# Practical Use of Deflectors in River Restoration Science Digest

## Aim

This issue of Science Digest addresses deflectors as a practical restoration method and provides an overview of how this technique can be designed and analysed, as well as the impacts on geomorphology, habitat, erosion and deposition. Each paper in this report has been summarised in order to provide a brief understanding of what the authors set out to achieve. Three main themes are discussed; however readers are encouraged to comment on these topics, suggest new ideas, and add examples, papers and case studies to this report. Additional papers and comments can be easily submitted through the Mendeley group: Practical use of deflectors in river restoration. Anyone is welcome to join the group, or share their thoughts or papers. Mendeley is a free software owned by the publisher Elsevier. This platform is used internationally to reference papers and scientific articles.



## Summary

### Background to Deflectors

Deflectors are also known as croys, groynes, spur dikes and vanes, therefore these key words were used during web searches to find as many suitable papers regarding deflectors or similar structures. Using Web of Science to find papers on “Deflectors” AND “River Restoration” only returns 9 articles; however using the key words “Vanes” and “River Restoration” returns 17 papers (Figure 1).

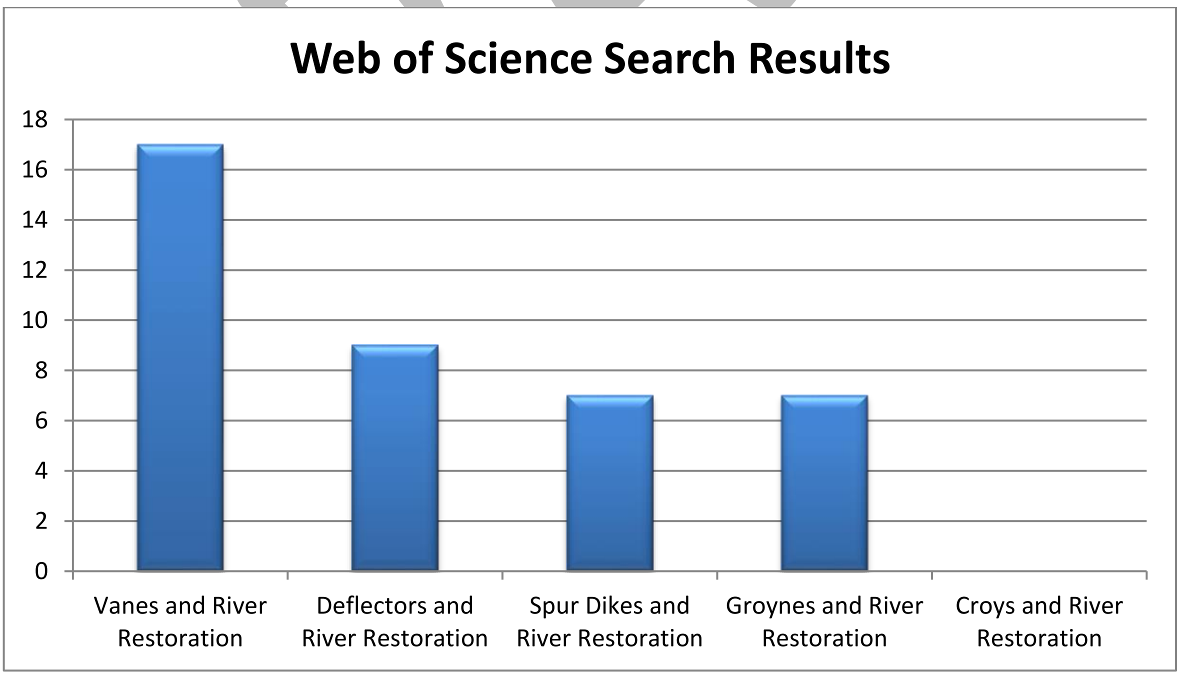


Figure 1 *Web of Science search results*

A search on Google Scholar returned 61 articles with “groynes” and “river” in the title. 38 of these are since 2000, with 16 published since 2010.

The distribution of publications on both deflectors and vanes over the years shows this technique is being continuously used in restoration projects. Deflectors are a common approach to river restoration, as they create variable flow conditions, narrow flow paths, deepen mid-channel flow for navigation, improve bank protection, and provide an area of refuge for fish in slow flowing water. Flow heterogeneity is important for fish species to develop and spawn, to avoid declining fish populations. These artificial structures, sometimes made up of logs or rocks, are suitable techniques for establishing natural pool and riffle sequences, with mid-channel scour pools, as well as diverting water energy away from the banks. Deflector heights, angles and degree of contraction have been researched in order to find a suitable design to influence scour hole development and bank erosion. Finding a suitable deflector design which maximises scour pool creation and reduces bank erosion is challenging, and various factors should be considered including river type, channel dimensions, flow conditions and sediment composition.

### Theme Outlines

- **Deflector Design** – testing the height and orientation of deflectors to determine the influence on bed scour and bank erosion
- **Three Dimensional Flow around Deflectors** – 3D numerical models are continuously being used to simulate how river flow is influenced by restoration features
- **Biological Impacts** – highlighting the impact of these structures on biodiversity, compared with reference reaches

## Scientific Publications

### Deflector Design

**Biron, P. M., Robson, C., Lapointe, M. F. & Gaskin, S. J. (2004) Deflector Designs for Fish Habitat Restoration. *Environmental Management,* 33 (1), 25-35**

Biron et al. introduce the key considerations when designing and implementing deflectors. These features should be installed to aid the generation of scour pools for fish, and reduce scour and erosion of the banks. The authors tested how changing the orientation and height of the deflectors influences the development of mid-channel pools, and affects the degree of bank scour (Figure 2). Experiments carried out in a flume showed scour pools developed at the tip of the deflectors, at every orientation and angle which was tested. Subsequently, sediment deposition was observed downstream of the structures. The deflectors which narrowed the channel the most, at an angle perpendicular to the flow (90° angle), were the most effective at producing mid-channel scour pools, whereas the deflectors placed at a 45°angle to flow, produced the least scour. When a larger contraction factor was used (0.50) and deflectors were longer, scour was higher than the lower contraction factor (0.25). The structures positioned at a 135° angle produced the most scour upstream of the deflectors. Furthermore, the 135° deflectors caused the largest potential bank erosion, whereas the 45° structures maintained bank stability more effectively. This paper demonstrates the benefits and disbenefits of deflector design. Downstream-oriented deflectors caused the least potential erosion, however the generation of scour pools was smallest. When using upstream-oriented deflectors or those at a 135° angle, due to the potential for detrimental bank erosion, protection strategies should be put in place alongside the deflectors, to stabilise the banks.

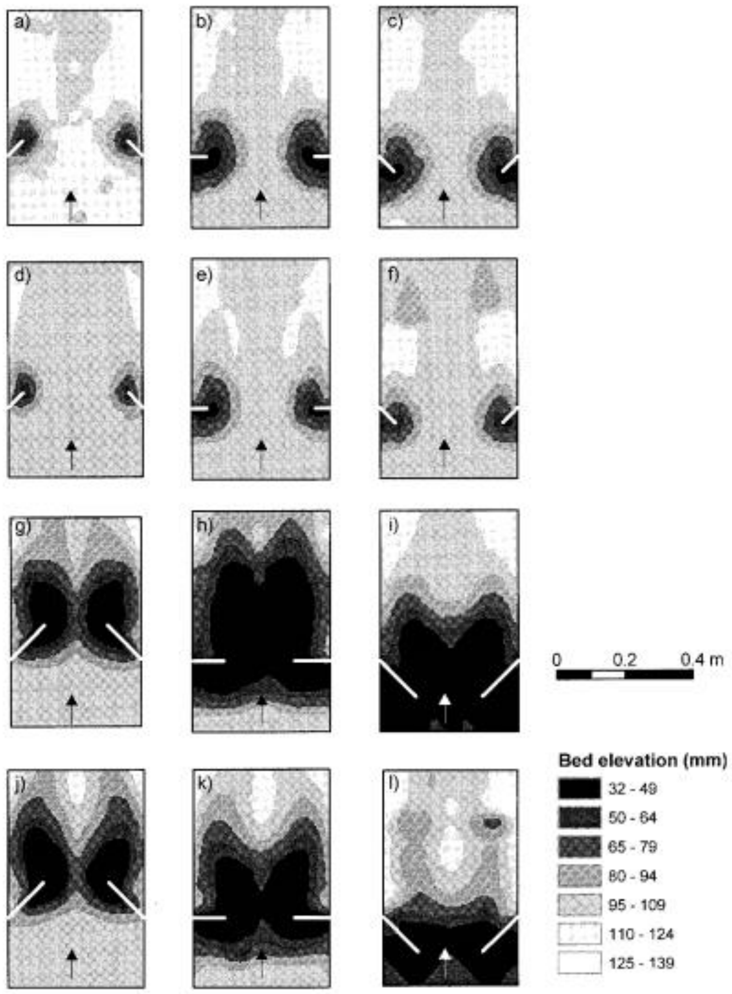


**Figure 2.** Bed topography close to the deflectors when flow is under the height of deflectors and contraction ratio is 0.25 for (**a**) 45°; (**b**) 90°; (**c**) 135° deflectors; when flow is over the height of deflector and contraction ratio is 0.25 for (**d**) 45°; (**e**) 90°; (**f**) 135° deflectors; when flow is under the height of deflectors and contraction ratio is 0.50 for (**g**) 45°; (**h**) 90°; (**i**) 135° deflectors; when flow is over the height of deflectors and contraction ratio is 0.50 for (**j**) 45°; (**k**) 90°; (**l**) 135° deflectors. Flow is from the bottom to top.

Figure 2 *Biron et al. (2004), Page 29, Figure 2*

Increased erosion was evident when flow was not overtopping the structures, however this flow level was also found to generate the most bed erosion. Therefore, extending the height of a deflector increases the potential for scour, and increases the chances of bank erosion. However, these findings differ depending on the shape of the deflector. Biron et al. identify the need for continual research into appropriate deflector shape, such as triangular features to maximise the flow of energy to the middle of the channel. Also, research in flumes is encouraged prior to field investigations. From their research, the authors found there was not a deflector design which encourages high levels of scour whilst reducing bank erosion. Also, rivers are dynamic systems therefore external considerations should not be overlooked, such as the influence of sediment characteristics.

**W. S. J. Uijttewaal (2005) Effects of Groyne Layout on the Flow in Groyne Fields: Laboratory Experiments. *Journal of Hydraulic Engineering,* p.782-791**

Groynes were previously used in low land meandering rivers, so it was crucial that deflector design considered keeping an area of deep water for channel navigation. Groynes are used on rivers depending on the river type and its past enhancements, but are typically found in Germany and Holland. Due to positioning of deflectors in low land areas, land may have to be reclaimed to allow appropriate design. For example the nature of a series of groynes allows a low flow area between structures for habitats, spawning grounds, sediment deposition and vegetation growth to stabilise the structures further.

Design considerations include the flow circulation and turbulence caused by groynes. Historically groynes were implemented perpendicular to flow with a spacing of one to three times the groyne length. The authors suggest structure height be just over the average water level to avoid being undermined during extreme low or high flows, whilst avoiding severely restricting flow at high water levels. Shaped or curved groynes can be used to shelter the low flow area of water between structures to benefit wildlife and habitats.

The authors tested 4 types of deflectors comparing permeability, submergence and groyne tip slope to determine the most effective design. The study found that the three designs incorporating impermeable submerged structures had more consequential velocity gradients, explaining the intricate 3D flow pattern. Furthermore, a gentler sloping submerged groyne tip created a wider shear layer and smoother flow. Slightly changing the groyne design impacted the velocity, turbulence and shear layer. This impacts the erosion, transport and deposition of material, and subsequently the bed morphology. This shows the importance of deflector design when considering ecological protection, flood risk management and navigation.

**Mohammed, V., Yaser, S. & Shaker, H. S. (2016) 'Effects of Distance Between the T-Shaped Spur Dikes on Flow and Scour Patterns in 90°C Bend Using the SSIIM Model', *Ain Shams Engineering Journal,* 7(1), 31-45**

Building on the research of Uijttewaal (2005), the authors state that groynes are used for navigation, flood protection and bank protection, and agree that the spacing between deflectors depends on their length. The authors give a brief, succinct review of the literature surrounding groyne spacing and positioning around a bend, and study the impact of spacing between T-shaped groynes, suggesting spacing no more than 5 times the deflector length.

**H. E. King, (2015) The Use of Groynes for Riverbank Erosion Protection and River Stabilisation: State of Art Report 2015**

Increased understanding of what causes river beds to erode and become unstable, has aided the establishment of the use of groynes to reduce flow velocities and enable bankside habitats and vegetation to establish. The authors suggest that vanes and groyne structures are a way of stabilising the banks using an environmentally friendly technique. These structures are considered indirect protection techniques to bank erosion, as they reduce the flow velocity causing bank stabilisation. This paper provides a series of case study examples on how groynes have been implemented between 1997 and 2015, followed by suggestions for improvements.

The size of erosion protection structures needs to be relative to the size and width of the river; and orientation and positioning need to be designed in order to avoid detrimental erosion of the opposite bank. With efficient design, groynes can avoid bank erosion and encourage deposition closer to the banks. Groynes which point upstream allow deposition to occur both sides of the structure, whilst encouraging the flow away from the bank, and generating a scour hole at the structure tip in the channel centre. Groynes which are orientated downstream however encourage deposition downstream of the structure, can channel the flow towards the bank, and provide less potential for a

mid-channel scour hole. Groynes perpendicular to the bed (90° angle) encourage sediment deposition either side of the structure whilst retaining the main flow in the centre of the channel. The authors discuss the benefits of deflectors including how they encourage natural flow patterns, enable the establishment of vegetation and deposition, and reduce erosion; however implementation is discouraged in channels which are very narrow.

Due to the complex nature of rivers, modelling and theoretical testing of erosion protection methods has become widespread. There is not a set guideline for how bank erosion structures should be designed. This is understandable considering how every river is different, and specific conditions and dimensions should not be overlooked. In meandering rivers, groyne design is important in order to avoid erosion and retain the natural flow type. In sharper bends, shorter groynes should suffice however a larger number of structures are necessary. It is important to remember that using more groynes increases the project costs. Sometimes using fewer, longer groynes positioned at a greater angle to flow, can be beneficial. The authors also suggest a standard spacing between groyne structures of 3 times the length which the groyne projects into the stream for meanders, and 6 times this length for straighter reaches.

**Hoey, T. B., Smart, D. W. J., Pender, G. & Metcalfe, N. (1998) Engineering Methods for Scottish Gravel Bed Rivers. *Scottish Natural Heritage Review, No 47*. University of Glasgow. Available at: http://www.snh.org.uk/pdfs/publications/review/047.pdf**

The authors provide some key information to consider when designing and constructing deflector structures, including whether the spurs are required to create scour or control erosion.

Deflectors are a cheaper option which are easily implemented and amended in the field. Groynes can be constructed using a range of different materials including stone, logs and gabions, in a variety of different shapes and sizes such as triangular. The size of the material which is used is important to avoid being washed away at high flow levels. The use of deflectors instead of revetments is encouraged, as deflectors can be implemented in a range of streams with all types of flow velocity. Also, the authors suggest using deflectors perpendicular to flow in gravel bed channels.

The authors mention how severe bank erosion from structure overtopping can lead to disconnection of the deflector from the bank. Embedding and securing the deflector to the bank is important to avoid this detrimental scour. Anchoring the deflectors to the bed by 0.5m and to the bank by several meters can increase structure stability. The height of the structure is important to ensure the groynes are as efficient as possible. This height depends on the low flow level of the river. The authors suggest a standard maximum height of 0.15-0.30m above the low flow level, in order to encourage maximum efficiency; as well as a suggested protrusion length no more than one third of the width of the channel. Moreover, when implementing a series of groynes, the structure height should decrease downstream to support sediment deposition.

The authors provide instruction on groyne design depending on the river type. In calmer channels with uniform discharge, flatter deflectors are acceptable. However in highly variable flow conditions with changing water levels, slightly angling the top of the structure avoids impacting the flow, although provides less bank protection. Furthermore, in regards to structure spacing, in straight reaches, deflectors should be spaced less than 4.5 times the length of the structure. However, greater spacing is suitable on convex bends, whilst less spacing is suggested for concave bends.

The design and height of the structure is important as, when visible, the deflectors can appear unnatural. Also, deflectors can create detrimental erosion to the opposite bank if designed inappropriately for the surrounding conditions. In some cases, supplementary revetments can avoid this, however this creates a more unnatural and engineered environment. When using deflectors, maintenance such as restoring damaged material is important to elongate the structure lifetime and improve effectiveness. Finally, monitoring the groynes is crucial for assessing implementation success. For example, check whether the angle of the structure is achieving the preferred result.

**Strategic Restoration and Management of The River Avon SAC, Advice Note. Available at: http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=home.showFile&rep=file&fil=STREAM_Restoration_Techniques_Advice_Note.pdf**

The authors indicate that understanding where scour and deposition should occur is crucial to successful deflector implementation. This guide demonstrates three types of deflector including D deflectors, islands and dragons teeth. D deflectors offer a more natural approach, using woody material and brushwood to demonstrate a natural vegetated appearance. Islands are similar structures, which appear as an oval shape in the centre of the channel. These structures are also vegetated with brushwood and provide a natural flow diversion. Finally, dragons teeth provide a triangular shaped bank deflector made up of woody material and brushwood. Wood and logs are anchored to the bed to support the structure and provide a base for vegetation. These structures can benefit a fluvial environment by providing simple techniques which can utilise local materials, and provide vegetation and habitats for biodiversity. However, maintenance is important to avoid the structures being washed away, and some techniques such as dragons teeth can require significant funding and availability of machinery. Furthermore, structure size needs to be relative to channel size in order to be effective.

**Lila, A., Chaudhari, M. & Korulla, M., River Training Structures: - Groynes, *Maccaferri Environmental Solutions Pvt. Ltd*.**

This paper points out the main intentions of a deflector including preventing bank erosion, controlling flow direction and strength, and aesthetic improvement. The authors suggest the main priorities when designing a deflector structure to be shape, length, spacing, orientation, crest elevation and slope, and material composition. The length, height and orientation of the structure needs to be best suited to the channel in order to maximise the efficiency of the structure to achieve its aims of bank protection or flow control. The height of the deflector therefore depends on the purpose of the structure; such as to avoid bank erosion the structure needs to be as high as the bank. Also, the permeability of the material needs to be considered. This will depend on the channel planform and the degree of flow control required, and can help avoid meander migration.

There are no stringent rules for designing deflectors; instead loose guidelines are in place to encourage consideration of a number of design features. The authors suggest straight groynes for the majority of bank protection works as they are easy to install and use less material for construction. Due to their environmentally friendly, natural, non-intrusive nature, groynes are frequently used to protect banks and restore geomorphology in rivers across the world.

**Ahmed, H. S., Hasan, M. M. & Tanaka, N. (2010) 'Analysis of Flow Around Impermeable Groynes on One Side of Symmetrical Compound Channel: An Experimental Study', *Water Science and Engineering,* 3 (1), 56-66**

Groynes are useful river restoration techniques as their flexibility means they can be adapted in line with the restoration aims, and river type. The authors point out a number of benefits of deflectors including flood risk management, stabilising water flow and channel depth, and providing ecological habitats to improve biodiversity. The authors suggest the main features to consider during groyne design are the relative length, spacing between each structure and 'arrangement type'. The study found that the flow pattern, velocity and depth were influenced by the type, length and spacing of groynes.

**Kang, J., Yeo, H., Kim, S. & Ji, U (2011) 'Permeability Effects of Single Groin on Flow Characteristics', *Journal of Hydraulic Research*, 49 (6), 728-735**

The authors looked into the impact of permeability of groynes on the flow depth, flow conditions and scour depth, in relation to habitat potential. The impermeable structures created the most flow recirculation, whereas groynes with higher degrees of permeability created lower flow separation and reduced velocity at the tip of the structure.

**Nasrollahi, A., Ghodsian, M. & Salehi, Neyshabouri, S. A. A. (2008) 'Local Scour at Permeable Spur Dikes' *Journal of Applied Sciences,* 8 (19), 3398-3406**

From their experiments, the authors observed that scour begins from the tip of the structure (Figure 3). Moreover, scour is deepest at the tip of impermeable structures, whereas similar scour depths occur around a permeable groyne. The depth of scour increased with increasing flow velocity. Additionally, the impermeable groynes resulted in higher amounts of scoured material.



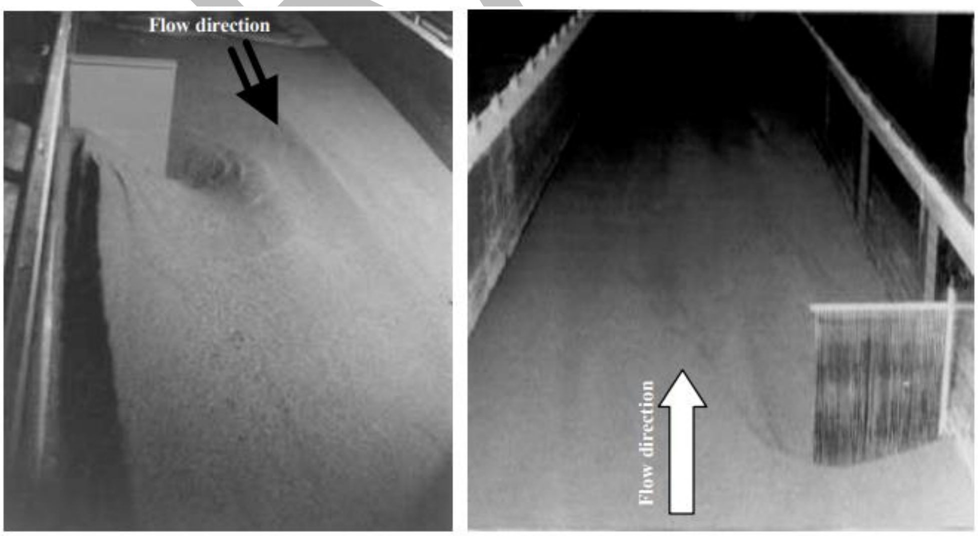


Fig. 4: Bed topography with $d_{50}$ = 1.3 mm, $u/u_c$ = 1.0 and L/y = 3.91, (a) Impermeable spur dike and (b) Permeable spur dike (R = 30%)

Figure 3 *Nasrollahi et al. (2008), Page 3402, Figure 4*

**Ibrahim, M. M. (2014) Local Bed Morphological Changes due to Oriented Groins in Straight Channels. *Ain Shams Engineering Journal,* 5(2), 333-341**

Groynes can be used to protect banks from erosion, however can also be useful for habitat creation, through scour pool formation therefore deflector design should consider both aspects.

The authors study the influence of deflector design on scour (Figure 4), including length, orientation and river discharge. Results found an increased degree of scour over time, with varying locations for structure orientation. **The longest, widest and deepest scour hole was measured for the longest, repelling structure.** The length of the structure was found to be more influential than the orientation or river discharge, at determining bed topography.

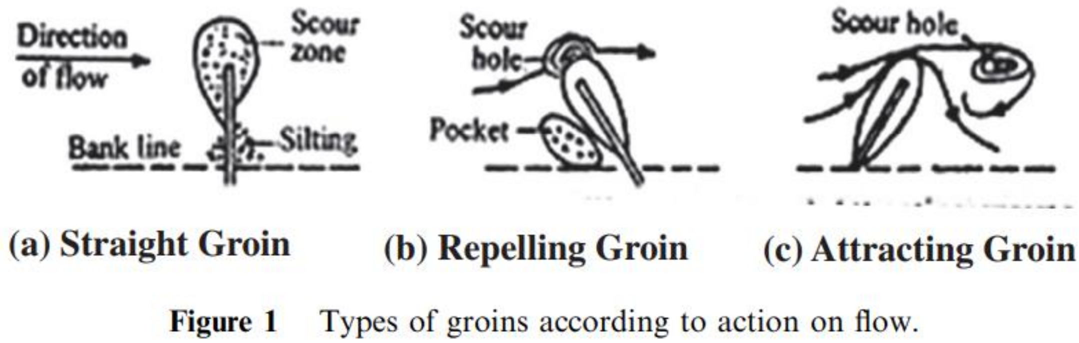


Figure 4 *Ibrahim (2014), Page 336, Figure 1*

**Miller, J. R. & Kochel, R. C. (2013) Use and Performance of In-Stream Structures for River Restoration: A Case Study from North Carolina. *Environmental Earth Sciences,* 68 (6), 1563-1574**

This paper assessed different instream structures and the influences on their stability and efficacy. Rock vanes were shown to fail in high energy streams due to erosion, and the structures becoming swamped by deposition in aggrading rivers.

**Pagliara, S. & Mahmoudi Kurdistani, S. (2013) Scour Downstream of Cross-Vane Structures. *Journal of Hydro-environment Research,* 7, 236-242**

This study investigates the scour downstream of cross vane structures. I-shape and U-shape vanes were used. The authors carried out numerical analysis where many influential parameters were used including channel width, structure height, structure length, flow depth surrounding the structure and channel bed slope, to determine the maximum scour depth.

**Pandey, M., Ahmad, Z. & Sharma, P. K. (2017) Scour around Impermeable Spur Dikes: A Review, *ISH Journal of Hydraulic Engineering,* DOI: 10.1080/09715010.2017.1342571**

Spur dikes historically used to avoid river bed and bank erosion. The authors outline the different types of spur dikes, depending on the shape of the structure head, including straight, T-shape, L-shape, hockey-shaped and mole-head. The paper gives a succinct review of scour and properties influencing scour development such as flow and sediment type.

**Rosgen, D. L. (2001) The Cross-Vane, W-Weir and J-Hook Vane Structures…Their Description, Design and Application for Stream Stabilisation and River Restoration. *Wetlands Engineering & River Restoration,* 1-22**

The author provides an illustrated description of j-hooks and cross vanes, with design considerations.

### *Deflector Height*

**Rodrigue-Gervais, K., Biron, P. M. & Lapointe, M. F. (2011) Temporal Development of Scour Holes around Submerged Stream Deflectors. *Journal of Hydraulic Engineering,* 137 (7), 781-785**

The authors state how deflectors are typically designed to be lower than the water level at high flows, in order to withstand the impact of instream transported material, and high flow velocity. However, this design needs to be investigated in order to avoid implementing a structure which is not at a height which will successfully narrow the flow and create mid-channel pools for fish habitats. The authors used a laboratory flume to test the impact of deflector height on the development of scour pools. Three heights were tested using paired deflectors at a 90° angle to the flow, with the same flow rate for each run. The investigation showed scour pools started to develop at the downstream end of the deflector, with subsequent deposition of material further downstream. The highest deflectors generated the largest, deepest and longest scour pools, whereas the lowest deflectors did not produce scour during the period of investigation, showing pools take longer to establish when the deflectors are lower, due to increased overtopping. Furthermore, the lowest deflectors produced the greatest scour upstream of the structures, whereas higher deflectors generated scour closer to the structure tip. Overtopping was found to alter the flow pattern of a stream, possibly altering the channel's ability to alter morphology.

**Thompson, D. M. (2002) Channel-Bed Scour with High versus Low Deflectors. *Journal of Hydraulic Engineering,* 640-643**

Previously deflectors have been used as low structures implemented across the width of the channel to benefit fish habitat. The authors encourage the use of deflectors in restoration due to their ability to alter flow path. Two deflector heights and designs were tested using a flume with six different discharge conditions. The shorter deflectors generated a scour pool which grew with river stage; however the taller structures showed a more distinct trend - at low flow a negligible pool was produced whereas a much larger mid-channel pool was created during higher than bankfull levels. Taller deflectors were therefore recommended for encouraging scour to improve biodiversity. However, this trend was evident on this river due to its channel dimensions and sediment type. The coarse bed material meant there was little scour at low flow due to low sediment transport, however at high flows, transport of coarse sediment lead to high erosion rates. The authors express the importance of bankfull discharge consideration when designing deflectors as this parameter is crucial to natural channel form changes.

**Pagliara, S., Kurdistani, S. M. & Santucci, I. (2013) Scour Downstream of J-Hook Vanes in Straight Horizontal Channels. *Acta Geophysica,* 61 (5), 1211-1228**

The authors focus on the development of bed scour downstream of j-hook deflectors in a flume experiment. Instream structures such as vanes can be designed to maximise scour hole length. The research identified structure height as an important parameter when estimating the maximum extent of bed scour.

### *Orientation*

**Kuhnle, R. A., Alonso, C. V. & Shields, D. Jr. (1999) Geometry of Scour Holes Associated With 90° Spur Dikes. *Journal of Hydraulic Engineering,* 972-978**

This study focuses on the extent of scour generated using deflectors at a 90° angle to flow, allowing overtopping to occur. Experiments were carried out in a flume, using two designs with varying lengths. The positioning and width of the scour pools were similar following investigations using each design; however longer deflectors resulted in higher scour pool length and depth.

**Kuhnle, R. A., Alonso, C. V. & Shields, F. D., Jr. (2002) Local Scour Associated with Angled Spur Dikes. *Journal of Hydraulic Engineering,* 1087-1093**

This paper investigates the best angle to implement deflectors in order to avoid bank erosion and encourage scour. Experiments carried out in a flume testing 3 angles showed deflectors at a 45° angle to flow caused the largest bed erosion close to the bank. Mid-channel scour was highest for the 135° angle which was considered the best design.

**Khosronejad, A., Kozarek, J. L., Diplas, P. & Sotiropoulos, F. (2015) Simulation-Based Optimisation of In-Stream Structures Design: J-Hook Vanes. *Journal of Hydraulic Research,* 53 (5) 588-608**

Using a computational simulation, this paper found that vanes at different angles to the flow suited rivers with different substrate. For gravel rivers, a vane placed facing upstream at an angle of 30° was more appropriate for diverting scour towards the middle of the channel. For sand based rivers however, the vane facing upstream at a 20° angle to flow provided increased bank protection. Moreover, multiple j-hooks were suggested to prevent erosion along the whole length of the outside meander bend. 3D flow fields were investigated to determine where the most stress is impacting the outer bend, in order to determine the best positioning of an additional vane.

**Bahrami Yarahmadi, M. & Shafai Bejestan, M. (2016) Sediment Management and Flow Patterns at River Bend Due to Triangular Vanes Attached to the Bank. *Journal of Hydro-environment Research,* 10, 64-75**

The authors highlight the importance of appropriate design in order to avoid failure of instream structure installation, as different structures and designs create variable flow patterns. Using a laboratory flume, triangular shaped deflector vanes were placed instream on the outside of the meander bend, facing upstream at an angle between 20° and 30° to the flow, sloping slightly to submerge the tip of the structure (Figure 5). The research found the vanes were effective at moving the thalweg away from the outer bank. Vanes at a 30° angle to the flow were shown to be the most effective at causing mid-channel scour and deposition at the outer bend. Scour developed at the tip of the structures, and as the spaces between them increased, the degree of scour increased. An appropriate spacing between vanes was determined, which maximised scour hole extent whilst avoiding increasing the scour so far that is reaches the outer bank. However, more research is necessary on suitable spacing between triangular vanes.

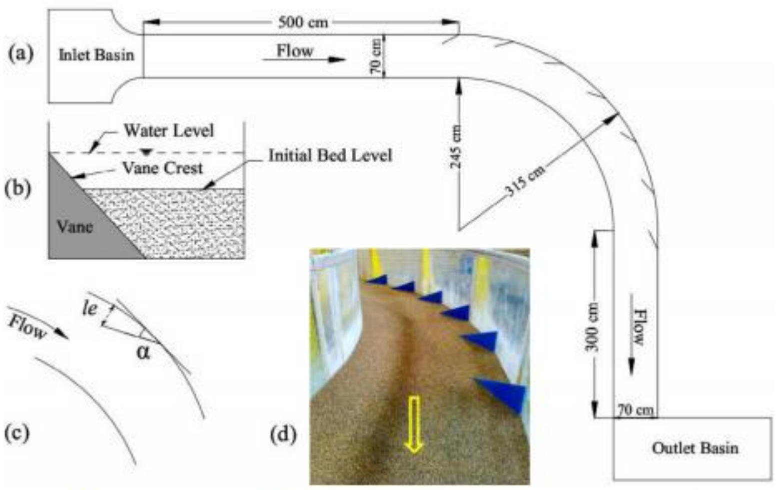


Fig. 1. (a) Plan view of the flume and the triangular vanes layout in the outer bank; (b) cross-sectional view of the single vane; (c) sketch of the vane parameters; (d) photograph of the vanes in the bend for space of 4*le* before starting of test.

Figure 5 *Bahrami Yarahmadi & Shafai Bejestan (2016), Page 65, Figure 1*

**Krishna Prasad. S., Indulekha, K. P. & Balan, K. (2016) 'Analysis of Groyne Placement on Minimising River Bank Erosion', *Procedia Technology,* 24, 47-53**

Groynes slow the flow along the outside of the channel, creating deeper, faster flowing water down the middle of the channel. The velocity gradients at the nose of the groyne can create turbulence, encouraging scour pools to develop.

The authors use the terms 'repelling spur' and 'attracting spur' for structures angled upstream and downstream respectively, as the design of the spur guides the flow in the desired pattern. The study introduces *cocologs* – using coconut fibres and coir textile to create groynes – and how they can be used effectively as groynes.

### Three Dimensional Flow around Deflectors

**Haltigin, T. W., Biron, P. M. & Lapointe, M. F. (2007) Three-Dimensional Numerical Simulation of Flow around Stream Deflectors: The Effect of Obstruction Angle and Length. *Journal of Hydraulic Research,* 45 (2), 227-238**

The response of the river flow to a deflector is influenced by the structure length and orientation. Haltigin et al. ran a 3D numerical simulation model in order to understand the movement of flow impacted by a deflector, and determine how deflector size and positioning affects the flow. The simulation found that as the flow approaches the deflector, 3D recirculation occurs due to the downward pressure of the water, and pressure on the bed. Water is forced to move in an asymmetrical lateral direction in order to navigate around the structure. With increasing deflector length, the flow separation extends, and downward pressures and scour increase, although this also depends on the deflector angle. Flow separation and 3D flow were found to be most severe around deflectors placed at larger angles to the flow (>90°); however angles of about 90° narrow the flow and create efficient downward movement of water to encourage scour pool establishment.

Deflectors which are subjected to continual overtopping have a smaller impact on flow and the development of scour pools. Also, with less flow being narrowed by the structures, the velocity is not being impacted, and erosive power is not being encouraged. The authors indicated that further research on deflectors experiencing overtopping is necessary in order to understand the response of the river geomorphology to natural events such as high rainfall and flooding.

**Biron, P. M., Robson, C., Lapointe, M. F. & Gaskin, S. J. (2005) Three-Dimensional Flow Dynamics around Deflectors. *River Research and Applications*, 21, 961-975**

Biron et al. indicate the role of deflectors as techniques for encouraging scour. Paired deflectors can operate together to form diverse mid-channel flow, surpassing the flow paths and scour pools produced by a single structure. This paper uses a flume to consider the 3D flow occurring around multiple types of paired deflectors, in order to provide information on how best to install these structures to benefit fish habitats. Deflectors were placed at angles of 45°, 90° and 135°, and two heights were tested in order to determine the response of the flow to overtopping and not overtopping the structure. The deflectors caused variable velocity across the river cross section, as velocity reduced as it was obstructed by the structure, and increased as it flowed downstream past the feature.

The deflectors angled at 90° created a larger recirculation zone than the deflectors at other angles, and generated the larger scour pools at both overtopping and not overtopping conditions. The deflectors angled at 45° did not have as much of an influence on geomorphology, although sand was deposited downstream following investigation of deflectors at each angle.

**Biron, P.M., Carré, D. M. & Gaskin, S. J. (2009) Hydraulics of Stream Deflectors Used In Fish-Habitat Restoration Schemes, *River Basin Management,* 124, 305-314**

This paper uses 3D Computational Fluid Dynamics to determine the flow around deflectors. During low flow conditions, scour pools were typically found to develop around the deflectors, whereas during overtopping, a larger pool developed, getting shallower as it extended further from the structure.

The authors describe how further research is needed on the composition of deflectors, as most previous studies incorporate smooth rather than rough, natural structures. The authors also stress how 3D models rather than 2D models are the preferred technique for flow investigations, as multiple dimensions are needed to understand how flow patterns are altered by these obstructions.

**Haltigin, T. W., Biron, P. M. & Lapointe, M. F. (2007) Predicting Equilibrium Scour-Hole Geometry near Angled Stream Deflectors Using a Three-Dimensional Numerical Flow Model. *Journal of Hydraulic Engineering,* 983-988**

It is important to investigate the flow patterns and bed morphology associated with instream structures. This paper uses a 3D numerical simulation of a flow field to investigate the development of mid-channel pools for deflectors at different angles to flow. The authors found the upstream limit of the flow separation determined the upstream extent of scour, and the width of the separation zone influenced the lateral scour. This type of research can be applied to restoration schemes where deflectors need to be at a suitable angle in order to develop scour pools of a certain depth to support biodiversity.

**McCoy, A., Constantinescu, G. & Weber, L. J. (2008) Numerical Investigation of Flow Hydrodynamics in a Channel with a Series of Groynes. *Journal of Hydraulic Engineering,* 134 (2), 157-172**

Groynes aim to move the area of deepest, fastest flow away from the river banks, avoid flooding events by moving a large volume of water through the channel, preventing erosion of the banks, and improving biodiversity. Consecutive groynes provide areas of still water between them, enabling diverse flow paths to establish. This paper investigates large eddy simulation (LES) of a series of groynes along a channel, to determine the mean flow velocities between the structures. 3D flow fields, turbulence and shear stress distribution were used to estimate the scour taking place around the groynes. The most turbulent flow was observed around the tip of the structure (Figure 6).

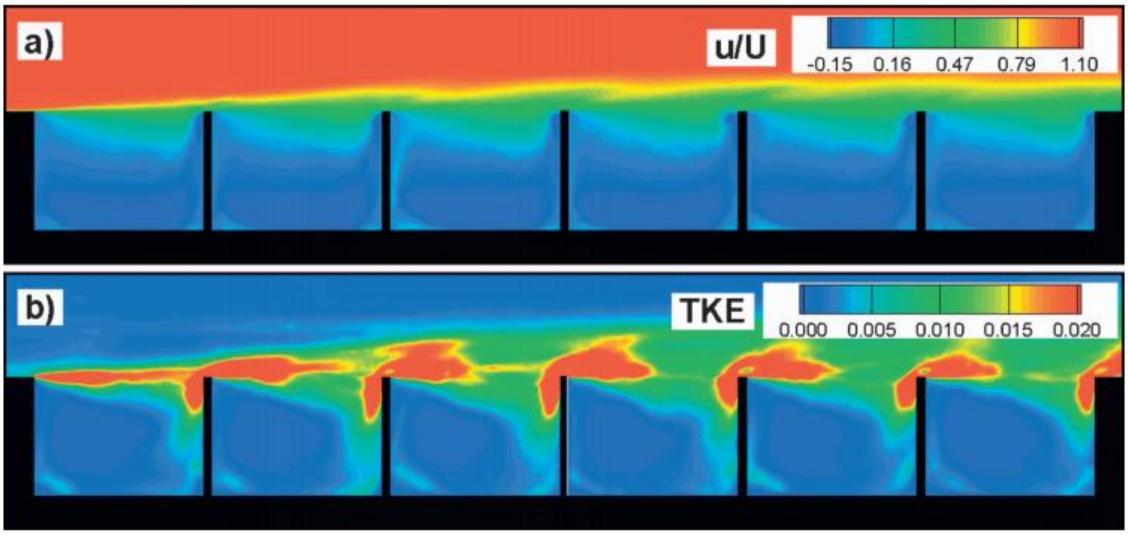


**Fig. 3.** (Color) Distributions of mean flow variables in a plane near the free surface ($z/D=0.95$) (a) streamwise velocity; (b) TKE

Figure 6 *McCoy et al (2008). Page 161, Figure 3*

**Yossef, M. F. M. & de Vriend, H. J. (2011) Flow Details near River Groynes: Experimental Investigation. *Journal of Hydraulic Engineering,* 137 (5), 504-516**

This paper aims to estimate turbulence near groynes in order to model flow processes around structures. Flume experiments were carried out to study the flow field around both submerged and emerged groynes. Different patterns were observed around the different structures. For the protruding groynes, a large eddy formed between successive structures as the flow recirculated towards the bank, downstream of each deflector. Another eddy formed at the tip of each groyne before moving and merging with the much larger eddy downstream. However, this eddy circulation was not evident around submerged groynes. Overtopping limited flow recirculation, creating low velocity areas.

**Koken, M. & Constantinescu, G. (2008) An Investigation of the Flow and Scour Mechanisms around Isolated Spur Dikes in a Shallow Open Channel: 2. Conditions Corresponding to the Final Stages of the Erosion and Deposition Process, *Water Resources Research,* 44 (8)**

The authors recognise the effects of scour around a spur dike structure. Using large eddy simulation (LES) and dye visualisations, this paper studies the flow fields surrounding spur structures, within straight channels at a low Reynolds number (laminar flow). The experiments explored flow patterns, the detached shear layer, sediment transportation and the influence of bed shear stress on flow characteristics. The paper found the deepest area of scour around the structure to be located close to the tip of the spur dike.

### *3D Flow in Meander Bends*

**Fazli, M., Ghodsian, M. & Neyshabouri, S. A. A. S. (2008) Scour and Flow Field Around a Spur Dike In a 90° Bend. *International Journal of Sediment Research,* 23, 56-68**

Spur dikes can be used to protect the river banks and increase channel depth. It is useful to estimate the amount of scour likely to be generated by spur dikes at different angles. This study focuses on the scour and 3D flow produced around a deflector in a meander bend. The channel characteristics, deflector design, sediment type and flow conditions influence the potential bed scour introduced by an obstruction. The experiment found flow separation and recirculation occurred, illustrated by diagrams to aid understanding of how flow reacts to deflectors at different angles and positions.

**Bhuiyan, F., Hey, R. D. & Wormleaton, P. R. (2010) Bank-Attached Vanes for Bank Erosion Control and Restoration of River Meanders. *Journal of Hydraulic Engineering.* 583-596**

The authors also recognise the disadvantages of spur dykes, including how narrowing the channel creates reverse flows and eddies upstream of the obstructions which results in siltation, impacting wildlife. Also, there are difficulties involved in the positioning and location of these structures, particularly in meander bends.

Experiments were carried out in a laboratory to determine the impacts of structures on flow and scour in a meander bend. 3D flow measurements were used to illustrate the differences in flow patterns and velocity around the vanes. The investigation found that placing vanes on the outer meander bend altered the flow pattern and deformed the bed. Bed scour and subsequent deposition downstream occurred rapidly following deflector implementation, before slowing. Flow patterns around the structures were found to be more complex in meander bends due to the morphology of the channel. The structures angled at 30° to the flow shifted the channel thalweg away from the outside bend, effectively protecting the bank.

**Zhou, T. & Endreny, T. (2012) Meander Hydrodynamics Initiated By River Restoration Deflectors. *Hydrological Processes,* 26. 3378-3392**

Meander bend erosion has led to increasing concern over river stability, and the need for restoration techniques, some of which alter the natural flow of a watercourse. Deflectors avoid detrimental bank erosion by diverting flow away from the outer bank, to the centre of the channel. This paper focuses on the j-hook deflector which is angled upstream, protruding into the flow, and changing the natural dynamics. These features deflect water energy to encourage shear stress in the centre of the channel and the establishment of a pool to facilitate wildlife habitats. This study simulates the impacts of j-hook deflectors, by using computational fluid dynamics to compare the response of a stream with and without the structures implemented. The simulation showed the j-hooks altered the natural flow behaviour of the meander bend, reducing scour on the outer bank. The authors also highlight the ecological impacts of such restoration techniques, including how refuge areas of slow flowing water may not benefit all aquatic wildlife. Although, deflectors create dynamic flow paths of both calm and turbulent flow, suitable for many species.

**Kang, S. & Sotiropoulos, F. (2015) Numerical Study of Flow Dynamics Around A Stream Restoration Structure In A Meandering Channel. *Journal of Hydraulic Research,* 53 (2), 178-185**

This paper uses numerical modelling (large eddy simulation, LES) to investigate 3D turbulence around structures in a meandering channel. Research was carried out at the field-scale, using a rock vane instream along the outside bank of the meander bend, facing upstream. LES computed models showed the presence of the rock vane shifted the faster flow away from the outer bend, avoiding any potential erosion. Additionally, an area of low velocity was generated directly downstream of the rock vane, near the outside bend. Using bathymetries, the rock vane on the outer bend created substantial bed scour protection downstream of the structure. Without the vane, bed erosion is elongated around the outer meander bend. However, the depth of erosion is increased by the vane, only around the tip of the structure. Moreover, without vanes, regions of high shear stress form close to the outer bend, whereas the vane displaces the high shear stress towards the middle of the channel. The authors found that one rock vane implemented instream had a significant impact on bed morphology. Also, they highlight the use of numerical simulations to improve understanding of how instream structures impact flow, and how they can be best designed to achieve restoration objectives.

**Zhang, H. & Nakagawa, H. (2008) Scour around Spur Dyke: Recent Advances and Future Researches. *Annuals of Disas*. 633-652**

The authors provide background information on spur dike implementation, and how numerical modelling can aid design. Numerical models can be used to help estimate the extent of bed scour by investigating the flow around an obstruction.

**Vaghefi, M., Ghodsian, M. & Akbari, M. (2017) Experimental Investigation of 3D Flow around a Single T-Shaped Spur Dike in a Bend. *Periodica Polytechnica Civil Engineering,* 61(3), 462-470**

Flow dynamics in a meander bend involve water near the surface flowing towards the outer bend whilst water near the bed flowing towards the inside of the bend. In these types of rivers, spur dykes or deflectors can be used to protect the outer bank and bed from erosion. The authors suggest spur dykes can negatively influence the flow in a meander bend, creating turbulence. Their experiment used a t-shaped spur dyke on the outside of the meander bend, and found that secondary flow which was produced at the start of the meander bend, grew stronger around the bend.

## Biological Impacts

**Harrison, S. S. C., Pretty, J. L., Shepherd, D., Hildrew, A. G., Smith, C. & Hey, R. D. (2004) The Effect of Instream Rehabilitation Structures on Macroinvertebrates in Lowland Streams. *Journal of Applied Ecology,* 41, 1140-1154**

The authors determine the influence of deflectors and artificial riffles on the biodiversity of a stream by quantifying the number of macroinvertebrates residing in the habitats created by the installed structures, and comparing this with reference reach conditions. The study found deflectors did not influence benthic macroinvertebrate community richness, as identified species abundance and diversity did not differ from typical habitats.

**Shamloo, H., Rajaratnam, N. & Katopodis. C. (2001) Hydraulics of Simple Habitat Structures, *Journal of Hydraulic Research,* 39(4), 351-366**

The authors define 'fish habitat structures' as in stream structures to improve habitats through sufficient provision of deeper, slower flowing water. The authors carried out a laboratory study looking at flow and erosion around habitat structures.

## Grey Literature

**Ohio Stream Management Guide – Deflectors**

This report provides an overview of parameters to consider during deflector design and implementation. It demonstrates how deflectors can be used in small adjusted channels, or streams with unstable banks, utilising a range of materials including rock, logs, and planting trees on the banks. Riprap can also be used adjacent to the deflector to stabilise the structure. This guide suggests deflector length should be a fifth to a third of the width of the channel; implemented deep enough into streambed substrate to make sure it is stable; and be at an appropriate height so that it is visible during low flow but overtopped during high flow conditions. The report illustrates positioning of deflectors to achieve different restoration objectives such as to narrow the channel and create meanders, or to protect the bank from erosion.

**Instream Structures – The Chalkstream Habitat Manual**

It is important to consider where to place deflectors along a channel in order to best position the resultant scour and deposition; such as avoiding scour in undesirable locations which may subsequently lead to deposition of fines in gravel spawning grounds.

**Stream Restoration: A Natural Channel Design Handbook. North Carolina Stream Restoration Institute and North Carolina Sea Grant**

This guide provides a brief description of vanes, and how to position them.