ENVIRONMENT AGENCY NORTH WEST

Geomorphological Considerations for the Introduction of Boulders and Groynes for Fisheries Enhancement:

Assessment of R. Eden at Carhead.

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FISHERIES ENHANCEMENT: BOULDER & GROYNE PLACEMENT

AIMS

This Evaluation seeks to briefly provide geomorphological guidance over the introduction of 'habitat enhancement' features for fisheries improvement which is an expanding area of interest throughout the region[1]. There has been a large quantity of literature published in recent years on habitat enhancement; (examples used are cited in appendix 1), this contains a variety of useful information, however it is at times contrasting, at others unsupported by successful field monitoring and on occasion not applicable to the conditions of the region. This document is therefore a primary attempt to draw together the salient details from these various sources with reference to boulder introduction and to groyne / deflector placement in NW rivers.

Secondly the potential introduction of such features is assessed, with reference to the proposed works at Carhead on the Eden, (in the area of NY 37055864). The site evaluation is based on the findings of a field visit made by Jim Walker with Liz Oliver and Ted Luckley on 2.3.1998, and on the drawings presented by the applicants, prepared by Harrison and Hetherington Ltd.

To fulfil these objectives the report below is broken down into four sections, firstly general issues of habitat enhancement for fisheries will be discussed, secondly the site specific considerations of boulder introduction will be reviewed. Thirdly, issues of groyne development and bank protection will be considered. Finally, a summary of suggestions as concerns the Carhead proposals is presented.

[1] This report is developed from the report: Introduction of Boulders to the R. Ribble: A Short Geomorphological Report, Jim Walker, 24.1.1998, Environment Agency NW.

1) GENERAL CONSIDERATIONS

1.1 The placement of artificial in-channel structures into any fluvial system needs to be considered carefully. A primary question that needs to be answered is; **'does the habitat at the potential introduction site show unnaturally low habitat diversity in its present condition?' Ie. is the habitat a 'degraded' one? If the answer is yes then enhancement works may be viewed as river rehabilitation. If it is no, then the works are river engineering/modification. The significance of this distinction depends on the nature of the proposed site, (eg. habitat quality, existing level of modification etc.), this is a matter for conservation/landscape consideration. The role of geomorphology is to provide process information, detailing the likely impacts of introductions.**

1.2 It must considered that there are a wide range of possible methods for increasing channel bed habitat diversity, different methods may or may not be applicable depending on the character of a given site, (for references with examples of different techniques see appendix 1). Geomorphological advice should be sought concerning the suitability of different techniques.

1.3 It should also be recognised that fluvial systems that display a paucity of in-channel habitat diversity, are often also prone to low bank habitat diversity, if this is the case, efforts should be made to improve the bank habitat in conjunction with any in-channel improvements.

1.4 It must be considered that in-channel enhancement works, have the potential to impact upon a wide range of functions in addition to Fisheries, and consultation with such functions should be an intricate part of the habitat improvement process.

1.5 In-channel structures may change patterns of erosion and deposition at an introduction site in ways that are intensional, and in others that may be more accidental. All such impacts need to be considered be a geomorphologist at a site, and upstream and downstream of it.

1.6 Any artificial feature placed into a channel will alter eventually, given enough time or a large enough / a series of large flood events. Even a structure represents a mass that the maximum possible flood in a river system is incapable of mobilising it, 'the river will change in relation to the structure', ie. the natural substrate into which the structure is placed will erode and change morphologically around it. Implications of long term change/failure of structures need to be considered.

1.7 Any works undertaken should be monitored regularly, to quantify success in terms of; fisheries objectives, geomorphological process development and structural stability. This may include quantitative observations such as electro-fishing before introduction and for a number of years afterwards, survey and resurvey of bed heights in the vicinity of any works in addition to visual inspections of site development, and surveying / resurveying of position of introduced features plus site stability assessments, respectively.

Eden at Carhead	
1.1	Decision for Area staff with detailed knowledge of site and site development.
1.2	Suggested techniques suitable with some modifications (see sects 2 & 3 below).
1.3	Planting & fencing discussed below.
1.4	Conservation and Flood Defence consulted via consent, report to Landscape officer for comments. English Nature to be consulted (SSSI).
1.5	Protection works included in designs, discussed below.
1.6	No negative impact on geomorphological processes from long term change.
1.7	Fisheries, geomorphological and structural monitoring recommended before / on completion of works and a reassessment within a year, (particularly in the advent of any flood flows).

2.0 BOULDER PLACEMENT

Boulders are used to increase habitat diversity breaking up monotonous flows by; i) providing an in-stream mass that gives flow shelter for fish, and ii) by encouraging the scouring of localised pools.

2.1 SITE CONSIDERATIONS

2.1.1 Are there existing boulders within the planned placement reach (eg. within 250m upstream / downstream of the site)?

2.1.2 For greatest effect boulders should be placed into faster flowing river reaches (average velocity > 1 m/s), with a Froude number in excess of 0.4.

2.1.3 The placement reach should be straight, or near straight.

2.1.4 The banks of the placement reach should be stable, ie. should not exhibit signs of erosion or slumping, (exceptions may include centre channel works in naturally very wide channels).

2.1.5 Central channel placements preferred, in the case of peripheral placement boulders should not be placed within 1 bank heights distance of the bank toe, and to expand on this: in channels where the width/bank height ratio is < 20:1 this should be expanded to, no placement within 1.5 bank heights distance of the toe.

2.2 MATERIAL CONSIDERATIONS

2.2.1 Boulders should be of a suitable (naturally occurring) geological type within a catchment context.

2.2.2 In reaches where exposed boulders are not naturally occurring channel features, introduced boulders should lie fully submerged at all but the most moderate of flows, (eg. Q^{95}). This will also help to ensure that they do not become feeding stations for fish-eating birds.

2.3 BOULDER PLACEMENT AND SHAPE

2.3.1 In high velocity environments, (peak velocities > 4 m/s), boulders should be chosen to have a long A axis in relation to there B and C axis, increasing mass without significantly increasing the entrainment surface are that the boulder presents to the flow. (Axis illustrated in appendix 2).

2.3.2 Boulders should be placed in a channel, so that their A axis is orientated in the direction of flow. (Illustrated in appendix 2).

2.3.3 Boulders should be buried to one third of their depth to increase the stability of placement, protect from undermining, minimise settlement and reduce their visual impact at low flows.

2.3.4 Placement of boulders should maximise scour efficiency, and habitat variation. Therefore where multiple placements are proposed the combination of 'upstream open V's' which create two discrete areas of scour, 'downstream open V's' which create a larger continuous area of scour, and single placement is recommended. See figure 1 below.

2.3.5 In marginal placement locations, (according to 2.1.2 above), rounded boulders should be used, as these maximise scour.

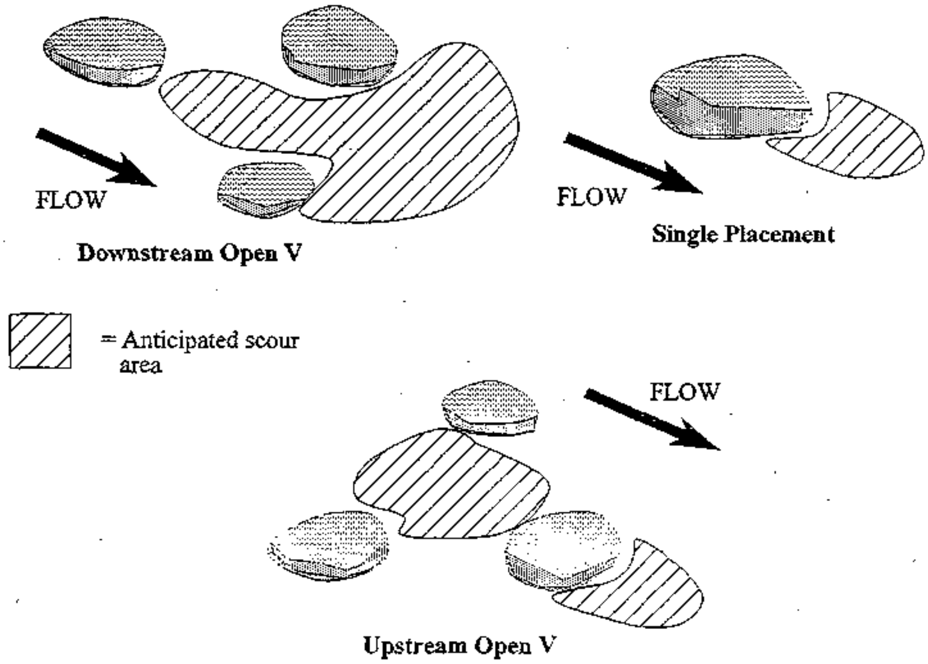


Figure 1: Scour patterns using different boulder placements, (adapted from Cowx and Welcomme, *Rehabilitation of Rivers for Fish*, FAO, 1998, p.127).

2.4 BOULDER SIZING

2.4.1 If stable boulders are naturally occurring in the placement reach some guidance on sizing may be taken from them, (note: signs of stability include lichenous growth on upper faces, well developed scour pools in the vicinity of boulders).

2.4.2 In reaches with no naturally occurring boulders it is necessary to employ empirical calculations to derive sizings. It is important to note that effort to provide transport formulae for all sizes of sediment (from clay to boulders) have been ongoing utilising flume and field experimentation since the end of the last century, and have led to the publication of hundreds of techniques. Many of these are suitable only for a limited range of particle sizes. There is no one recognised 'universal formula'. In terms of the placement of larger particles, in gravel & gravel-cobble bed rivers, such as the majority of systems in the North West, extensive review recommends a small group of formulae as suitable[2], these include the techniques of Scoklitsch, Meyer-Peter and Muller, Parker, duBoys, Einstein, Ackers and White, Profitt and Sutherland and Bagnold.

Eden at Carhead	
2.1.1	None visible

[2]Ref: Gomez and Church (1989), Water Resources Research, 25 (6), 1161-1186.

2.1.2	Average velocities in region of 1m/s (estimate), flood velocities approx. 2m/s, (see appendix 3), Froude number is approx. 0.4-0.5. Thus only moderate scour may be expected at the site.
2.1.3	Relatively straight reach.
2.1.4	Wide channel, groyne works include protection / measures addressing erosion .
2.1.5	Mid channel working.
2.2.1	Type of stone not specified on application drawings.
2.2.2	Simple hydrological modelling results suggest that conservatively Q^{95} depth may be as low as 300-350mm at the proposed site, however these consider fluvial inputs only, and do not take tidal variation into account.
2.3.1	N/A, bankfull velocity = approx. 2m/s, (see appendix 3).
2.3.2	N/A.
2.3.3	Suggested burial may exceed one third of depth, to reduce visual impacts at low flows.
2.3.4	Suggested variation of proposed placement scheme to include 'downstream open V's' and single placements.
2.3.5	Suggested use of rounded boulders.
2.4.1	None Visible.
2.4.2	The width and flood discharge of the Eden at Carhead mean that it is outside the effective performance range of the gravel bed sediment transport formulae reviewed. Therefore the approach of Hey and Heritage 1993, p.75 is adopted, (full reference in appendix 1). This suggests that a 100 kg boulder would be adequate to with stand velocities of approx. 2m/s. Assuming a specific gravity of 2.65 this implies a boulder of approx. 340mm cubed.

B) GROYNE CONSTRUCTION

Groynes are introduced to channels to deflect flow away from riverbanks, this can be undertaken purely for habitat enhancement purposes, for the purposes of addressing bank erosion / retreat problems, or a combination of the two. Deflectors are the most commonly used form of river groyne, they are shorter and lower than true groynes, they encourage a wider variety of bed scour, and they impede large flows only marginally.

3.1 SITE CONSIDERATIONS
2.1.1 Is the site suited to groyne introduction? This form of structure should not be used on rivers with gradients of less than 0.5%, (evidence exists to show that the most dramatic habitat development results have been achieved on gradients over 3%).
3.1.2 What is the intension of groyne introduction, habitat development or amelioration of riverbank erosion problems?
3.1.3 What is the root course of any erosion? Ie. is it caused by natural riverine processes, artificially accelerated riverine processes, stock damage, erosion from formal or informal riverside footpaths, wash from river traffic or a combination of any or all of these factors. Are groynes a suitable technique to address erosion at the site? Do other techniques need to be considered in addition / as an alternative?
3.1.4 What are the likely impacts of introduction on the stability / erosion rate of banks at a site, and upstream, and downstream of it, both in terms of the bank into which the groyne will be keyed and the opposite bank? This depends largely on length, height and angle of structure, in addition to nature of bank materials and cover, and the hydraulic conditions in operation at the site.

3.2 MATERIAL CONSIDERATIONS
3.2.1 If stone-built, is construction material of a naturally occurring stone type, within a catchment context? If artificial material, is this appropriate, (advice of Conservation and Landscape interests needed)? If timber, is it appropriate and substantial enough?

3.3 GROYNE PLACEMENT
3.3.1 What is the design of the groyne? 'Wing' shapes are preferred. Linear features such as single beams may accelerate bank erosion at the introduction bank if overtopped by high flows, particularly if angled downstream.
3.3.2 In the case of wing structures, at what angle are the edges of the structure to the flow? The upstream edge should not be perpendicular to the flow as this will impede flows, rather than directing them, and may cause eddying to undermine the bed upstream of the structure. Therefore a softer downstream pointing angle is suggested, particularly in high velocity circumstances. Wing deflectors are commonly effective at encouraging pool development with upstream edge angles as low as 45 degrees. (Illustrated in figure 2 below).
3.3.3 How is the structure finished in relation to the bed? Structures with an angled 'skirt' (eg. of riprap) encourage less bed scour than structures which form a right-angle with the bed.
3.3.4 In the case of groyne placement primarily for bank erosion protection a single groyne will offer some protection to the bank for 3 - 3.5 times its length downstream, (figures reduce on sharp meanders). Therefore where the interval between structures exceeds this, and erosion is a

problem, additional measures should be used to offer bank protection / stabilisation.

3.3.5 What is the proposed level of the groyne in relation to flow levels? Optimum habitat enhancement potential is achieved by the use of a deflector which protrudes above summer flows (Q^{95}), but well below high flows. Problems of determining flow levels in some documented case studies have led this to be interpreted as 'an optimum deflectors should be below one third bankfull height'.

3.3.6 Are the foundations of the structure deep enough to protect against any local problems of scour / settlement?

3.4 GROYNE SHAPE AND SIZE

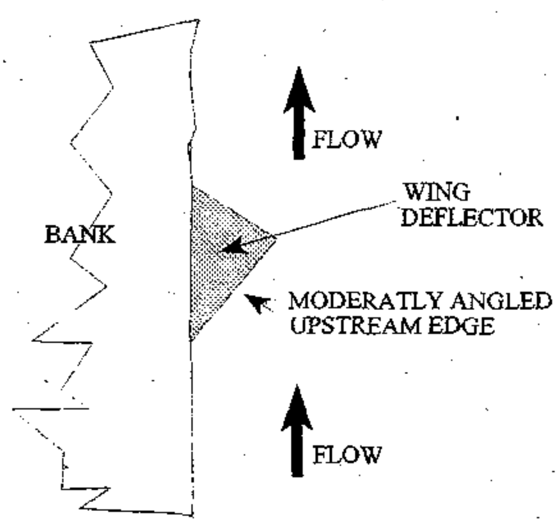
3.4.1 What is the length of the groyne in relation to channel width? A rough guide of 20% of channel width is recommended as a maximum length, however this will vary greatly depending on site details.

3.4.2 How are the edges of the groyne finished.? A rounded finish maximises the efficiency of flow deflection.

3.4.3 If stone materials used, are individual stones large enough to withstand entrainment pressures.

3.4.4 *The upper surface of a structure should slope upwards towards the bank. This stops the* formation of a 'wash plane' across the top of the structure which may cause erosion at the interface between the structure and the bank.

Figure 2: Wing deflector angles, (adapted from Hey and Heritage, *River Engineering Works in Gravel-Bed Rivers,* R&D project record 387/1/W, NRA, 1993, p.69).



Eden at Carhead	
3.1.1	O.K. (Though a little marginal), Gradient = 0.6 - 0.7%
3.1.2	Combined.
3.1.3	Stock damage and natural riverine processes combined. (Although the site forms the downstream extent of a long meander, and is thus not a position where locally high velocity currents or erosion would naturally be expected, bedrock outcrops in the channel near the opposite bank may cause some secondary direction of flow currents towards the site).
3.1.4	Some possible impact on the introduction bank in the vicinity of the structure, (bank material predominately non-cohesive sand). No impact likely on opposite bank, (structures too short).
3.2.1	Stone type not specified.
3.3.1	Wing-shaped deflector design.
3.3.2	Upstream face is near perpendicular to the flow, recommend that this angle is reduced.
3.3.3	Design drawings unclear, right-angle finish assumed.
3.3.4	Interval between structures exceeds 3-3.5 times length, but interim bank protection measures proposed, comments below.
3.3.5	Level = 1 metre and 1.5 metres at 'groynes 1 & 2'. Suggested that upper course is removed from groyne 2 up to line of existing bank level, reducing level to approx. one third bankfull height.
3.3.6	Designs show foundations at one course of stone thick. Two courses depth would offer more scour protection.
3.4.1	Max. 4m. (<6% channel width).
3.4.2	Not shown on designs, rounded finish to stones suggested.
3.4.3	Designs imply stones 0.3-0.5m. diameter. 100kg minimum is suggested, (as derived in 2.4.2 above), design size should approximately satisfy this.
3.4.4	Upper face of structure slopes upwards towards bank.

4.0 SUMMARY OF SUGGESTIONS FOR EDEN AT CARHEAD SITE

4.1 BOULDERS

- Mid channel introduction should be used as per design drawings.
- Boulders used should be > 100kg. and have a non-angular rounded shape.
- Type of stone used should be from a local source of the same geological type as the natural bedrock which outcrops at the bed in the site reach.
- Boulders should be buried one third of their depth into the bed.
- The standing height of boulders, (height above bed), should not exceed 350mm.
- A range of 'upstream open V', 'downstream open V' and single placements should be used (as shown in figure 1), as opposed to the design proposals of downstream open V placement for all groups.

4.2 GROYNES AND BANK PROTECTION

- Groynes designed are strictly speaking deflectors.
- Structures should use stone from a local source of the same geological type as the natural bedrock which outcrops at the bed in the site reach.
- Individual stones used in construction should be minimum 100kg, and those that form the outside of the structures should preferably have rounded edges.
- Shape of structure should be slightly redesigned to give a softer angled upstream edge, (see figure 3 below).

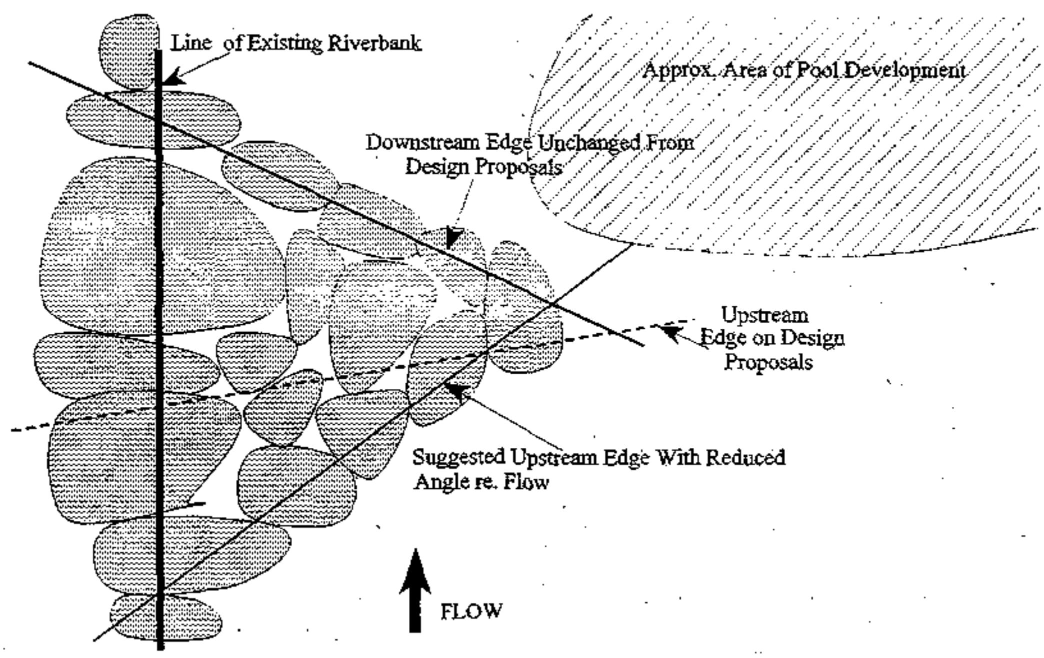


Figure 3: Suggested variations to drawing 3 design proposals, 'Groynes 1 & 2 generic plan'.

- Suggested that upper coarse is removed from groyne 2 up to line of existing bank level, reducing level to approx. one third bankfull height. (See figure 4).

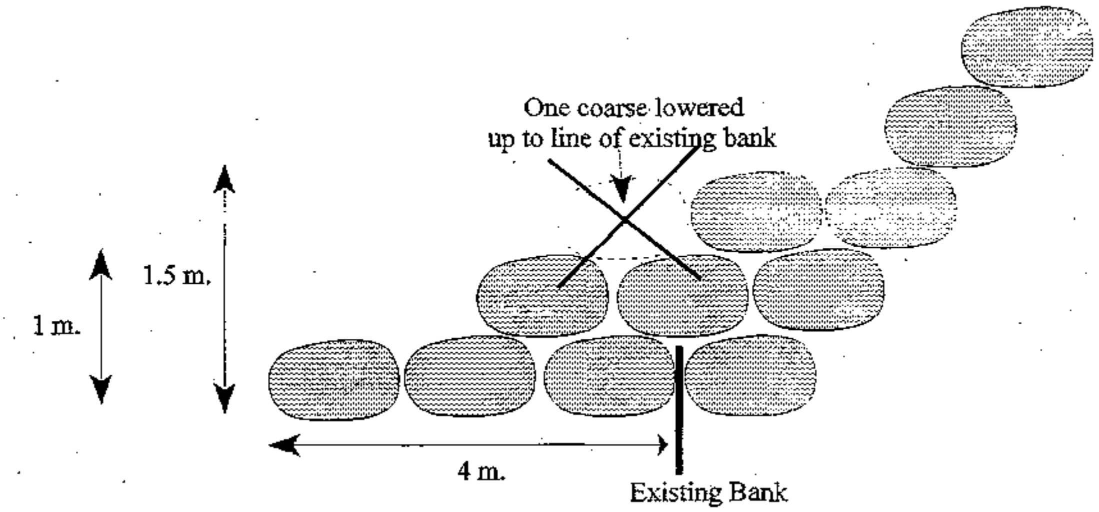


Figure 4: Suggested adaptation of drawing 3 design proposals 'groyne 2'.

- Consider whether two courses depth of foundations may be better than the proposed one to protect against scour protection.
- Bank protection should be installed as per design drawings in the vicinity of the two structures, ie. at the point that they join the bank, and for 10m. upstream and 10m. downstream, (using locally sourced stone as per comments relating to groynes and boulders above).
- The section in between the two groynes and this local stone protection should be battered back to an angle of approx 1:2.5 and planted with willow stakes, and sown with grass seed. Willow stakes should be planted densely at the ends of the stone revetment, providing a transition from hard to soft engineering, and thus reducing the likelihood on erosion transfer. **This area should then be fenced off effectively to exclude stock. The planting and fencing elements of these suggestions are essential to overall design success.**
- Monitoring recommended before / on completion of works and a reassessment within a year, (particularly in the advent of any flood flows) to quantify success in terms of; fisheries objectives, geomorphological process development and structural stability. This may include quantitative observations such as electro-fishing before introduction and for a number of years afterwards, survey and resurvey of bed heights in the vicinity of any

works in addition to visual inspections of site development, and surveying / resurveying of position of introduced features plus site stability assessments, respectively.

Appendix 1.

Sources of Further Information:

Brookes and Shields, *River Channel Restoration*, Wiley, 1996.

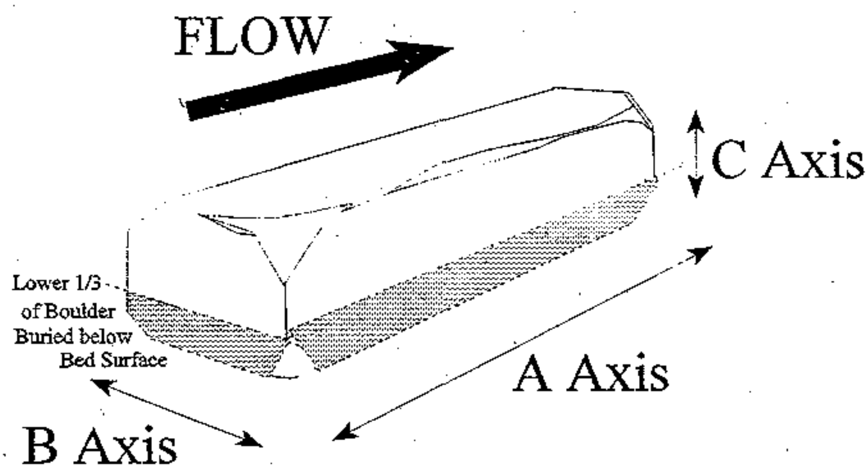
Cowx and Welcomme, *Rehabilitation of Rivers for Fish*, FAO, 1998.

Hey and Heritage, *River Engineering Works in Gravel-Bed Rivers*, R&D project record 387/1/W, NRA, 1993.

Summers, Giles and Willis, *Restoration of Riverine Trout Habitats, A Guidance Manual*, E.A. Technical Report W18, 1996.

Appendix 2.

Boulder Axis, Shape and Orientation



Appendix 3

Empirical calculation of Approximate site Velocity Using Manning Formula, (ref. Open-Channel Hydraulics, Chow, 1959).

$$V = {}^{1}/_{n}\, R^{2}/_{3}\, S^{1}/_{2}$$

Where: R = hydraulic radius (w*d/2d+w), S = slope, n = roughness coefficient, (w = width, d = depth).

According to Cowan 1956, (ref in Chow) $n = (n^0 + n^1 + n^2 + n^3 + n^4)m^5$.

Calculate of n for Carhead site		
Factor	Definition	Site value
n^0	basic value	0.028
n^1	surface irregularities	0.01
n^2	variations in cross section	0.005
n^3	obstructions	0.02
n^4	vegetation	0.01
m^5	planform	1.0
		= 0.073

Therefore: n = 0.073
S = 0.0072 (m/m) [from 1:10000 O.S. Maps NY35NE & NY45NW)
R = 2.33

V = 13.7 * 1.748 * 0.0849

V = 2.0 m/s (to 1 decimal place).