagoon and the stop-go-stop variant of the SRT was used.

The gate remains closed until the tide has risen high enough for saline water to have reached the gate. As levels rise further the gate gradually opens to allow the saline water in the lagoon to become replenished. When the tide reaches a pre-determined level, the gate then closes to ensure that no additional water enters the area behind the defences. A drawing showing the operating sequence of the stop-go-stop SRT can be seen in figure 2-2.

Figure 3-3 Distant aerial view of the site at Seaton. Location of outfall to estuary through SRT is indicated by arrow

3.1.1 Operation of the Seaton prototype

Following the installation, a short period of setup was required to finalise the position of the float and radial arms to maximise the intake of saline water, while maintaining the flood defence upstream. Since these positions have been set they have not had to be readjusted.

All items of the gate were inspected for damage and wear 12 months after installation; the only problem noted was that the bottom plate-guide, which is used to prevent the rotating plate separating from the nylon sealing face, had become detached. The exact reason for this is unknown, but following some further consideration this item was redesigned and improved in the second (Lymington) prototype.

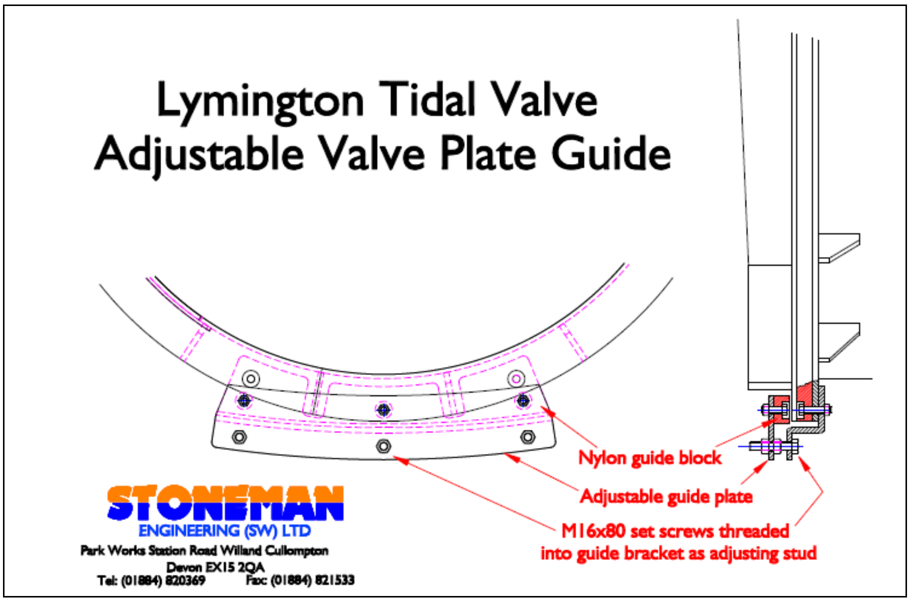


Figure 3-4 Revised valve plate guide

Algal growth is present on those areas of the gate subject to regular immersion; this has not presented any operational problems and could be cleaned off if required. However, it does make the gate less obvious by reducing its visual impact.

Figure 3-5 SRT installation in closed position in low water condition

Figure 3-6 SRT installation in partially open position enabling water passage. Here, water is shown draining out on a falling tide

No problems have been encountered with debris being trapped in the gate and restricting its operation. This appears to be a feature of SRT and may be due to flows occurring in both directions, preventing the sort of accumulation of debris sometimes encountered on traditional outfalls. However, until more SRTs have been installed, a regular inspection regime is encouraged until this is confirmed.

3.1.2 Seaton on-site issues

Over the first 12 months of installation, the SRT has operated with very few issues and any that did arise have been relatively easy to rectify. One of the first modifications carried out was the replacement of the float; this was carried out not due to damage or poor performance but was changed as the original yellow float was too visible from the other side of the estuary. The original float that can be seen in figure 3.7 was replaced with a three-piece green float. The three-piece float also helped to increase the counterweight effect as it allowed one section to be half-filled with water.

Figure 3-7 Original valve float versus replacement float

Discharge from the Axe estuary to the sea is restricted due to its narrow mouth. This means that during high river flows the estuary often fails to drain fully at low tide and also becomes largely fresh water at high tide. Under normal operating conditions this can mean that the SRT opens, allowing fresh water to flow into the lagoon and reducing its salinity.

To counteract this problem the float can be disengaged from the rotating plate by withdrawing the bolts securing the radial arm to the quadrant piece. This allows the float to operate independently while the rotating plate remains closed (reducing stresses in the float arm). Excess water can still escape from the lagoon through the integral flap valve built into the SRT (see figure 3.8 below). Once the level of fresh water in the estuary had reduced and the storm conditions had eased, the securing bolts were reinstalled and the SRT operated as normal.

The original bolts have now been replaced with a captive bolt system that makes it easier to disconnect and reconnect the radial arm and eliminates the risk of losing nuts during the process. However, this is a reasonably onerous operational requirement so a further development would be to provide a locking pin into the radial quadrant (which simply prevents the gate opening) and to design the float arm to withstand the stresses imposed by the restrained buoyancy forces.

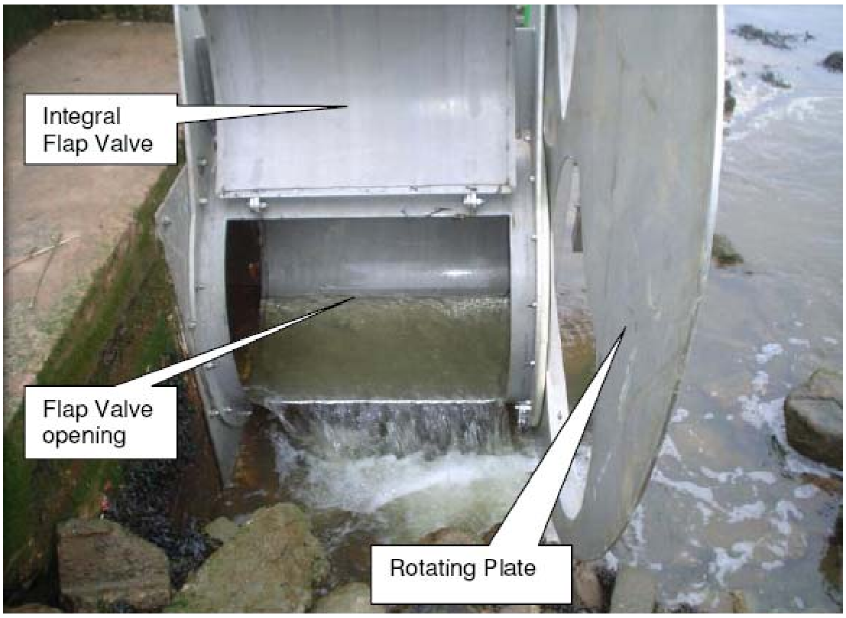


Figure 3-8 Integral flap valve (shown held open manually)

3.2 Lymington

The second site selected for the prototype SRT was Lymington in Hampshire. The tidal limit on the Lymington river is demarked by an embankment (Bridge Road) constructed in the 1800s. Directly upstream of the embankment is the Lymington River Reedbed site of special scientific interest (SSSI), part of the Solent Maritime special protected area (SPA). In 2006, Natural England classified components of the SSSI as being in unfavourable condition. A review of the Lymington River Reedbed water level management plan concluded the only sustainable option available to restore the SSSI was to allow some tidal inundation of the reedbeds.

Figure 3-9 Lymington site location

The Lymington river discharges into the estuary under Bridge Road. A mitred-gate and three top-hung tidal flaps controls the passage of water under Bridge Road, allowing the Lymington River to discharge water into the estuary when the tidal level is lower than the river level, but preventing the passage of tidal water upstream.

A primary objective of the project was to allow the controlled introduction of tidal water upstream of Bridge Road, whilst maintaining flood risk protection in extreme tidal events. Fulfilling this criteria, a SRT was selected as the appropriate control structure. With the impact of introducing saline water upstream being relatively unknown, only the eastern-most top-hung tidal flap was selected to be replaced.

Concerns about existing fish passage under Bridge Road further supported the selection of this SRT. The Lymington river is an important river for salmonids, but declining numbers have been attributed to the obstruction of the embankment and outfall structures. It is hoped this structure will provide much needed passage through the embankment.

In addition to the factors above, the timing of the detailed design and construction phases of the water level management plan coincided well with the Science R&D project.

Figure 3-10 Top-hung tidal flaps at Lymington, furthest one replaced by SRT

3.2.1 Additional design considerations at Lymington

Requirements at Lymington for an open culvert to allow the passage of tidal water at all tidal conditions (except for extreme events), indicated the most appropriate gate configuration was 'go-stop'.

The three top-hung gates at Lymington are located close together and the SRT design extends the culvert by approximately one metre out into the estuary. There was no concern that the SRT would impede the top-hung tidal flap. However, in case there was a need for a further SRT to replace the remaining top-hung tidal flaps, the gate was designed to be offset by adding in an angled section of culvert adjacent to the headwall (figure 3-11).

Dimensions of the culvert discharging to the top-hung tidal flap were 1,200mm x 1,200mm therefore an SRT with a diameter of 1,200mm was selected. This reduced the capacity of the outfall slightly, but hydraulic modelling confirmed that it had a minimal impact on water levels and therefore, flood risk upstream.

Unlike Seaton, the concrete apron beneath the flaps at Lymington is only occasionally exposed at extreme low tides. During the detailed design stage, consideration was given to accessing the gate for operational and maintenance purposes. Stoneman included the addition of a walkway with handrails along the top of the circular steel culvert extension to the front of the gate (figure 3-6) to aid access and maintenance of the structure.

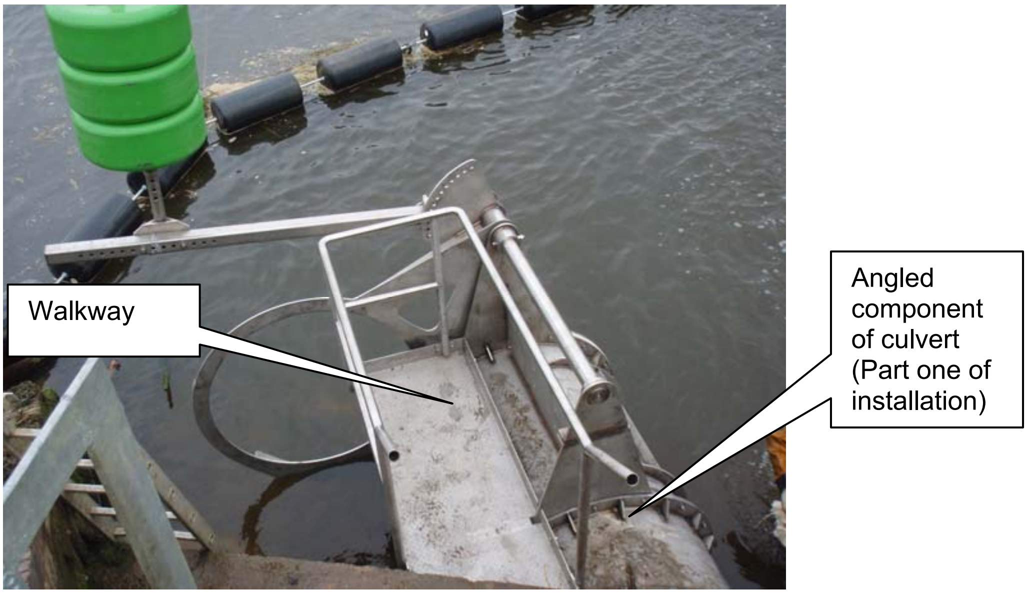


Figure 3-11 Site specific adjustment to SRT at Lymington

The introduction of tidal water upstream at this location gave some concern about the potential risk of scour during periods of tidal inflow. This was resolved by installing a concrete grout mattress upstream of the culvert entrance prior to installation of the SRT.

The head difference created by high tidal levels and low river levels raised concerns that a vortex could be created on the seaward side of the gate. Consideration of public health and safety and the ease of access to the gate via both the water and foreshore led to the installation of a boom downstream of the SRT. Its aim was to act as a warning and reduce ease of accidental access by canoeists and swimmers.

3.2.2 Installation

Access to the site was gained via Bridge Road which is the furthest downstream bridge point on the Lymington river and the main vehicle route between Lymington and the ferry.

Stoneman delivered the SRT to site in two parts for installation over two low tides. During the first low tide, the top-hung gate was removed and the angled component of the gate and the headwall attachment was craned into place. Over the second low tide the remainder of the gate was craned into place and bolted onto part one. Divers were employed during the first low tide to assist in drilling the fixing locations.

3.2.3 Lymington on-site issues

Following installation of the SRT at Lymington, it was bolted closed for approximately four weeks whilst the final surveys of vegetation and protected species were completed upstream. When Environment Agency staff tried to remove the bolt and operate the gate, they discovered that they were unable to; they needed a crane or a gantry to take the weight of the float arm to release the bolt. However, the Lymington SRT did not have a gantry and a crane was not readily available.

When the bolt was finally removed with the use of a Hiab, the gate was very stiff and would not rotate without assistance. This problem was attributed to the slight hydrophilic nature of the neoprene seal, which has caused it to swell. The problem can be resolved by loosening the bottom bracket, but the tidal conditions at Lymington requires waiting for several weeks until the tide is low enough to expose the bottom bracket.

When the floats are adjusted on the float arm, removing the bolts will cause the floats to detach and fall off. This can be rectified by attaching the floats to the arm with a sleeve over the float arm, or by using a captive bolt system similar to the one on the radial arm.

The walkway installed on the gate at Lymington to provide access is insufficient to make all the required adjustments to the gate. For example, it is not possible to adjust the float arm or fill the floats from the walkway and the use of a boat or the installation of additional access is required. An L-shaped platform is recommended for future installations relying on access to the gate from above.

Environment Agency staff also identified a need for mesh panelling in the railing adjacent to the gate to eliminate potential injury to feet should the gate suddenly close.

To improve access to the float valves, the current arrangement at Lymington should be replaced with a single float unit with one top opening valve or three separate floats with valves accessible from the side.

4.0 Monitoring operation of the SRT

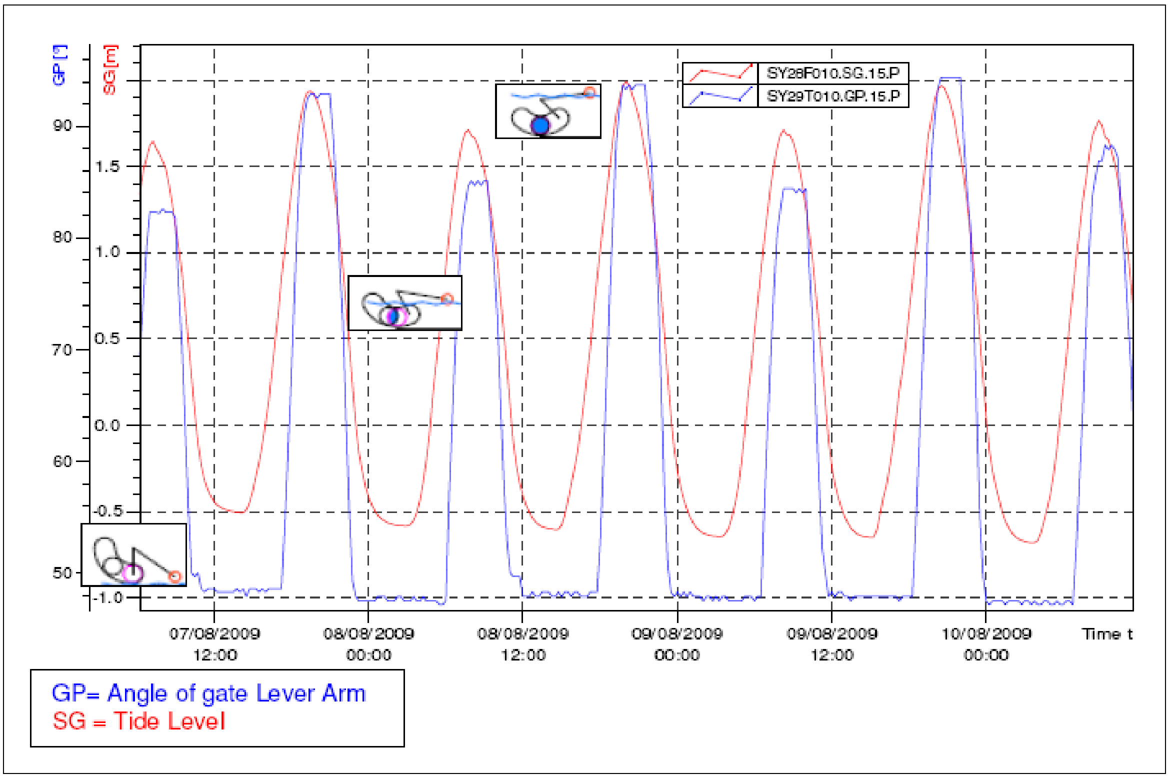
After the stop-go-stop gate was installed at Seaton it was decided that a position indicator would be installed to check:

- that the gate moves smoothly during its opening and closing;
- if the gate opens and closes on every tide;
- that gate completely closes on every low tide.

The results of the monitoring would also indicate if weeds or wood were getting trapped between the tube and sliding plate. The details of the position indicator can be found in appendix A.

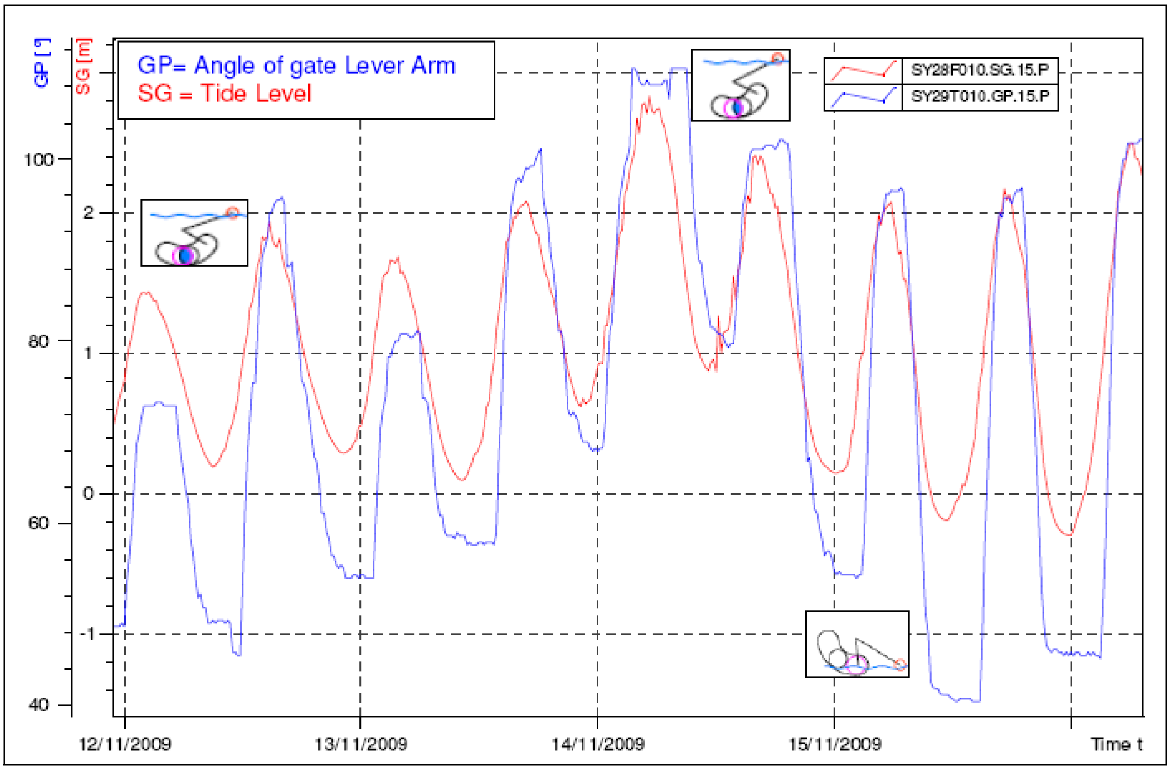
The results from the position indicator were recorded on an on-site data logger and are shown on graphs 1 and 2 below.

Graph 1 (below) indicates 'normal' tidal operation which shows that the gate consistently starts to open as the tide reaches 0.6m AOD as it was designed to do. There appears to be some minor 'sticking' at the top of the tide cycle which may be associated with the buoyancy and friction forces being at equilibrium. However, this is consistent across each tidal cycle and generally the gate can be seen to be operating as designed.



Graph 1 Trace from the SRT monitoring device plotted against the tide level recorded at Seaton tide gauge (normal condition)

Graph 2 (below) illustrates the operation of the gate during a larger tide event when the rotating plate passes fully over the culvert opening and the second solid section begins cover the opening. Whilst the operation is more erratic, this is consistent with the variations in the tide level.



Graph 2 Trace from the SRT monitoring device plotted against the tide level recorded at Seaton tide gauge (extreme tides)

The Seaton stop-go-stop gate rotates through an arc of 84 degrees, between fully closed at low tide and fully closed again on extreme tides to being fully open half way through the arc. The graph suggests that the gate is almost reaching the fully open position during most normal tides and is partially closing again on the bigger tides as designed.

There is still some uncertainty about how the gate will perform in a coastal situation where there is potential for wave energy to impact upon the valve. Should the need arise for a valve to be installed in unsheltered tidal waters, a wave defence or energy dissipater should be considered (for example, an open top or bottom bulk head manufactured from either wood or steel, or a series of columns to break up the wave action). The defence would prevent wave energy from being exerted directly against the valve and potentially causing damage to its structure.

An alternative to the data logger would be to provide a link to a telemetry system and transmit live data back to a central system. This may provide essential early information to enable any problems that may occur to be reacted to in good time.

5.0 Summary

The SRT has now been proven to be ideal for an estuarine location where the water level rises and falls gradually and with little wave action. However, there is still some uncertainty about how the gate will perform in a more exposed coastal situation and further research is recommended in this area.

The general design of the gates is generic and it can be adapted to suit a wide range of site specific requirements, although it is not ideal for every situation. The principal decision criteria on whether to use an SRT (and the type of SRT to use) include:

What are the aims for the habitat?	It should be possible to create a range of inter-tidal habitats using the SRT. If there are specific requirements e.g. saltmarsh or saline lagoon it is possible to manage the operation to favour the preferred habitat.
What is the flood risk?	Where there is significant flood risk, very careful consideration must be given to the effect of regulated tidal exchange on this risk. A flood risk assessment is likely to be required if planning permission is needed.
How is the site defended at present?	Consider if set back defences and/or a wing wall/training wall will be required to allow RTE to proceed.
How many land owners will need to be consulted / contacted?	Sites with multiple ownership are inherently more difficult to work on. The impact on third parties must also be carefully assessed.
What is the tidal range?	The tidal range affects the rate of operation of the SRT. A large tidal range has caused the SRT to close sooner than might be desired, restricting the volume of water that can pass through the gate. At the RSPB's experimental site at Goosemoor, this resulted in less water entering the site during spring tides than during neap tides
What amount of water needs to be moved through the SRT?	An understanding of the volumes required to inundate the desired area is important, although at present rating curves are not available. Flow through the gate will vary according to the changing head on both sides of the gate, the variable aperture and the length of the culvert.
Can the velocity of water through the SRT be kept low, to ensure no bank erosion is caused?	The larger the aperture, the lower the velocity will be, but fine estuarine sediments are vulnerable to erosion. This can be a particular problem where the outfall is set back against an embankment with an extensive area of fringing saltmarsh.
How will the success of the project be measured?	Establishing a monitoring programme is desirable, particularly as this will help us to establish a greater understanding of the results under varying conditions. Parameters that should be measured include depth and salinity of inundation, sedimentation / erosion, habitat change, invertebrate, fish and bird diversity and abundance.
What are the public safety issues?	There may be a need to incorporate fencing or other measures to prevent unauthorised access, both from the land and water. Signs to deter access may be sufficient in some circumstances.

What size and number of culverts or outfalls are required?	The design is intended to work for sizes between 300mm and 1,200mm diameter. A single SRT should be suitable for sites up to eight hectares, depending on the site topography. Larger sites may be catered for by use of multiple SRTs, although if the requirement would be for more than two, other forms of RTE or MR should be considered as they may be more appropriate

Other considerations include:

- The maintenance regime for the valve should be considered on a site-by-site basis, as in many cases there will be a hard standing apron that can be used as a platform at low tide. If there is no apron, or it is unsuitable for working off, a purpose-built platform can be considered and secured directly to the valve.
- It is important to think carefully about access to the site and gate even at low tide. If platform access is required, it should enable easy access to all components of the gate.
- Public health and safety should be considered as part of the design process to identify what mitigation measures are required, for example the boom at Lymington.
- Floats should be attached to the arm with a sleeve to prevent the float falling off when being adjusted.

Although the SRT has been developed to assist in creating more inter-tidal habitats, it has many other benefits and a version in currently being installed into existing large flood gates to improve fish passage.

References

Environment Agency, 2009. Self-regulating tidegate design facilitates habitat creation: Interim report. Science project SC070031. *Environment Agency, Peterborough.* http://publications.environment-agency.gov.uk/pdf/SCHO1009BRCP-e-e.pdf

Lamberth, C. and Haycock, N., 2001. Case Studies and Guidelines for the Assessment of Sites Capable of Supporting a Saline Wetland Creation Project Using Regulated Tidal Exchange Techniques. Report to RSPB and Environment Agency, *Haycock Associates Limited, St. Albans*

Lamberth, C. and Haycock, N., 2002. Regulated Tidal Exchange: An Inter-tidal Habitat Creation Technique. Report to RSPB and Environment Agency, *Haycock Associates Limited, St. Albans*

RSPB and Environment Agency, 2003. Regulated Tidal Exchange: An Inter-tidal Habitat Creation Technique. *Environment Agency, Peterborough.* http://www.rspb.org.uk/Images/RTE_tcm9-261368.pdf

Website: ABP Marine Environmental Research Limited. OMReG - The Online Managed Realignment Guide http://www.abpmer.net/omreg/

List of abbreviations

RTE	- Regulated tidal exchange
MR	- Managed realignment
SRT	- Self-regulating tide gate
BAP	- Biodiversity action plan

Appendix A – Details of the position indicator

After the gate was installed at Seaton it was decided that a position indicator would be installed to check:

- if the gate moves smoothly during its opening and closing
- if the gate opens and closes on every tide
- that gate completely closes on every low tide

The results of the monitoring would also indicate if weeds or wood were getting trapped between the tube and sliding plate, if telemetry is utilised.

The angle measurement setup uses a pendulum on a potentiometer, mounted in a sealed box which is fastened to the yellow counterweights.

Note: The outstation or logger will need a potentiometric input to interface to the sensor.

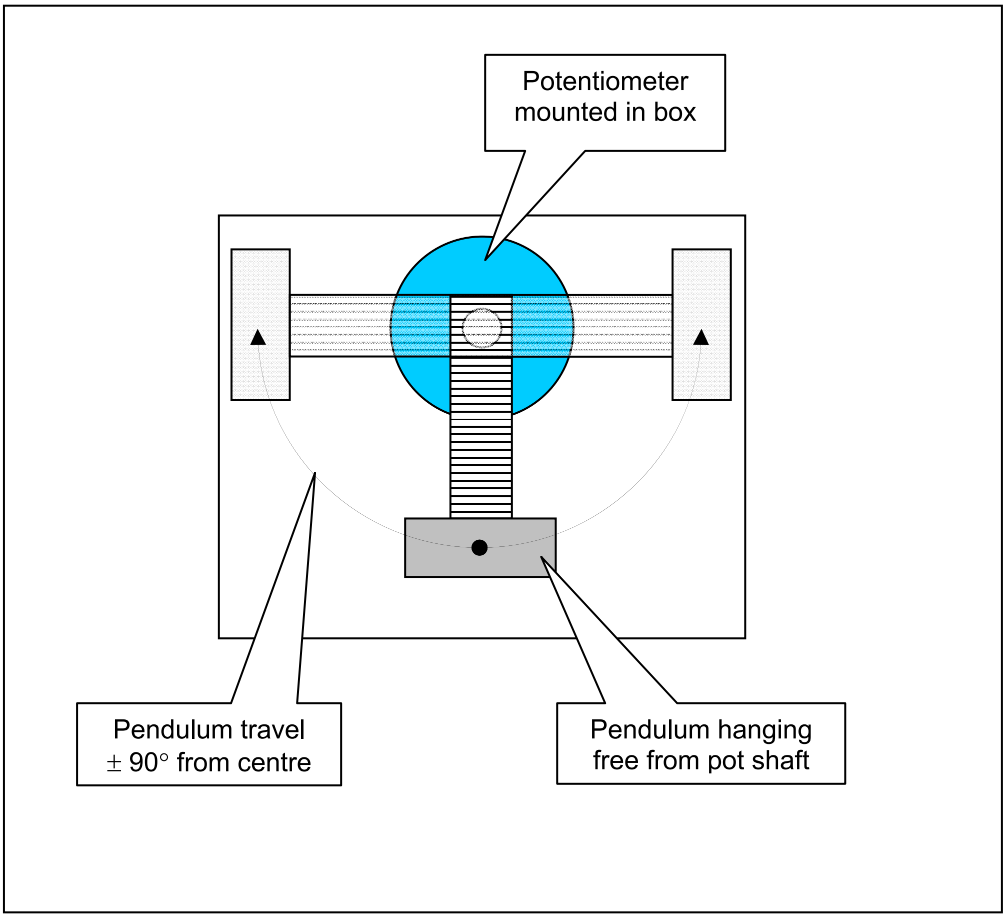


Figure A1. Angle measuring potentiometer general mounting arrangement

Figure A1 shows the general requirement for the mounting of the pendulum onto the potentiometer. A clearance hole is drilled in the side of the bolt to take the pot shaft. A tapped hole is drilled from the top to take a grub screw that locks the bolt onto the pot shaft. The bolt used for the pendulum was M12 x 50mm. The actual size is not critical but it should not foul the box when turned between its limits.

When mounting the pendulum on the pot, set the pot to mid position then with the bolt in its central position, lock the bolt to the pot shaft. The sliding plate of the gate will also have to be set to mid position; some form of lifting equipment may be required for this.

The potentiometer, M12 bolt acting as a pendulum and locking grub screw used to the test the principle of the position indicator can be seen below in figure A2. It should be noted that the pot shown is not the item used in the completed unit; this pot has lower torque and is single turn.

Figure A2 Pendulum mounted on potentiometer

The potentiometer complete with pendulum is then to be mounted inside an IP 68 rated enclosure and fitted to the yellow counterweight. An adaptor plate may be required to enable this mounting as shown in figure A3.

Figure A3 Sensor mounting

The results from the position indicator were recorded on an onsite data logger but could be linked to a telemetry system and transmitted live back to a central control room. The results recorded from the SRT at Black Hole Marsh show that the gate has been operating smoothly with no indication of sticking. The results also show that the gate has moved with every tide and has fully closed at every low tide, confirming that nothing has become jammed in the valve.

Appendix B – RSPB and Environment Agency report (2003) Regulated Tidal Exchange: An Inter-tidal Habitat Creation Technique

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Regulated Tidal Exchange: An Inter-tidal Habitat Creation Technique

April 2003

RSPB

Environment Agency

This document is a reproduction of the original report published by the Environment Agency in 2003.

The Environment Agency is the leading public body protecting and improving the environment in England and Wales.

It's our job to make sure that air, land and water are looked after by everyone on today's society, so that tomorrow's generations inherit a cleaner, healthier world.

Our work includes tackling flooding and pollution incidents, reducing industry's impacts on the environment, cleaning up rivers, coastal waters and contaminated land, and improving wildlife habitats.

The RSPB works for a healthy environment rich in birds and wildlife. It depends on the support and generosity of others to make a difference. It works with others with bird and habitat conservation organisations in a global partnership called BirdLife International.

The RSPB is deeply concerned by the ongoing losses of saltmarsh and mudflats and the implications this has for wildlife. As a result the Society is actively seeking opportunities to restore intertidal habitats.

This publication summarises the work of Haycock Associates under contract to the Environment Agency and RSPB.

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Front cover photograph is 'Tidal exchange scheme at Abbot's Hall, Essex prior to managed realignment', John Carr, 2002
Back Cover photograph is 'Two self-reguilatibng tide gates at Turney Creek, Fairfield, Connecticut, demonstrated by their designer Tom Steinke'.

Introduction

Coastal habitats are disappearing at an unprecedented rate. It has been estimated that sea level rise will result in the loss of 8,000 to 10,000 hectares of intertidal mudflats in England between 1993 and 2013.

This equates to some 450 hectares per year. The current estimate of saltmarsh loss to coastal squeeze and erosion is 100 hectares per year. The overall objective of the UK Biodiversity Action (BAP) for saltmarsh is to ensure that there is sufficient saltmarsh creation to maintain the current extent of approximately 45,500 ha. To ensure no net loss will therefore require creation of 100 ha per year. The BAP also has a target to restore the 600 ha lost between 1992 (the date the Habitats Directive was signed) and 1998, over the next 15 years.[1]

The low-lying coastline of southern and eastern England is under the greatest threat. Eastern England contains some 23% of the total UK coastal habitat resources of which almost one third of the saltmarsh and 7% of the mudflat will be lost by 2050.[1]

One solution is to set back hard sea walls to allow tidal flooding of previously defended land to create new intertidal habitat. The total area of current or planned projects in the UK is about 375ha, with several pilot projects underway in eastern England. This includes 78 ha by EA and RSPB in the Wash at Freiston Shore in Lincolnshire and 9 ha at Havergate Island by RSPB in the Alde-Ore estuary in Suffolk, with more projects planned. However, opportunities for such managed realignment of sea defences are unlikely to be sufficient to replace the predicted area of habitat lost, let alone the loss of ecological function, as habitat creation needs to occur on a massive scale to keep up with losses of about 550 ha per year of mudflat and saltmarsh combined. The RSPB have identified over 9,000 ha nationally of potential coastal habitat restoration sites[2] which is equivalent to 68% of the habitat creation target for 2020.[3]

Regulated Tidal Exchange (RTE) is a technique to develop mudflats, saltmarsh or brackish lagoons behind permanent sea defences, particularly where walls will remain in place and/or as part of a phased realignment strategy.

A review of schemes where RTE has been conducted has identified over 60 locations. There 16 sites were selected to form the basis of a more detailed investigation of the technique to:-

- Understand fully the advantages and potential for habitat creation behind 'fixed' sea defences using tidal exchange techniques.
- Demonstrate the potential of these techniques to key decision-makers as an element of responding to climate change and sea level rise especially related to present and past habitat loss and its replacement.
- To prepare guidance notes to support and implement the technique.

The objectives of this study did not include the consideration of technical engineering or flood defence practicalities of using Regulated Tidal Exchange. These considerations may form part of further research into the technique.

[1] Sharpe, J. *Coast in Crisis protecting wildlife from climate change and sea level rise.* RSPB East Anglia Regional Office, Norwich. And references therein.

[2] Sharpe, J. *Pers. Comm.,* 2002

[3] Pye, K. and French, P. W. 1993. *Targets for coastal habitat re-creation. English Nature Science No. 13,* England Nature, Peterborough; *Biodiversity: The UK Action Plan 1994 (Cm 2428),* HMSO, London; Biodiversity: *The UK Steering Group Report 1995, Volume 1: Meeting the Rio Challenge,* HMSO, London; *Government Response to the UK Steering Group Report on Biodiversity 1996 (Cm 3260),* HMSO, London.

What is Regulated Tidal Exchange?

Regulated Tidal Exchange is the regulated exchange of seawater to an area behind fixed sea defences, through engineered structures such as sluices, tide-gates or pipes, to create saline or brackish habitats.

Figure 1 shows the technique as a schematic. This is based on the parameters of an actual site on the east coast of England. Numerous projects have been reviewed that demonstrate that the technique works and that ecological benefits have resulted.

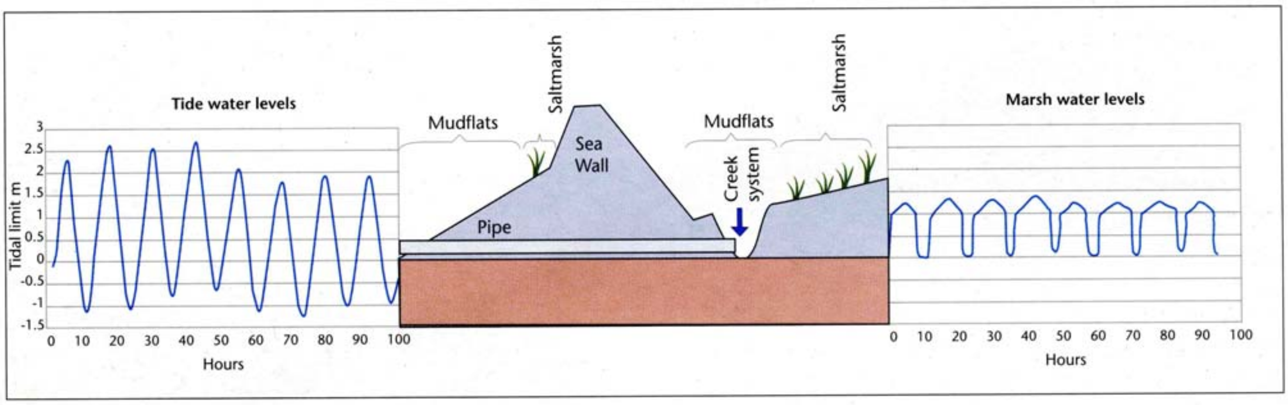


Figure 1 Schematic representation of Regulated Tidal Exchange showing the tidal variation and natural mudflat and saltmarsh 'squeezed' against hard sea defences. The figure shows Regulated Tidal Exchange allowing mudflats and saltmarsh to develop inside the sea wall and the modelled response of the marsh water levels. Diagram developed from actual tidal data and land elevations at a site in eastern England.

RTE differs from Managed Realignment in that it does not involve the establishment of a new primary defence line.

Sites that have been found unsuitable for managed realignment might well be suitable for RTE.

Regulated Tidal Exchange is a potentially valuable tool in two particular scenarios:

1. Where coastal defences are likely to remain in place for the foreseeable future;

2. As the first phase of a longer term realignment strategy. RTE may help to raise land levels through prompting sedimentation, at a rate equal or greater than sea level rise. Once land levels have been raised it may be possible to breach seawalls to allow a more natural tidal regime with unregulated tidal flows. In time the remaining coastal defences are likely to disappear through natural erosion allowing full restoration of the coastal environment.

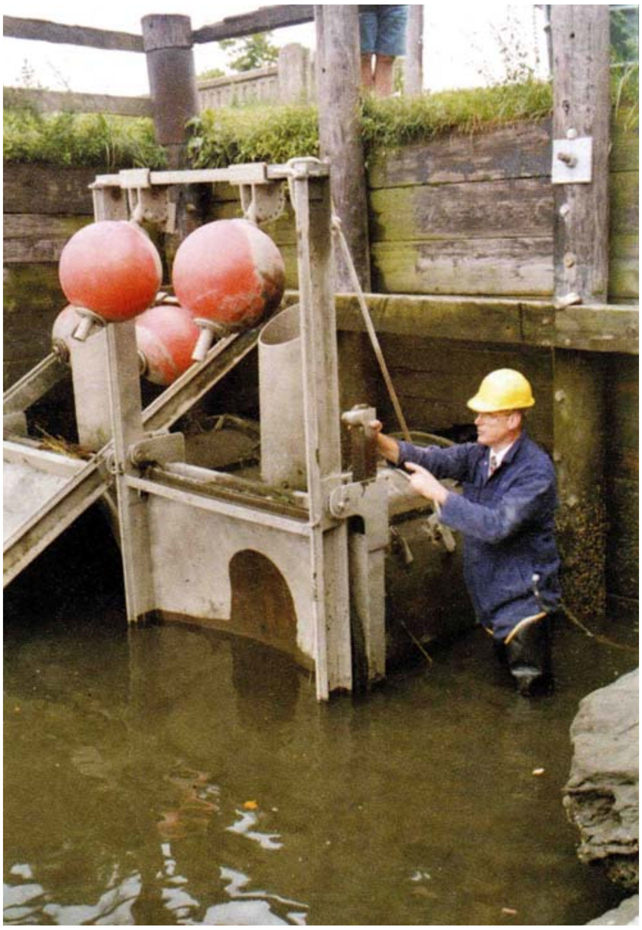
How Does Regulated Tidal Exchange Work?

Several different types of structures have been used to allow regulated exchange of saltwater in and out of the site. These include pipes, tide gates, sluices, spillways as well as more complex systems using artesian wells.

The engineering structure or structures should enable enough water to pass into and out of the site to maintain the habitat as well as meet other physical constraints. For example, the structure has to be strong enough to cope with the hydraulic capacity needed to exchange water.

If there is a possibility that the seawall may not be maintained in the long term, then it will be prudent to maximise accretion processes within the site as far as possible. The effectiveness of the accretion processes needed to maintain or exceed the rate of sea level rise is critically dependent on the type of engineering structure and will influence the lifetime of the habitat created. If Regulated Tidal Exchange is to be used to create inter-tidal habitats then high rates of land accretion will be needed to keep pace with sea level rise.

Several techniques have been described in the literature and used at the case study sites to deliver seawater through some form of permanent sea defences. Some have been used in actual examples, while some may be feasible if special physical conditions exist to enable the technique to work. This study has been approached from an ecological and hydrological point of view and is not an appraisal of Regulated Tidal Exchange from a flood and engineering perspective. Table 1 is a summary of RTE examples, with comments on critical requirements, advantages and disadvantages. Further details of each technique, together with information on sites where they have been implemented, can be found in the main RTE report.[iii]

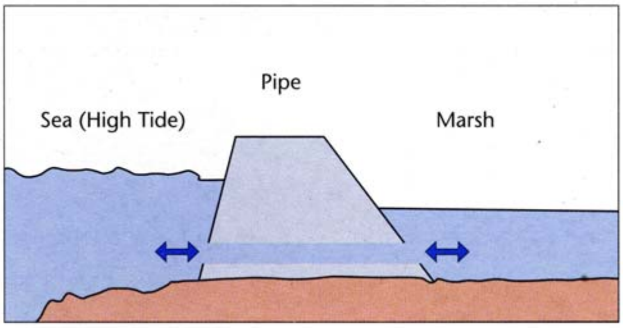


Self regulating tides gates have been extensively used to achieve regulated tidal exchange in the US, as here at Fairfield, Connecticut.

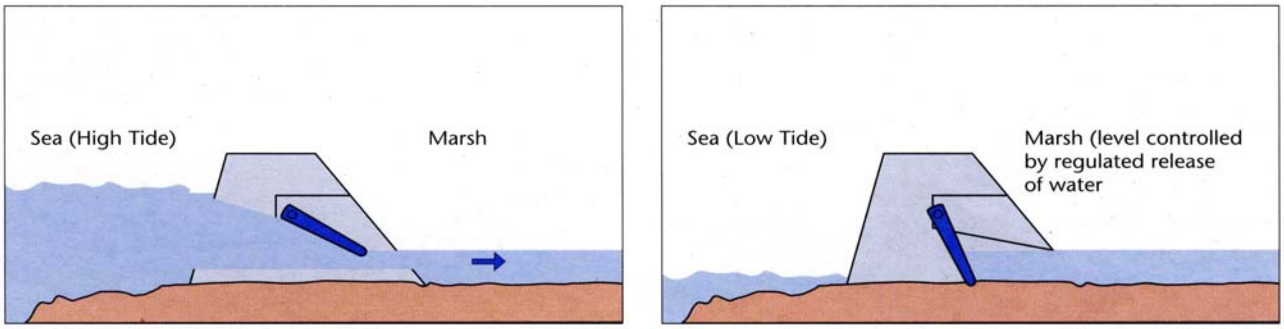
Table 1: Summary of RTE examples with critical requirements for each technique and advantages and disadvantages

Type of Engineering Structure	Sluice or Tide Gate System (no pipe)	Pipe Through Sea Wall	Spillway System	Artesian Well System
Examples	Thousand Acre Marsh, Wellfleet, USA	Barn Island Marshes USA, Gwent Levels UK, Tees Estuary UK	Saltram, Plymouth, UK	Schouwen, Netherlands
Critical Requirements				
Ecological Success	Good	Good	Good	Moderate
Typical area, ha	120-600	5-150	5	40
Seawall or permanent impoundment	✓	✓	✓	✓
Water entry point	✓	✓	✓	
Water exit point	✓	✓	✓	✓
Impervious upper strata or marsh base	✓	✓	✓	✓
Permeable sub-strata or marsh base				✓
High differential tidal pressure needed to achieve sufficient saline ground water flow				✓
Freshwater source to prevent hyper-salinity				✓
Controlled inundation	✓	✓	✓	✓
Installation	Complex	Simple	Simple	Complex
Risk of breaching sea defences	Moderate	Low	Moderate	None
Area inundated	Larger	Limited	Larger	Limited
Cost	High	Low	Moderate	Low
Tidal Flow Rate	High	Low	High	Low
Risk of Hyper-salinity		✓		✓
Silting and bio-fowling	✓	✓		
Accretion rate	Low-High	Low	Low-High	Low

Pipe System: A pipe through the sea defences, with or without a flapper to make the system uni-directional.



Flapper system: A flapper or tidal gate held by culvert blacks, usually uni-directional, with or without sluices for level control. A flapper or tide gate can be considered as a large-scale pipe system.



Spillway System: A lowered portion of the sea wall allows sea water to enter the marsh at high tides.

Leaky Seawall: Permeable seawall allowing some intrusion of seawater landward. The leaky seawall may exist already as a result of thinning of the sea wall by coastal erosion.

Pumped system: Sea water is pumped into a marsh and allowed to flow naturally out of a marsh. Similar to the artesian well system with similar advantages and disadvantages.

Siphon System: A pipe permanently filled with seawater, which allows free seawater exchange between marsh and sea over an impediment that is higher than the sea level (such as a beach).

Artesian Well System: A series of artesian wells are used to supply seawater to inland marsh areas.

As with all engineering structures used for flood defence, local Environment Agency staff will need input to access the sustainability of structures built within sea defences, based on engineering safety and cost. The advice of regional and area environment Agency staff should always be sought.

The Ecological Benefits of Regulated Tidal Exchange

Regulated Tidal Exchange has been shown to be a technique to create a range of habitats.

These habitats include:-

- Mudflats (1 UK and 1 US example)
- Saltmarsh (5 UK, 5 US and 1 European example)
- Brackish grazing marsh (2 UK, 2 US and 1 European example)
- Saline Lagoons (5 UK and 2 US examples)

Colonisation of each habitat type should occur naturally once the conditions for the target habitat have been created. In this review we concentrate in particular on the development of mudflat and saltmarsh habitats.

As part of the review, site managers, wardens or landowners were interviewed to determine the overall success of Regulated Tidal Exchange schemes and whether problems had arisen in the development of the scheme. 60% of the schemes were rated as 'good' in that the site significantly achieved its initial objectives. Many of the sites rated as 'good' are also still developing and their final habitat composition has yet to be reached. A variety of habitats were reported as associated with the schemes including sand dunes, saltmarsh, inter-tidal sand and mudflats, shingle structures, saline lagoons, brackish lagoons, marine grassland and freshwater wetlands.[4]

Mudflats

A good example of the recreation of mudflats by Regulated Tidal Exchange is proved by Teesmouth National Nature Reserve. The aims of the project were to provide feeding ground for wading birds during high tides, to maximise the water margin and movement of this margin across the mud surface and to ensure a high site coverage during the highest monthly tides to prevent the spread of vegetation.[5]

The nine hectare site was opened to tidal influences September, 1993 by the installation of a 60m long, 1.05m diameter pipe and no living animals were found in any of the ten cores taken from the site just before inundation began. The colonisation of the site by marine invertebrates was studied and found that:-

- The mud snail (*Hydrobia ulvae*) took about one year to start to colonise the site.
- The ragworm (*Nereis diversicolor*) an important food of large shorebirds took about two years to colonise the site.
- The crustacean (*Corophium volutator*) an important food for several smaller shorebird species took about three years to colonise the site.

Within three years, seven species of shorebird had fed or roosted on the site. Teal and Redshank fed regularly at low tide whilst Curlew, Ringed Plover, Grey Plover, Shelduck and Dunlin fed on the site mainly two hours before high water in August and September or when populations marine invertebrates had developed some two years after inundation.

The study concluded that it takes at least three years for mudflats to develop a permanent population of marine invertebrates and successful feeding ground for shorebirds.[6]

[4] Here, the definition of freshwater is with a salinity level of less than 10 ppt, 10-15 ppt is brackish water, above 15 ppt as saline with seawater about 34 ppt and hyper-saline conditions above 34 ppt.

[5] Simulation of the Inter-Tidal Scheme for ICI's Number Six Brinefield. Bradby, I. R. ICI Engineering, Chilton House, Billingham, IRB0078/JM/2843, February, 1992.

[6] Creation of Temperate-Climate Intertidal Mudflats: Factors Affecting Colonisation and Use by Benthic Invertebrates and their Bird Predators. Evans, P. R., Ward, R. M., Bone, M. and Leaky, M. Marine Pollution Bulletin, Vol. 37, Nos. 8-12 pp. 535-545, 1998.

Saltmarsh

Regulated Tidal Exchange schemes specifically targeting saltmarsh creation include Abbotts Hall (Essex), Carnforth Marsh at Morecambe Bay (Lancashire) and Blaxton Meadow at Saltram (Devon) in the UK, with many other sites in the US. Experience from these schemes is summarised below.

A total of 10 species of saltmarsh plants colonised the 20 ha Abbotts Hall site within two years after inundation began in 1996. Pioneer species in this case were Spear-leaved orache (*Atriplex Prostrata),* Sea couch (*Elytrigia atherica*) and Annual sea-blite (*Suaeda maritime*).[7]

Equally rapid colonisation by saltmarsh plants was observed at Blaxton Meadow. Within two years of inundation, 11 species of halophytes had colonised in flooded areas and 16 in five years. Partially flooded areas had seven species of salt tolerant plants. However, damage to the spillway system allowed the meadow to revert to lower marsh and mudflat habitats with an increasing population of feeding shorebirds including 12 not seen in the area before such as Little Ringed Plover.[8]

The rate at which natural restoration and re-colonisation of saltmarsh habitats occur depends on the proximity of the site to other saltmarshes. Re-establishment of the saltmarsh vegetation has been reported to occur through spontaneous means and without planting in a time period of between 1 to 5 years.[9] Pioneer plant species varies according to site but Mud Rush (*juncus gerardii*), Sea Arrowgrass (*Triglochin maritima*) and Sea-milkwort (*Glaux maritima*) were first to appear in recently flooded areas of Morecambe Bay.[10]

Invertebrate and fish re-colonisation was reported to take longer than plants and tended to follow development of the correct plant species but characteristic saltmarsh invertebrates and fish appeared within 12 years of restored tidal flushing.[11] Salinity levels tend to control the type of invertebrates found. Salinities above 10 and below 35 ppt will favour *Corophium volutator, Neris diversicolor and Palaemonetes varians.* Lower salinities (5 to 15 ppt) favour chironomids, corixids and *Neomysis integer,* the main food item for Avocet chicks.[12]

Investigations of bird use of restored marshes have demonstrated the suitability of the tidal wetlands for particular bird species. Progression from low marsh to high marsh during a typical marsh restoration may reduce the availability of breeding habitat. Conversely an increase in the rate of relative sea level rise may result in a wetter habitat and favour wetland birds that breed in Smooth Cord grass (*Spartina alterniflora*) on the high marsh. US experience is that bird species diversity and density tend to be greatest in wetlands with an adequate supply of fresh water, areas of open water and vegetation and a diversity of vegetation types.[13]

The project has developed site specific criteria based on previous experience to identify what sort of coastal site would be suitable for creating particular habitat types. Dichotomous keys are included in the main RTE report which allow determination of the habitat type which would be most likely to result at a particular site and also to determine the most appropriate engineering structure for a given site.

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[7] Diack, I., 1998. ADAS Report to the Ministry of Agriculture, Fisheries and Food, Botanical Monitoring of the Saltmarsh Option of the Habitat Scheme, 1995-1997. April, 1998, ADAS, Oxford.

[8] Gray, A. J., Reading, C. J., Garbutt, R. A., Barratt, D. R. Myhill, D. G., Cox, R. and Rothery, P., 1988. Large Scale Experimental Managed Realignment. Tollesbury, Essex and Saltram, Devon. ITE Annual report to MAFF.

[9] Rozsa, R., 1997. Tidal Wetland Restoration in Connecticut (Part 1), June, 21, 1997/DEP's tidal Wetland Restoration Program/webmaster@po.state.ct.us.

[10] Wilson, J., 1991. RSPB Management Case Study. The management of salt marsh and lagoon creation at Morecambe Bay, Lancs. February, 1991.

[11] Fell, P. E., Department of Zoology, Connecticut College, New London, CT, USA. McGraw-Hill Higher Education, Marine Biology Case Study. http://www.mhhe.com/biosci/pae/marinebiology/casestudies/case_02.mhtml.

[12] RSPB Minsmere Case Study.

[13] Hunter Brawley BA et al, 1988. Bird use of restoration and reference marshes with the barn island wildlife management area, Stonington, Connecticut, USA. Environmental Management, 1988, 22(4), 625-633.

Characteristics of sites where Regulated Tidal Exchange would create mudflats

Sites where RTE would create mudflats would have the following specific characteristics:-

- Mudflats would develop on sites with 450 to 600 inundations per year. One inundation should not last more than a few tidal cycles. If the intention is to create mudflat, water should be let in fast and let out slowly.

- Gradient of 1 to 3%.

- Site elevation between mean high water neap and mean high water spring tides, generally lower than 2.1m ODN.[ii]

Mudflats, like these on the Wash in Norfolk, support thriving invertebrate communities which in turn provide food for wading birds.

Characteristics of sites where Regulated Tidal Exchange would create saltmarsh

Sites where RTE would create saltmarsh would have the following specific characteristics:-

- Saltmarsh would develop on sites with fewer than 450 to 500 inundations per year, with one inundation not lasting for much longer than a few tidal cycles. Lower saltmarsh habitats develop where there are between 500 and 30 inundations per year and upper saltmarsh where there are fewer than 30 inundations per year.

- Gradient of 1 to 3%.

- Elevation below the highest tide level, but generally at 2.1m ODN or above.[iii]

Saltmarshes, like these at Copperas Bay in Essex, are an important wildlife habitat but are disappearing at a rate of 100 ha each year.

The Types of Site Where Regulated Tidal Exchange can be used to create Intertidal Habitat

A set of fundamental requirements for RTE in the UK have been identified.[iii]

These are:-

- Sites that have some form of permanent sea defences in places such as a sea wall, dyke or impoundment, which would allow the construction of a pipe, sluice or tidegates without affecting the integrity of the sea defences.
- Sites that can be flooded, without affecting adjacent agricultural land, property or amenity areas. This may require the construction of a low bund to limit the extent of saltwater flooding.
- Sites with a source of seawater that can be engineered to flood and drain from the site to allow effective salt water flushing. Ideally, the seawater should have sufficient suspended sediment to ensure an accretion rate within the site that equals or exceeds predicted sea level rise.
- Sites that have not been claimed recently from the sea so that the land behind the sea defences is at least 0.1m are insufficient to ensure adequate flows onto and off the site and the site may be more suitable for managed realignment.
- Sites where the tidal range is at least 3m.
- Sites with an impermeable underlying geology, not prone to erosion or contamination of aquifers. This rules out peat and chalk sites, but permits RTE on clay sand silts.
- Sites with gradients of 1 to 6%. The gradient determines the ratio of saltmarsh to mudflat. The lower the gradient the larger the area of a single habitat that can be created. Control of water levels becomes more important on sites with low gradients as levels affect distribution of habitat.

Further Practical Ecological Considerations

For RTE to be successful there are a number of additional criteria that should be considered

Water Exchange

One of the most important is to ensure that there is sufficient water exchange to and from the site. Water exchange is necessary in order to:-

- Prevent hyper-salinity and salt accumulation.
- Prevent low oxygen conditions in summer.
- Ensure a minimum accretion rate for the site.

Accretion Rates

It is important for the sustainability of any site which is likely to be opened to full tidal influence in the future, that the rate of accretion be higher than the expected sea level rise. For instance any marsh areas on the east coast of Britain will have to have an accretion rate of at least 1cm per year in order to remain above sea level. The effectiveness of the accretion processes is critically dependent on the type of engineering structure. RTE can raise land levels and create intertidal habitat, as long as high rates of land accretion can be achieved to keep pace with sea level rise.

Salinity Levels

Salinity levels dictate the type and abundance of plant species and may vary throughout the year and should be controlled if possible between upper and lower limits depending on the type of target habitat.[iv, v]

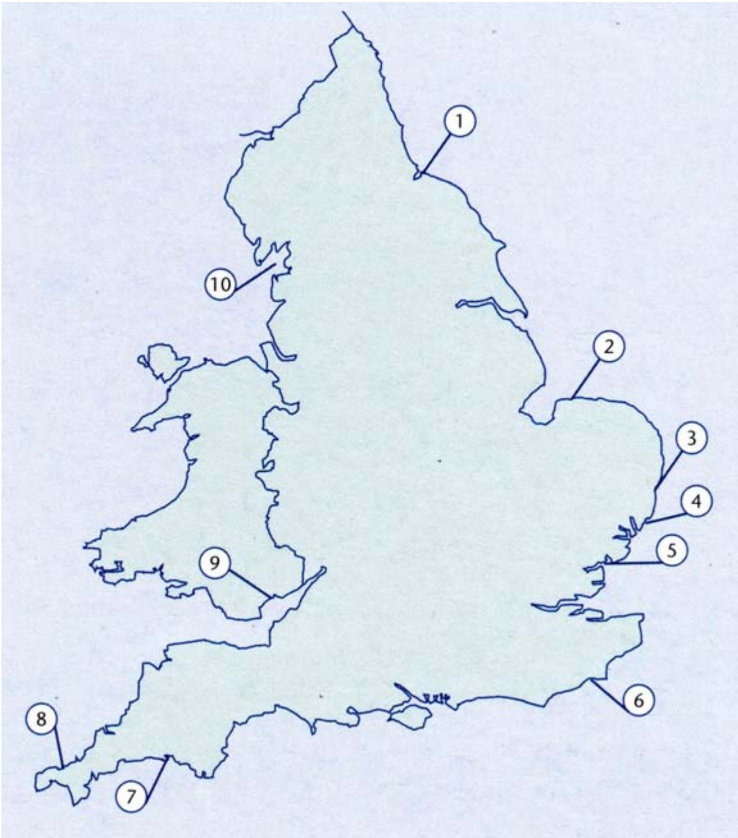
Creek Excavation

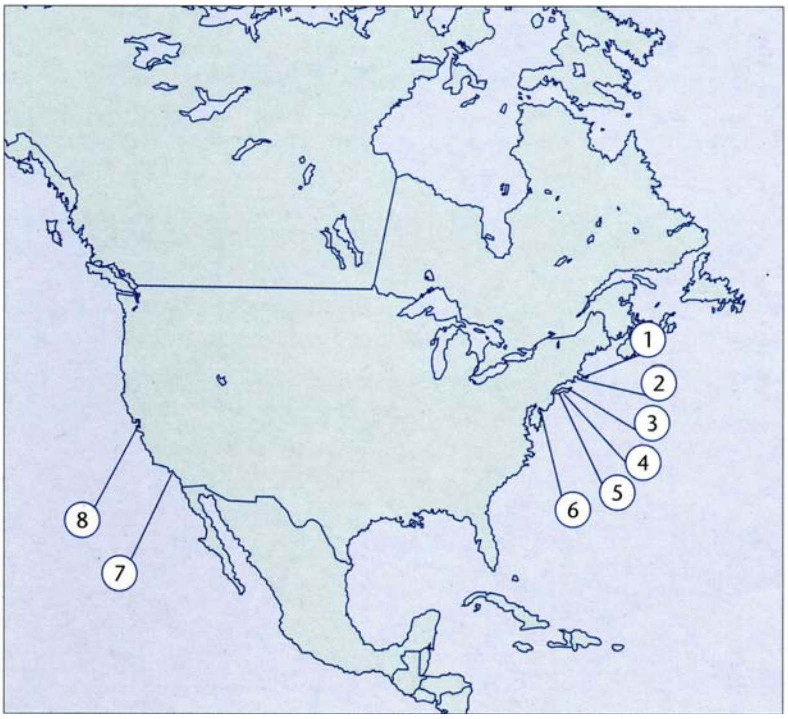
At most sites in the US the new control structures were sited where dykes crossed existing creeks. The general rule is that if the appropriate hydrology was reinstated little extra local engineering was needed and the system organised itself in response to the tidal regime i.e. creeks will form themselves if not there already. However, if there are ditches already present these will tend to dominate site hydrology and new creeks will not form.

Examples of where Regulated Tidal Exchange has been used

Table 2: UK Regulated Tidal Exchange Site Locations

Location	Site Name	Area (hectares)
1	Tees Estuary	9
2	Titchwell Marsh	36
3	Minsmere	20.9
4	Havergate Island	12
5	Abbott's Hall and Lanton Marsh, Essex	20
6	Rye Harbour LNR	40
7	Saltram (Blaxton Meadow)	5
8	Ryan's Field (Hayle)	6
9	Gwent Levels	10.8
10	Carnforth Marsh, Morecambe Bay	51.2





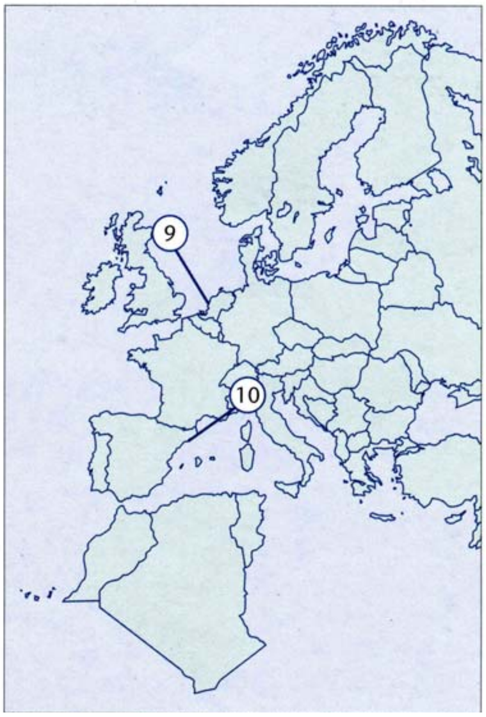


Table 3: US and European Regulated Tidal Exchange Site Locations

Location	Site Name	Area (hectares)
1	Wellfleet	600
2	Hammock River, Clinton Restoration	120
3	Broad Dyke Marsh	85
4	Barn Island Marshes, Stonington, Long Island Sounds	150
5	Fairfield, Stonington, Long Island Sounds	52.5
6	Thousand Acre Marsh	465
7	San Dieguito Lagoon	150
8	Decker Island	5
9	Schouwen, zuidkust van Schouwen (the southern shoreline of Schouwen	40
10	Ebre Delta, Spain	32,000

Bibliography

[i] ***UK Biodiversity Group, 1999.*** Tranche 2 Action Plans Volume V – maritime species and habitats, *English Nature, Peterborough.*

[ii] ***Burd, F. 1995.*** Managed Retreat: a practical guide, IECS report to *English Nature, English Nature, Peterborough.*

[iii] ***Lamberth, C. and Haycock, N., 2002.*** Regulated Tidal Exchange: An Intertidal Habitat Creation Technique, Report to RSPB and Environment Agency by *Haycock Associates Limited, St. Albans.*

[iv] ***Broome, S. W., Seneca, E. D. and Woodhouse, W. W., 1988*****.** *Tidal salt Marsh restoration, Aquatic Botany 32, 1-22*

[v] ***Hill, D., de Jong, S., Cadbury, J. and Partridge, J., 1988.*** *Hydrological management and lagoon creation for Avocets and Havergate, RSPB Management Case Study, unpublished.*

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