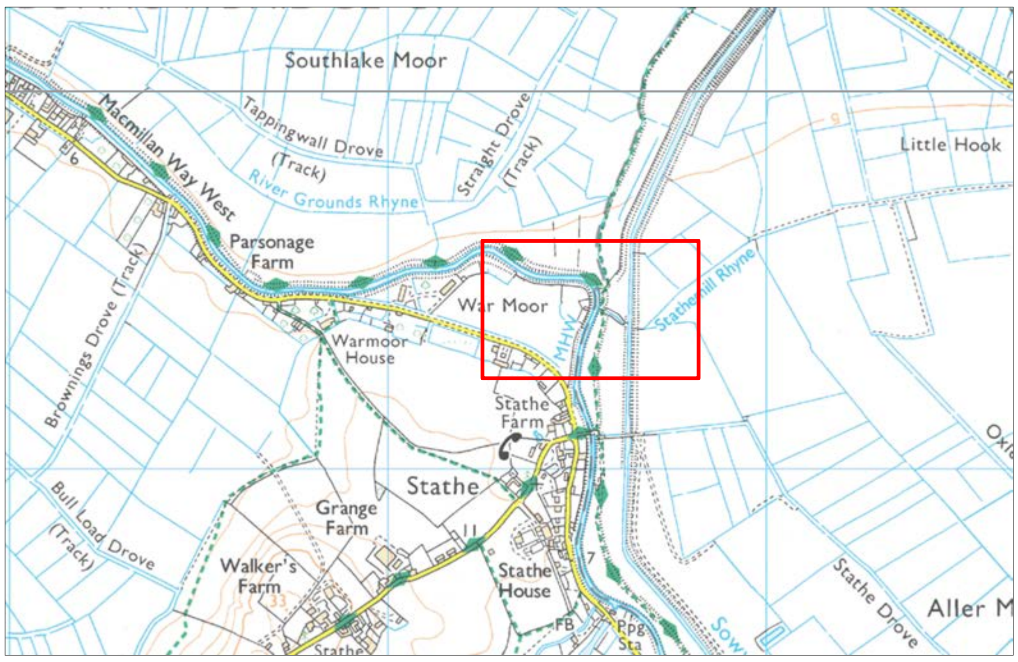
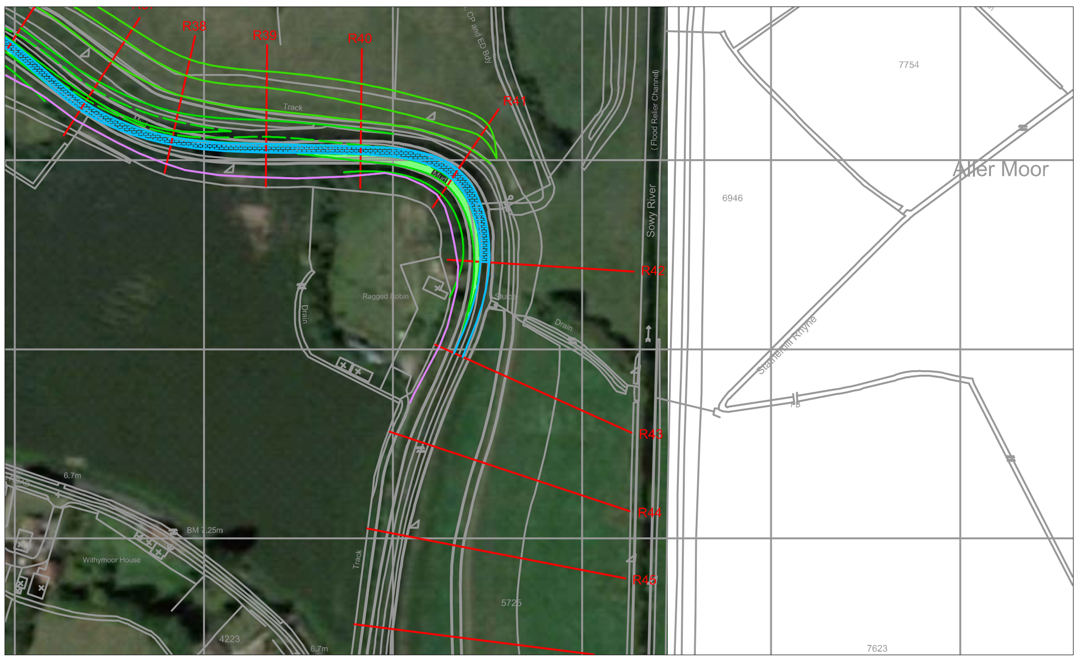
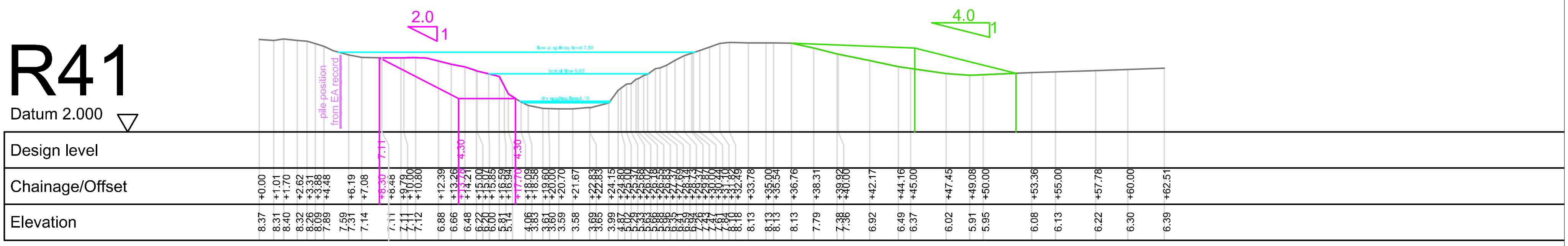
Oath to Burrowbridge Dredging and Associated Activities

Volume 3: Appendices Part 8 Section 2







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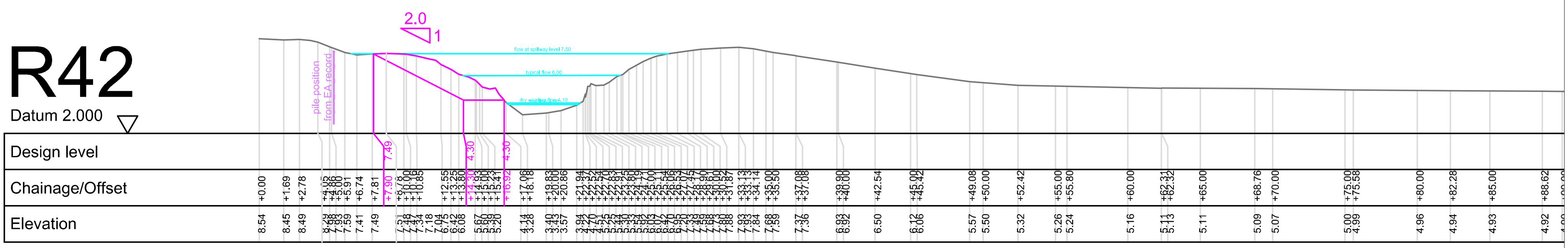

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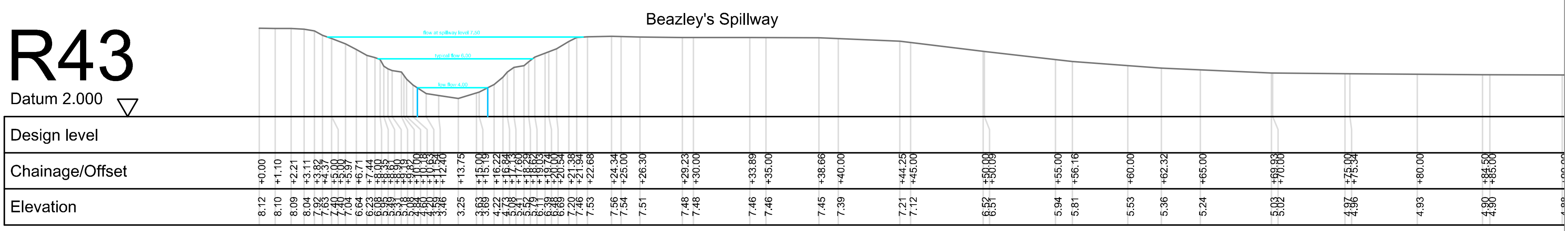

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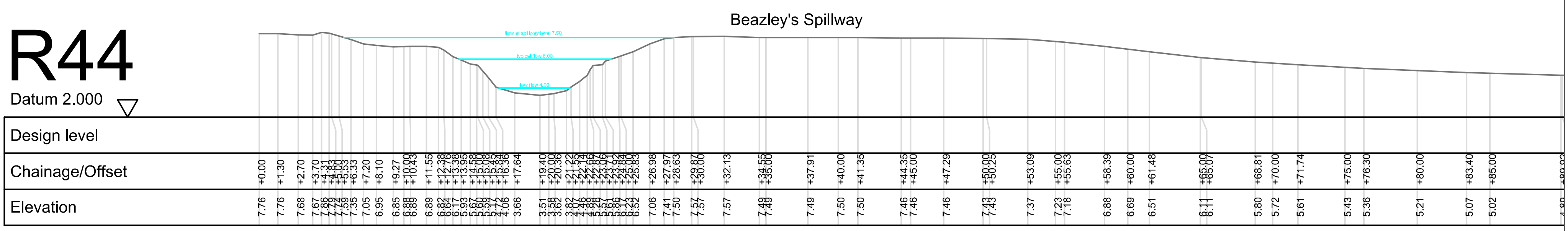

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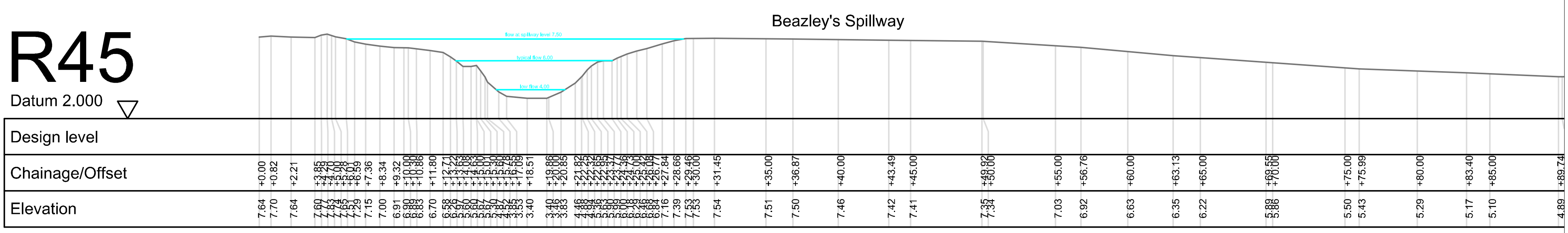

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SOMERSET DRAINAGE BOARDS CONSORTIUM

Parrett Internal Drainage Board
Bradbury House
33-34 Market Street
Highbridge
Somerset TA9 3BW

Telephone 01278 789906
email admin@somersetdbs.co.uk

safety health & environmental:

Safety:
1. Working with variying fluvial and tidal flows
2. Load bearing capacity of river banks
3. Access to parts of left bank may be difficult

Health:
1. Potential residual contamination from agricultural activity
2. Uneven ground that may be slippery when wet/frozen

Environment:
1. Part of the site is SSSI designated
2. Rare and protected species may be present

key:

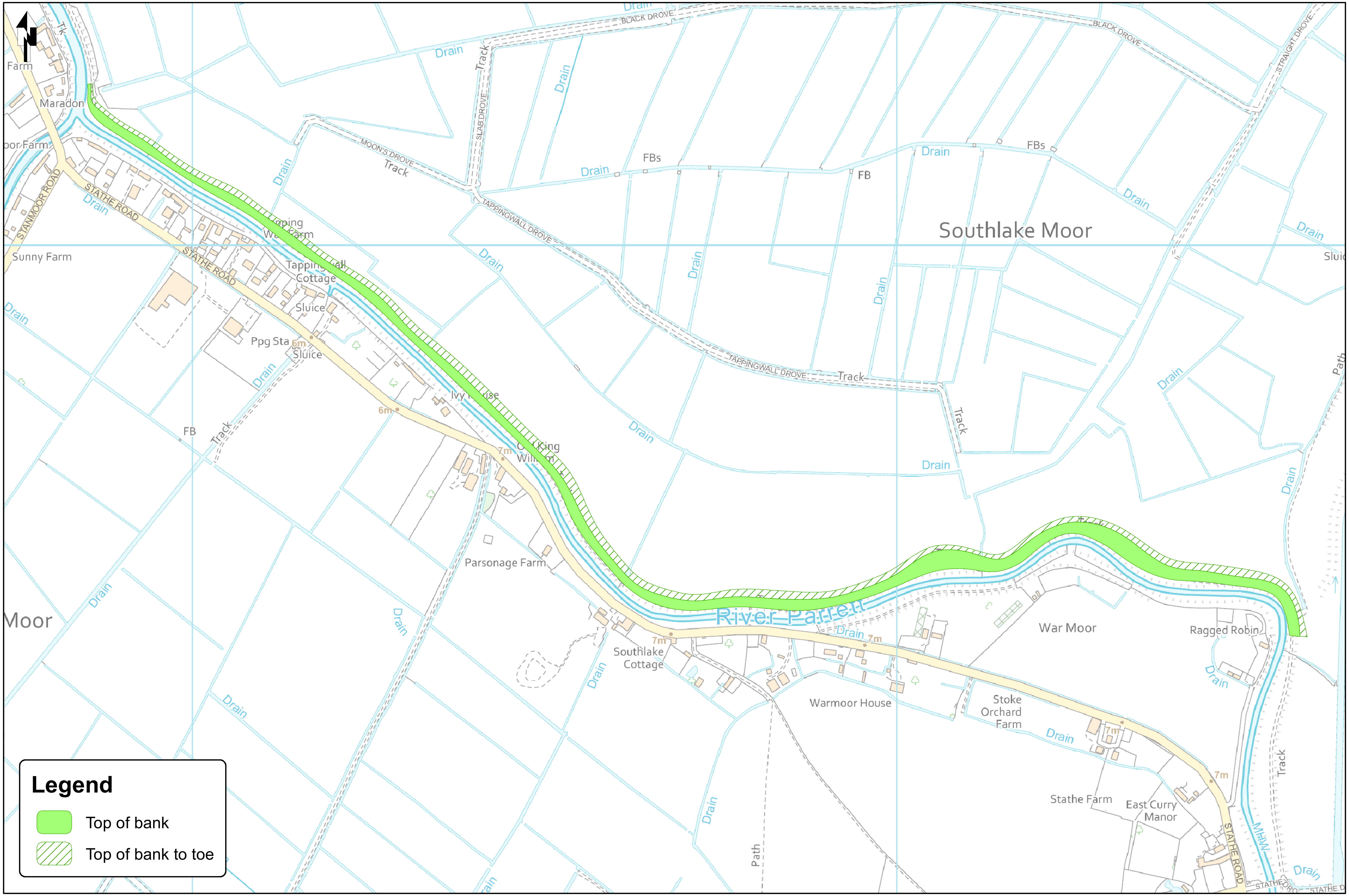
- Flow at spillway level
- Cut
- 2.0 / 1 Design bank cut gradient
- Fill
- 4.0 / 1 Design bank fill gradient

project: Pioneer dredging of River Parrett Oath to Burrowbridge

title: Design Profiles Sections R41-R45

drawn: RK	date: Dec 2018
approved:	issue: Consultation
scale: 1:400 natural @ A3	
drg no: GD06-18-209B	

revisions:
Rev A: 20/03/19 Left bank design mods
Rev B: 21/03/19 Left bank reduction & fill adjusted



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Stathe to Burrowbridge dredge - location of deposition on back of bank

10/05/2019

Pioneer Dredging of the River Parrett – Oath to Burrowbridge

Appendix B - Specification

PARRETT INTERNAL DRAINAGE BOARD
Part of the Somerset Drainage Boards Consortium

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1.0 SPECIFICATION

1.1 The Specification consists of:

- The 'Civil Engineering Specification for the Water Industry', 7th edition (CESWI-7), published by WRc in March 2011 and which is supplemented by the Supplementary Clauses included in section 3.0 below.
- The General Clauses listed below specific to this specification document.

1.2 In so far as the drawings, notes on drawings or General Clauses or Supplementary Clauses may conflict with or be inconsistent with any provision of CESWI-7, the drawings, notes and General Clauses and Supplementary Clauses shall always prevail.

1.3 Any clauses in the Specification which relate to work or materials not required by the *works* shall be deemed not to apply.

1.4 The following definitions apply to the roles defined in CESWI-7 and/or the following General Special and Clauses:

- The "Client" is the *Employer*;
- The "Contract Administrator" or the "Supervisor" is the *Employer* or his delegate;
- The "Constructor" is the *Contractor*.

2.0 GENERAL CLAUSES

2.1 Public Relations

All activities are to be carried out so to minimise any disruption and nuisance to the local population, ensure that adequate notice of any temporary closures or traffic restrictions necessary to carry out works is given and good liaison with landowners and the public is maintained. The *Contractor* shall be responsible for public relations in consultation with the *Employer*. See also section 1.6 of the Supplementary clauses to CESWI relating to consultation with landowners and tenants.

2.2 Access for the Employer

The *Contractor* shall allow access to Board members and staff of the Parrett Internal Drainage Board to inspect the *works.* Access shall be in accordance with the *Contractor's* health and safety policy. Instructions concerning the *works* shall only be accepted from designated officers of the *Employer* or delegates appointed in accordance with Clause 14.4 of the *conditions of contract*.

2.3 Operations & Maintenance Manual / As-built records

The *Contractor* shall supply as-built records within 2 weeks of completion of the *works*.

3.0 SUPPLEMENTARY CLAUSES to CESWI 7th Edition

The Supplementary Clauses are arranged in sections to generally follow the format of the CESWI-7. Specification requirements related to existing clauses are numbered as additional sub clauses. New clauses unrelated to existing clauses are numbered to follow the last clause of the appropriate Section.

- Where the Works Information refers to the "*Project Manager*" or "Engineer", this is interpreted as meaning the "*Project Manager*" and/ or the "*Supervisor*" as the context demands. If the *Contractor* is in any doubt as to whether a matter should be raised with *Project Manager* or *Supervisor*, he shall ask the *Project Manager* to decide the issue.

- References in the specification to "submission for approval" or to "approval" shall be read as "submission for acceptance" or "acceptance" respectively.

- Where the specification refers to plant or equipment, the following definitions are to apply:

- "Plant" is items which (together with Materials) are intended to be included (incorporated) in the works.

- "Equipment" is items provided by the Contractor and used by him to provide the works.

- References in the Works Information to equipment should be read as references to Plant or Equipment, as the context requires.

- If the *Contractor* is in any doubt as to an interpretation, the matter should be raised with the *Project Manager* who shall decide the issue.

- References in the Works Information to the particular works information shall be read as references to the Works Information.

- References in the Works Information to the client or purchaser shall be read as references to the *Employer*.

- References in the Works Information to the Site shall be read as references to the Working Area.

SECTION 1 GENERAL

1.1 DEFINITIONS

7 "Dredging" means the removal and disposal of silt and other deposits from the river banks and channel irrespective of the method used.

1.2 ACCOMMODATION FOR THE CONTRACT

5 All temporary offices, sanitary arrangements, stores, compounds, parking areas and the like necessary for use of the staff and workforce engaged in the completion of the works and correction of defects shall be provided, erected, constructed, maintained and subsequently removed by the Contractor.

6. The *Contractor* shall be responsible for the installation, maintenance and removal of all temporary site services required, including liaison with the relevant suppliers and payment of necessary fees and costs. The *Contractor* shall also be responsible for paying any Council Taxes due. Temporary site services shall include a potable water supply, sewage disposal and waste disposal.

7. The instruments provided by the *Contractor* for the proper setting out of the *works* shall be maintained in good working order and properly calibrated at all times and shall be available for the use of the *Employer* as required for checking the setting out or taking measurements.

8. The *Contractor* shall, whenever required during working hours, provide the *Employer* with such facilities and assistance as deemed necessary by the *Employer* for the taking of levels, checking dimensions, examining works and testing, sampling or monitoring related to the *works*. The *Contractor* shall provide a capable experienced person suitable for the task in question.

9. The *Contractor* shall provide and maintain a site office for the exclusive use of the *Employer* comprising:

- Office not less than $12m^2$
- Access to toilet facilities
- Table/desk with 4 chairs
- Minimum $4^{no.}$ 220-240V power points
- Secure, lockable doors with 2 sets of keys issued to the employer
- Adequate natural lighting and ventilation
- Electricity, heating and hot & cold potable water supply
- Appropriate fire fighting appliances

1.6 ENTRY ONTO THE SITE

6. The Employer will contact all landowners and tenants within the site in advance of the contract to agree the principles of entry. A statutory Notice of Entry will be served by the Employer to facilitate entry into working areas.
7. The Contractor shall deliver the works to have a minimum practicable period of occupation of any of the site.

1.7 SURVEY OF HIGHWAYS, PROPERTIES AND LAND

5. The surveys shall consist of digital photographs and a report clearly showing when and where the photographs were taken. Details of the general condition of the surveyed areas together with any specific areas of existing damage or degradation shall also be recorded.

1.8 LEVELS AND REFERENCE POINTS

5. All the levels shown on the drawings are shown in metres relative to Ordinance Survey GNSS Transformation OSTN15 and are based on the topographic survey undertaken as part of the Scheme's development. Unless demonstrated to the contrary, this survey shall be assumed to be an accurate record of the existing ground levels.

6. Before any dredging is commenced, the Contractor shall define, by appropriate means, the reference lines and levels for setting out the works. These reference points shall be regularly checked for accuracy throughout the Contract and where any displacement has occurred due to water action, vandalism, equipment movements, etc., shall be accurately reset in their former positions.

1.9 SITE FENCING AND GATES

7. The Contractor shall include his fencing and security proposals in his method statement

8. On removal of all temporary fencing, all post holes shall be immediately and properly infilled with materials to suit existing surfaces.

9. Where access to the site is required over unpaved land, the Contractor shall ensure that the land remains in a condition no worse than that which existed before commencement of the construction works. All damage caused to any part of the access route(s) and working areas shall be made good as and when directed by the Client.

10. Where additional strengthening of the temporary access and/or working area/compound is required beyond that afforded by the stripping of topsoil, a fabric sheet or Geogrid is to be laid on the sub-soil and then covered with a depth and grading of material to be designed by the Contractor and agreed by the Employer. Upon completion of the construction works the fabric and stone are to be removed and the ground reinstated to the requirements of Specification Clause 3.9.

1.10 INTERFERENCE WITH LAND INTERESTS

4. The works shall be programmed and executed in a manner that causes the least possible interference or disruption to the local community.

1.11 INTERFERENCE WITH ANY ACCESS TO PROPERTY, APPARATUS OR SERVICE

5 Vehicular access along all highways and droves shall be maintained at all times unless subject to a road closure notice. Works must be programmed and executed accordingly so as to cause the least possible disruption to traffic, farmers and the local community.

1.15 WORKS AFFECTING WATERCOURSES

6. The Contractor is to take measures to protect all personnel (employed and visiting the *site*), Plant, Materials and Equipment from harm or damage irrespective of the magnitude of a flood event.

1.17 APPARATUS OF STATUTORY UNDERTAKERS, HIGHWAY AND ROADS AUTHORITY AND OTHERS

5. Notwithstanding any information regarding apparatus supplied by or on behalf of the Client, the Contractor shall be responsible for ascertaining from inspection of the site, and from the respective supply utilities, other relevant companies and any public bodies, the position of all mains, pipes and cables. The Contractor shall carry out thorough searches, including the use on the site of electromagnetic or other suitable locating Equipment, followed by excavation by hand, to exactly locate all apparatus.

6. The Contractor shall exercise the greatest care during the construction of the works to avoid damage to or interference with any existing services and shall be responsible for any such damage caused by him or his agents either directly or arising indirectly from anything done or omitted to be done. The Contractor shall carry out all temporary works necessary to adequately support and protect any existing services.

7. The Contractor shall take any and all measures reasonably required by any Public or Statutory Authority for the support and full protection of its mains, pipe, cables and other apparatus during the progress of the construction works, and shall construct and provide to the satisfaction of the Authority concerned all works necessary for the prevention of damage or interruption of services. If any interruption of or delay to the provision of any service is caused the Contractor shall bear and pay the cost reasonably incurred by the Authority concerned in making good such damage and shall make full compensation to the Authority for any loss sustained by reason of such interruption or delay.

8. The Contractor shall make his own arrangements for any diversion or removal of existing services which he may require for his own convenience or because of his proposed method of working and shall, in all cases, inform the Employer in advance of his proposals.

1.18 TRAFFIC REQUIREMENTS

12. The Contractor shall include in his method statement proposals for:

    - the management of traffic arriving/leaving the site;
    - the management and movement of traffic around the *site*.

13. Due allowance should be made by the Contractor to keep any of the local Highways clear of any debris and mud from vehicles accessing and leaving the site and a methodology contained in his method statements. The Contractor will be directly responsible to the local Highways Authority in this respect.

1.19 EMERGENCY ARRANGEMENTS

3. The Contractor shall provide an Emergency Contact List to include at least two names of responsible representatives of the Contractor and telephone numbers at which they can be contacted at all times outside normal working hours. One of these telephone numbers should be that of the Contractor's Construction Manager.

1.22 CUSTOMER CARE

2 The Contractor shall be responsible for notifying local residents and The Local Authority's Environmental Health Officer of any unavoidable disruptive operations, particularly when these are to take place outside the normal working hours, and for fostering good public relations generally in respect of the works, copies shall be notified and available to the Client.

3 A contact name within the Contractor's organisation shall be provided to residents who would be available to deal with complaints or queries in relation to the works.

4 The Contractor is expected to work to the principles of the Considerate Constructor Scheme (www.ccscheme.org.uk) for the site and dealings with the public.

1.25 SUBMISSIONS TO THE CLIENT

1. The following information shall be submitted to the Client for approval, at 2 weeks before the start of work on site:

    - First Programme for acceptance (if different to that provided with his Tender)
    - Method Statement for the works (if different to that provided with his Tender)
    - CDM Construction Phase Plan (see item 1.34 below)
    - Any other information requested.

2. The following information shall be submitted to the Client for acceptance during the course of the construction works:

    - Method Statements for all types of work. Method statements shall be submitted at least 5 working days before the relevant work begins

- Details of any discussions with the landowner and tenant farmers
- Early warnings and compensation event notifications
- Delays experienced
- Health and Safety incidents
- Environmental incidents
- Any other information requested

1.26 SETTING OUT OF THE WORKS

1. The locations of all new works are shown as precisely as possible on the drawings. It is the responsibility of the Contractor to carry out all levelling and setting out required to complete the work in a satisfactory manner. The setting out of all works in respect of locations shall be agreed with the Client before commencement of the works. The responsibility for the setting out of the works in respect of the final levels shall remain with the Contractor.

1.27 TOLERANCES

1. Unless otherwise specified by the Works Information, the following tolerances on specified levels shall apply:

   Final dredged level (as shown by the immediate post dredge survey) within +/-150mm on a section. Average over all sections +/-100mm.

1.28 ENVIRONMENT AND SUSTAINABILITY

1. Specific environmental requirements for these works are detailed in Appendix E: Environmental Report
2. Activities within the watercourse shall be carried out in such a manner as to minimise environmental disturbance and in accordance with Contractor's Method Statements accepted by the Client.
3. The Client is committed to the environmental principles of stewardship and sustainability. The Contractor shall plan and order all his activities to assist the Client to honour these principles. In addition to this general requirement, particular areas for action are:

   - Avoidance of pollution of any waters (surface or underground).

   In the event of a watercourse being polluted as a result of his work, the Contractor shall be responsible for taking immediate action to prevent the pollution spreading downstream, and to advise the Client immediately. If it proves necessary for the Client to take action concerning any pollution of a watercourse due to the Contractor's works the cost of any such action will be charged to the Contractor. The Contractor shall also inform the Client immediately of any incident.

   and:

   - Avoidance of pollution of any land;
   - Preservation of flora and fauna;
   - Avoidance of nuisance of sounds, vibrations and dust;
   - Minimise energy and water use.

3. The Contractor shall demonstrate in his written Method Statement his proposals to minimise environmental impact and satisfy the above requirements. The Contractor shall submit all Method Statements to the Client

for acceptance. Reference shall be made to the Environment Agency Pollution Prevention Guidelines 1, 5, 6, 8 and 21. The following should be addressed in the Method Statement(s):

- Equipment which leaks any fuel, lubricant or hydraulic fluid shall not be used.
- Bio-degradable hydraulic fluid is mandatory
- Equipment shall be maintained to ensure efficiency and to minimise emissions.
- Equipment shall be steam cleaned prior to delivery to the *site*.
- Fuel and oil storage shall be away from watercourses, fully bunded to 110% of the volume stored and maintained in a secure and clean manner. Delivery and vent pipes shall terminate within the bund.
- Refueling or servicing of Equipment shall be carried out in designated locations away from watercourses.
- Refueling shall be supervised and shall be carried out by pumping through a trigger type delivery nozzle.
- An adequate supply of oil absorbent materials shall be readily available onsite at all times (e.g. in cab of Equipment).
- Any spillage shall be immediately contained, removed from the *site* and disposed to a licensed tip, the Client being promptly informed.
- Equipment shall be effectively silenced and shall comply with any stated requirements of the Local Authority as well as BS 5228-1: 1997: Noise control on construction and open sites.

5. Where materials arising from or required for the "Works" constitute Controlled Waste under the Environmental Protection Act 1990 (Sections 33 and 34), the Contractor shall provide the Client with a copy of the Carriers' licence to transport the materials, and copies of all Waste transfer notes. The Contractor shall retain a copy of all waste transfer notes onsite for inspection.

6. Imported soil conditioners shall be free from Peat and Coir, be manufactured from composted matter, recycled and renewable materials fully pasteurised and free from weed seeds, disease and fungal organisms. The Contractor shall provide details of any proposed soil conditioner for acceptance prior to commencement of landscaping works.

1.29 WATER VOLES

Water Voles are fully protected under Section 9 of the Wildlife and Countryside Act 1981, which makes it an offence to intentionally kill, injure or take (capture) a water vole, or intentionally or recklessly damage, destroy or obstruct access to any structure or place which water voles use for shelter or protection or disturb water voles while they are using such a place. Water Vole burrows and other activity has been detected on parts of the left bank where dredging is to take place. This work can be undertaken lawfully by application of the Natural England Class Licence CL24 (Copy included in Appendix E-Environmental Information). As soon as possible after 15th September the Contractor shall clear vegetation from the designated area to initiate water vole displacement and continue in accordance with the conditions of the class licence. Dredging work may not proceed on the left bank before the water vole displacement has been concluded.

1.30 BADGERS

Badgers are protected species and the Contractor must not disturb badger setts. Known locations of active badger setts in the area are shown on drawing GD06-18-103 in Appendix A. The Contractor must fence badger setts, without obstructing badger access, to exclude vehicles and prevent damage to badger setts. If the Contractor finds a badger sett during works, the Contractor must avoid working in the immediate vicinity of the sett and inform the Client, so an assessment can be made of the risks of disturbance and any required mitigation measures can be identified and implemented. Works may be carried out lawfully by application of the Natural England Class Licence CL27 (Copy included in Appendix E-Environmental Information). The Contractor shall not spread dredged material within 10m of an active badger sett.

1.31 OTTERS

Otters are protected species and the Contractor must not disturb otter Holts. The Client's Project Ecologist will provide the Contractor with the known locations of otter Holts in the area. The Contractor must fence otter Holts, without obstructing otter access, to exclude vehicles and prevent damage to Holts. If the Contractor finds an otter holt during works, the Contractor must avoid working in the immediate vicinity of the holt and inform Client, so an assessment can be made of the risks of disturbance and any required mitigation measures can be identified and implemented. The Contractor shall not spread dredged material within 10m of an otter Holt.

1.32 INVASIVE SPECIES

Invasive Species: The Client's Project Ecologist will undertake pre-construction checks of all working areas and land adjacent to working areas and provide the Contractor with the known locations of invasive species. The Contractor must ensure all dredging equipment (including boats) are not contaminated prior to use and will provide biosecurity measures such, as machinery cleaning, on site. If during works the Contractor finds either Giant Hogweed or Japanese Knotweed on site, the Contractor must avoid working in the immediate area and inform the Client, so an assessment can be made and any required mitigation measures can be identified and implemented.

1.33 REMOVAL OF UNSUITABLE PLANT

1. Where any Equipment brought by the Contractor onto the site is deemed by the Client to be unsuitable for any reason, inter alia:

   (a) it is causing or is likely to cause damage due to weight;

   (b) it is a source of pollution such as spillage of oil;

   (c) it is the source of excessive noise;

   (d) it does not comply with the relevant safety regulation

   then the Client shall have the power to order the removal of such Equipment .

1.34 CONSTRUCTION (DESIGN AND MANAGEMENT) REGULATIONS (CDM)

1. The CDM Pre Construction Information prepared for these works is provided in Appendix C.
2. At least 10 days before the commencement of the construction works the Contractor shall produce a CDM Construction Phase Plan, which will include but not limited to, a Traffic Management Plan, Emergency Plan and the initial site work method statements and risk assessments. The Construction Phase Plan will be reviewed by the Principal Designer. Site work cannot start until the Plan has been accepted by the Client.
3. Subsequent method statements will be reviewed by the Client. The Contractor shall ensure that all method statements are submitted at least 5 days before the work activity is due to commence.
4. The Contractor shall provide the Client with two copies of all information which is required to be placed on the H&S File. It is proposed that a draft of the Health & Safety File will be developed as the work progresses to expedite the production of the final document.

1.35 STATEMENT OF ACCOUNT

1. The Contractor's statements shall detail the following:
   - Work done against the Price List
   - Total value of work done

- Agreed Compensation Events and Day Work items

2. All evidence of expenditure by the Contractor to carry out the construction works shall be held onsite by the Contractor and shall be available for inspection by the Client at any time within working hours.

SECTION 2 MATERIALS

2.40 FIELD GATES

3. Gates shall be securely fixed to prevent removal, e.g. by using opposing hinge bolts.

2.89 PERMANENT FENCING

2. Timber post and rail fencing shall be type SPR 13/4 as specified in BS 1722 Part 7.
3. All posts are to be treated with waterborne preservative by impregnation under pressure or by hot and cold treatment unless cut from the heartwood of oak, larch or sweet chestnut.
4. Staples are to be galvanised 38 mm long x No 8 SWG.
5. Strainers are to be galvanised 250 mm x 9 mm eyebolts.

2.126 TIMBER AND PRESERVATION OF TIMBER

4. Timber preservative treatment shall be carried out away from watercourses and in a manner to avoid any spillage or loss. Creosote shall not be used unless the Contractor can demonstrate that no viable alternative exists.
5. Details of all timber to be used in the works shall be submitted to the Client for acceptance.

SECTION 3 EXCAVATION, BACKFILLING AND RESTORATION

3.9 REINSTATEMENT OF UNPAVED LAND

6. A minimum of 100mm compacted depth of topsoil shall be placed wherever grass seeding is required and lightly compacted with a tracked excavator where slopes allow or the back of a bucket on slopes.
7. The topsoil shall be kept free from weeds and grasses by light cultivation or treatment with a foliar acting herbicide accepted for use near watercourses by the Environment Agency until grass cover has been established or the area is handed back to the landowner for his/her own reinstatement.
8. Prior to grass seeding any stones having one linear dimension in excess of 50 mm shall be removed and disposed of to a location agreed with the Client. The surface should be lightly and uniformly firmed and reduced to a friable tilth by raking or harrowing. An appropriate pre-germination fertiliser shall be applied at the prescribed rates in accordance with Clause 2.39.
9. Grass seed mixture type in accordance with Clause 2.56 shall be sown at the prescribed rates after pre-seeding fertiliser application (see Clause 2.39). Immediately after the application of grass seed, the reinstated area will be lightly harrowed and rolled.
10. Any areas where the seed has not taken will be re-seeded by the Contractor

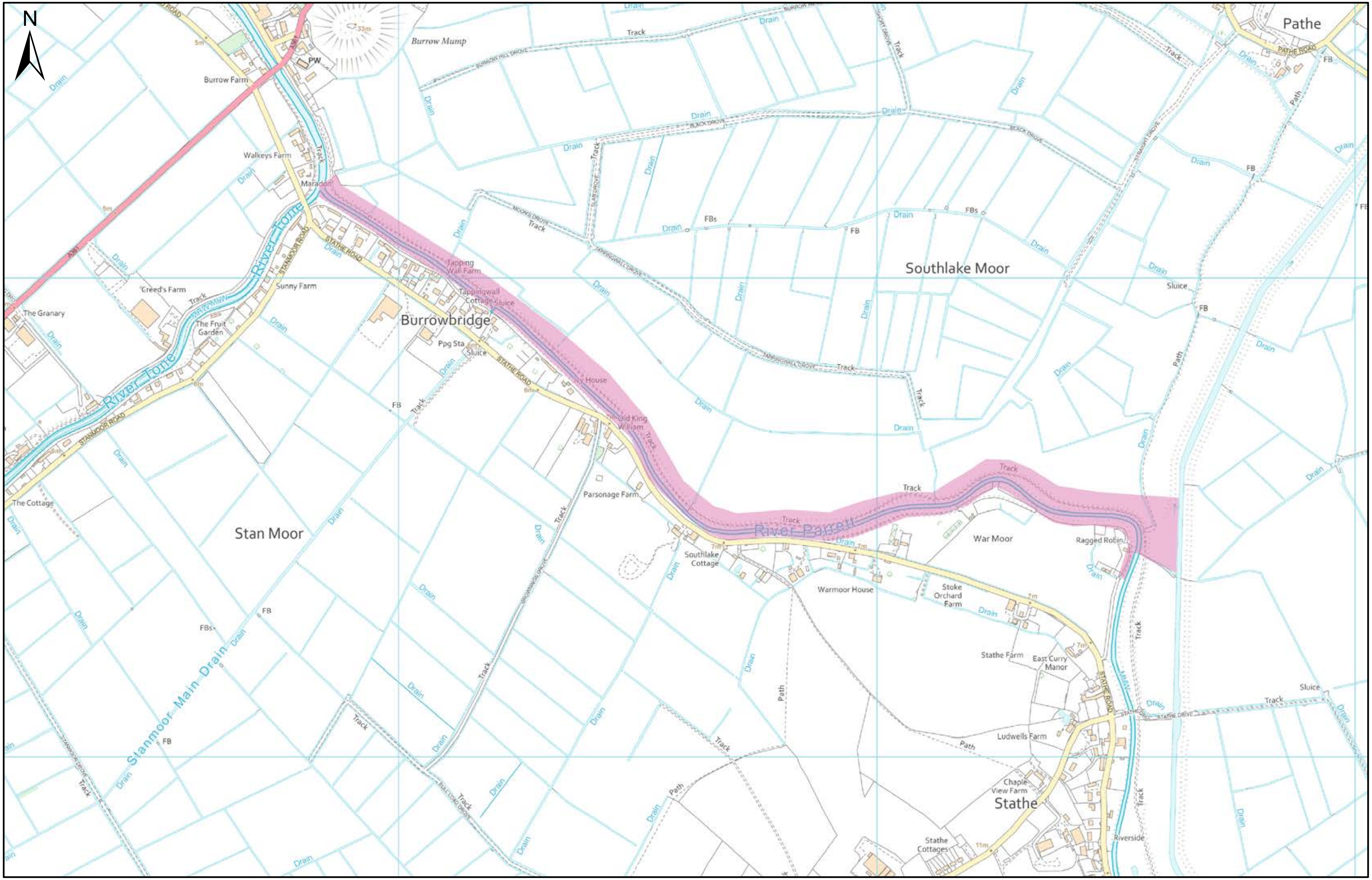
3.10 TREES

5. Where small trees, hedgerows or large woody shrubs, having an individual girth less than 500mm measured 1m above ground, are to be removed they shall be clearly identified and confirmed for removal by the project manager.
6. Roots shall be thoroughly grubbed out and all arisings removed from site.
7. Holes shall be backfilled with well compacted impermeable material and grass cover established to provide a uniform well-grassed surface to resist erosion from overflow.

SECTION 7 TESTING AND DISINFECTION

7.19 TESTING DISOLVED OXYGEN, TEMPERATURE AND AMMONIA

1. Testing is to be carried out at an agreed mid-channel position downstream of the working area.
2. Testing is to use properly calibrated equipment which is appropriate for the purpose.
3. Testing frequency to be not less than every 15 minutes.
4. Testing to commence at least 24 hours before any dredging commences and continue until at least 24 hours after all dredging has been completed.
5. Test thresholds are:
    - Water temperature exceeding 15°C
    - Dissolved oxygen outside the range 30% to 120%
6. Test time, date, location and readings are to be recorded with data loggers linked to a telemetry system and alarms for threshold exceedance.
7. Satisfactory operation of the testing, recording and telemetry equipment to be checked at least daily during dredging operations.



SOMERSET DRAINAGE BOARDS CONSORTIUM
AXE BRUE AND PARRETT INTERNAL DRAINAGE BOARDS

Oath to Burrowbridge dredge - working area

Appendix 2

Technical note: 2018 pre-dredge River Parrett fish surveys

Dr Andrew Pledger

Quantitative fish surveys were conducted under baseflow conditions July-September 2018 on the River Parrett. Sites were located 1) immediately upstream of the Tone/Parrett confluence (ST 35845 30178), 2) approximately halfway between the Tone/Parrett confluence and West Sedgemoor pumping station (ST 37544 29426) and 3) adjacent to West Sedgemoor pumping station (ST 37599 28647). Two three-pass electric fishing surveys were completed per site and prior to surveying on each occasion, a 100-m reach was isolated with stop nets. Three-pass removal sampling was carried out using a pulsed FC3000GP252 electric fishing machine in conjunction with an EC4000 frame electric fishing generator, 2 anodes (10m cable) and a cathode with 6m cable and 4m heavy duty tinned copper braid. Additional pertinent survey equipment included a Rigiflex Aquapeche 370 boat, 13 x 2 m stop nets, aerators/ oxygen cylinders with regulators, fish holding tanks and 17.5” D standard steel dip nets. Captured fish were speciated, weighed and measured after each pass and fish were returned up/downstream of the survey reach after processing.

A total of 766 fish, representing 13 species (Thin-lipped Grey Mullet *Chelon ramada*: total abundance = 2, mean total length = 7.6 ± 0.8 cm; Tench *Tinca tinca:* total abundance = 1, mean total length = 13.50 ± 0 cm; Common bleak *Alburnus alburnus*: total abundance = 248, mean total length = 9.0 ± 2.6 cm; Roach *Rutilus rutilus*: total abundance = 183, mean total length = 12.6 ± 3.6 cm; Gudgeon *Gobio gobio*: total abundance = 91, mean total length = 9.8 ± 1.9 cm; Pike *Esox lucius*: total abundance = 6, mean total length = 49 ± 20.4 cm; Common Bream *Abramis brama*: total abundance = 54, mean total length = 14.9 ± 6.1 cm; Chub *Squalius cehalus*: total abundance = 86, mean total length = 15.3 ± 8.6 cm; Flounder *Paralichthys dentatus*: total abundance = 7, mean total length = 7.1 ± 2.5 cm; European Eel *Anguilla Anguilla*: total abundance = 48, mean total length = 22.9 ± 5.8 cm; Perch *Perca fluviatilis*: total abundance = 26, mean total length = 15.2 ± 2.7 cm; Roach *Rutilus rutilus* - Common Bream *Abramis brama* hybrid: total abundance = 12, mean total length = 20.2 ± 6.2 cm; Rudd *Scardinius erythrophthalmus*: total abundance = 2, mean total length = 15.1 ± 1.3 cm; ± STDEV) were recorded during the multi-pass electric fishing surveys. As expected, the majority of captured individuals (757, representing 99% of the total catch) were freshwater rather than marine fish. Fish communities were similar between sites with mean abundance and species richness values calculated as 134 and 8, 94.5 and 8 and 154.5 and 8 for sites 1, 2 and 3, respectively (Figure 1). On average, common Bleak *Alburnus alburnus*, Roach *Rutilus rutilus*, Gudgeon *Gobio gobio*, Common Bream *Abramis brama*, Chub *Squalius cehalus* and European Eel *Anguilla Anguilla* were most prevalent, in terms of abundance, across sites (Figure 2). Piscivores, including Pike *Esox Lucius*, Chub *Squalis cephalus* and Perch *Perca fluviatilis* were present at each of the surveyed sites. The European Eel *Anguilla anguilla* was observed at each of the sites with the greatest mean abundance (21; Figure 2) recorded near the confluence, at site 3.

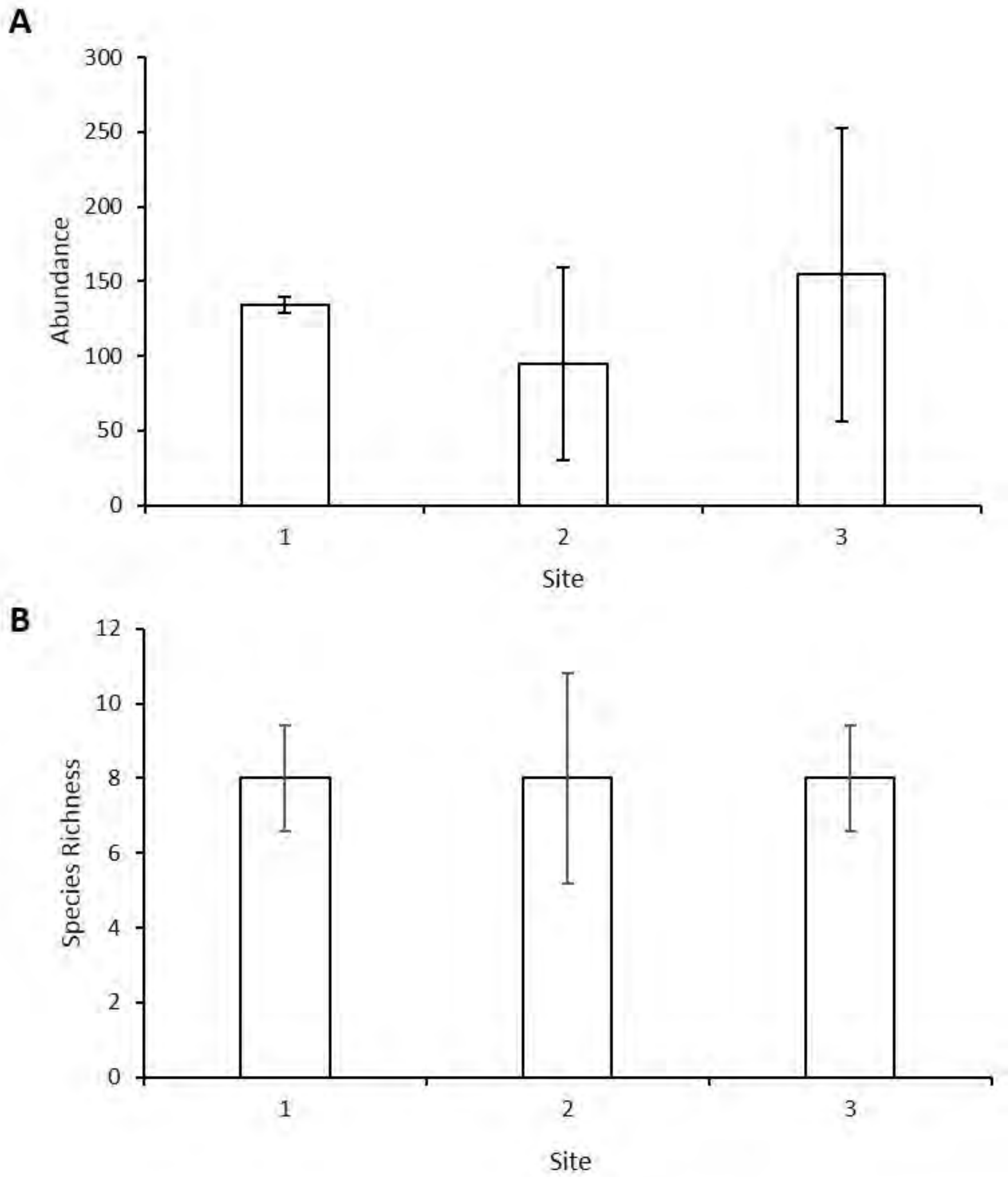


Figure 1: A total abundance and **B** species richness data derived from fish sampling at sites 1, 2 and 3. Presented are site means (n = 2) ± STDEV.

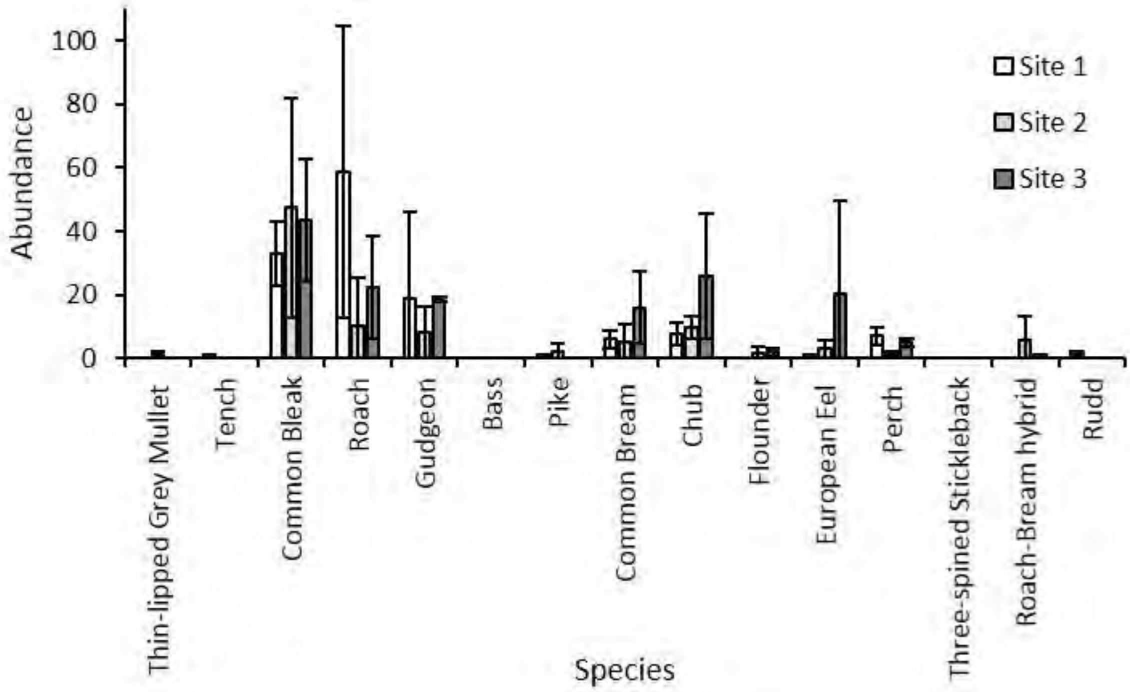


Figure 2: Abundance per species data derived from fish sampling at sites 1, 2 and 3. Presented are site means (n = 2) ± STDEV.

Interim report: Ecological Impacts of Water Injection Dredging, Somerset Levels

Dr Andrew Pledger, Dr Dapeng Yu, Prof. Paul Wood, Dr David Ryves.
Department of Geography, Centre for Hydrology and Ecosystem Science, Loughborough University, Leicestershire, LE11 3TU, UK.

Corresponding author: Dr Andrew Pledger, a.g.pledger@lboro.ac.uk

1.0 Introduction

This interim report presents some preliminary findings from the 2016/2017 River Parrett ecological monitoring program, commissioned by the Somerset Drainage Boards Consortium. The report considers the effects of water injection dredging on fish health and mortality during operations. In addition, we consider the pre- and immediate post-dredging effects on fish community composition, macroinvertebrate communities recorded at the channel margins and the benthic macroinvertebrate communities.

2.0 Effects of water injection dredging on fish health and mortality

236 fish, representing 4 species (Thinlip grey mullet *Chelon Ramada*: abundance = 91, mean total length = 74 ± 1 mm; Gudgeon *Gobio gobio*: abundance = 16, mean total length = 38 ± 5 mm; European Bass *Dicentrarchus labrax*: abundance = 9, mean total length = 35 ± 5 mm; Chub *Squalius cephalus*: abundance = 2, mean total length = 175 ± 47 mm; ± STDEV) were captured via pelagic trawling at a downstream location during the dredging operation. *C. ramada* were most abundant, emphasising importance of the system for marine fish. All captured fish were alive, showed no obvious signs of dredging-induced stress and were returned unharmed post-processing. The caudal fins of seven fish, representing a small proportion (8.26%) of the total catch, were either split or torn but injuries did not appear to influence swimming capabilities of fish. The injuries incurred by these fish were unlikely to be the result of dredging (although this cannot be completely ruled out), and are typical in nature and extent to those observed in other, similar fisheries. No further signs of fish damage or ill health were observed.

3.0 Effects of water injection dredging on fish community characteristics

Sampling occurred at an upstream site (control), within the managed area (treatment) and downstream of the dredge site (downstream) on three occasions before (pre) and after (post) dredging. However, at this point in time only pre- and immediately post-dredging control and treatment data are considered. On each occasion, seine netting was undertaken at each site on the two slack tides which marked the transitions between flood and ebb tides and ebb and flood tides.

During the pre-dredging survey, 179 and 92 individuals, corresponding to 12 and 7 species, were caught at the control and treatment sites respectively. Both fresh and marine water species were recorded and included Common Bleak (*Alburnus alburnus*), Roach (*Ruttilus ruttilus*), European Eel (*Anguilla Anguilla*), Bass (*Dicentrarchus labrax*) and Thin-lipped Grey Mullet (*Chelon ramada*) (full species list included as appendix 1). The majority of the marine fish captured were juveniles, highlighting the importance of the system as a nursery habitat.

There was a significant decrease in fish abundance following operations at the dredged site (One-way Anova: F1 = 8.300, P = 0.028), with mean values declining from 15.3 to 3 (Figure 1a). Dredging did not have a statistically significant effect on species richness or Shannon Weiner, Simpson or Berger Parker biodiversity indices (Figure1b-e). Post-dredging, fish abundances within the upstream (control) site were also significantly reduced (One-Way Anova: F1 = 8.620, P = 0.026), with mean values declining from around 30 to 11 individuals (Figure 2a). No other parameters or biotic indices were significantly affected at the control site (Figure 2b-e). Reductions in fish abundance within the managed area and at the control site (due to close proximity to the dredge reach) were likely due to fish avoidance of the dredging vessel.

4.0 Effects of WID on marginal macroinvertebrate communities

Marginal macroinvertebrate communities were monitored on three occasions before (pre) and after (post) dredging at 6 sites. Two of these sites were located upstream (control) and within (treatment) the dredge reach and were consistent with those utilised during seine netting. Only data collected from the two sites (control and treatment), as per Section 3.0, are considered here.

At the treatment site, dredging was associated with significant changes in Simpson's (One-Way Anova: $F_2 = 167.627$, $P = 0.049$) and Berger Parker (One-Way Anova: $F_2 = 258.364$, $P = 0.04$) indices (Figure 3d,e). At the control site, abundance was significantly lower in the post dredging period (One-Way Anova: $F_2 = 2204.32$, $P = 0.014$; Figure 4a) but reflects the trend observed at other sites. Data suggest changes in community structure (Simpson's Diversity and Berger Parker) were the result of dredging at the treatment site but the overall effect was limited on invertebrate abundance.

5.0 Effects of WID on benthic macroinvertebrate communities

Benthic samples from the main channel yielded low abundances where samples were taken from soft mobile fine sediments. However, in a few places where the sample was clearly collected from a more compacted/ stable bed, more individuals were observed. Diversity was low in the main channel compared to the margins primarily as a function of instability of the habitat in the main channel combined with the increased risk of predation due to limited refuge availability. It is reasonable to assume that due to low numbers of invertebrates within pre-management samples, dredging had limited effect on the abundance and diversity of the community for the pre- and post-dredging periods, although this assertion requires testing once all samples have been processed.

6.0 Conclusion

Dredging had an effect on some of the measured ecological parameters presented here. Specifically, significant changes in fish abundance and invertebrate community structure characteristics were detected for the control and/or treatment sites. Importantly, no dead fish were caught and submitted for post-mortem examination during the dredging program suggesting either: 1) water physico-chemistry was suitable for fish life throughout the operation; or 2) fish were capable of avoiding the dredging vessel and associated sediment plume. Reductions in abundance at both control and treatment sites support the argument for fish avoidance of the dredging vessel. Further analysis is required to better understand the causes of community changes to assess whether these were in response to management or other natural biotic/ abiotic factors.

6.0 Figures

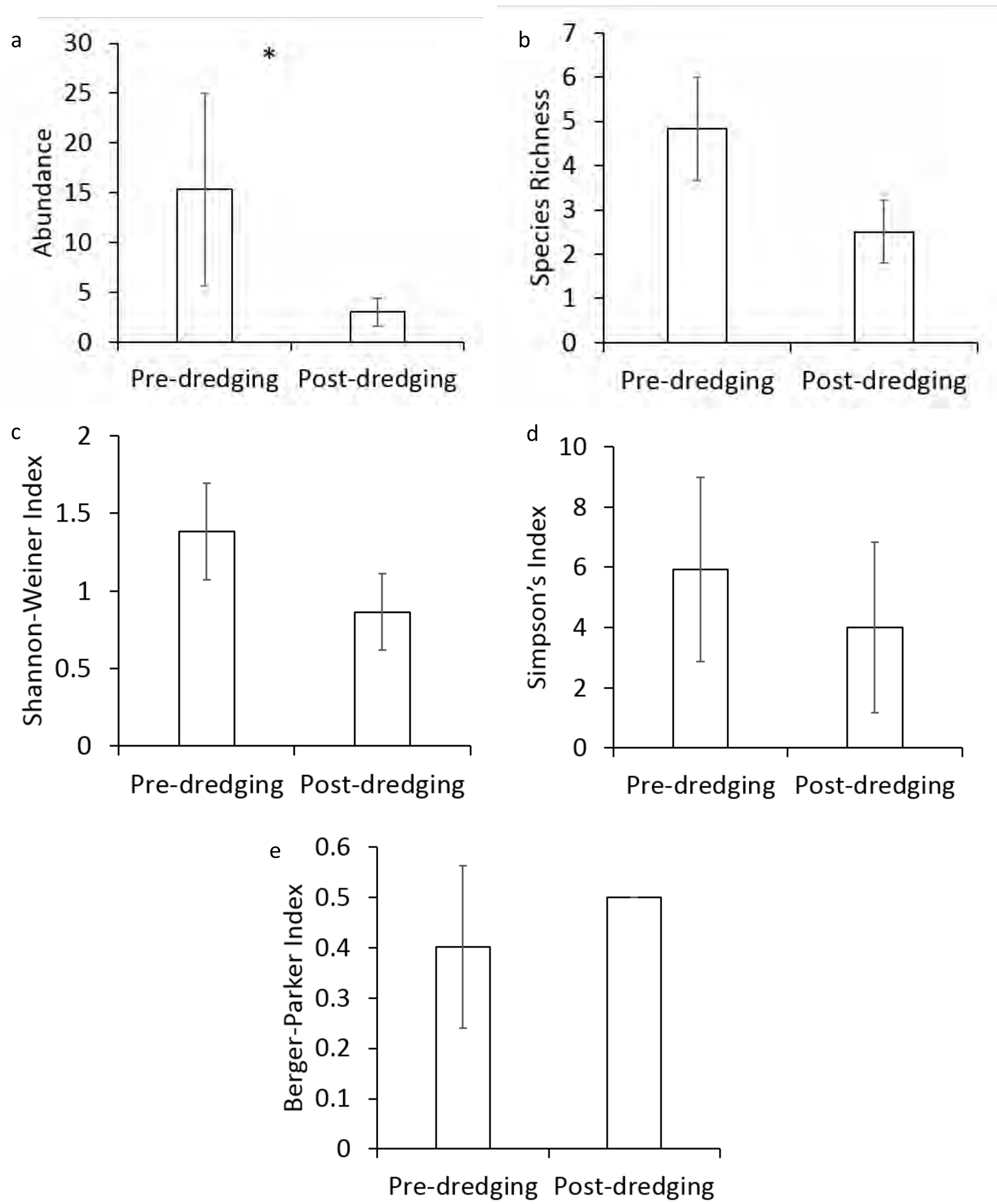


Figure 1: a) Abundance, b) species richness, c) Shannon Weiner, d) Simpson's index and e) Berger Parker data derived from fish sampling at the dredged site, before and immediately after management. Significant differences indicated by asterisks above bars.

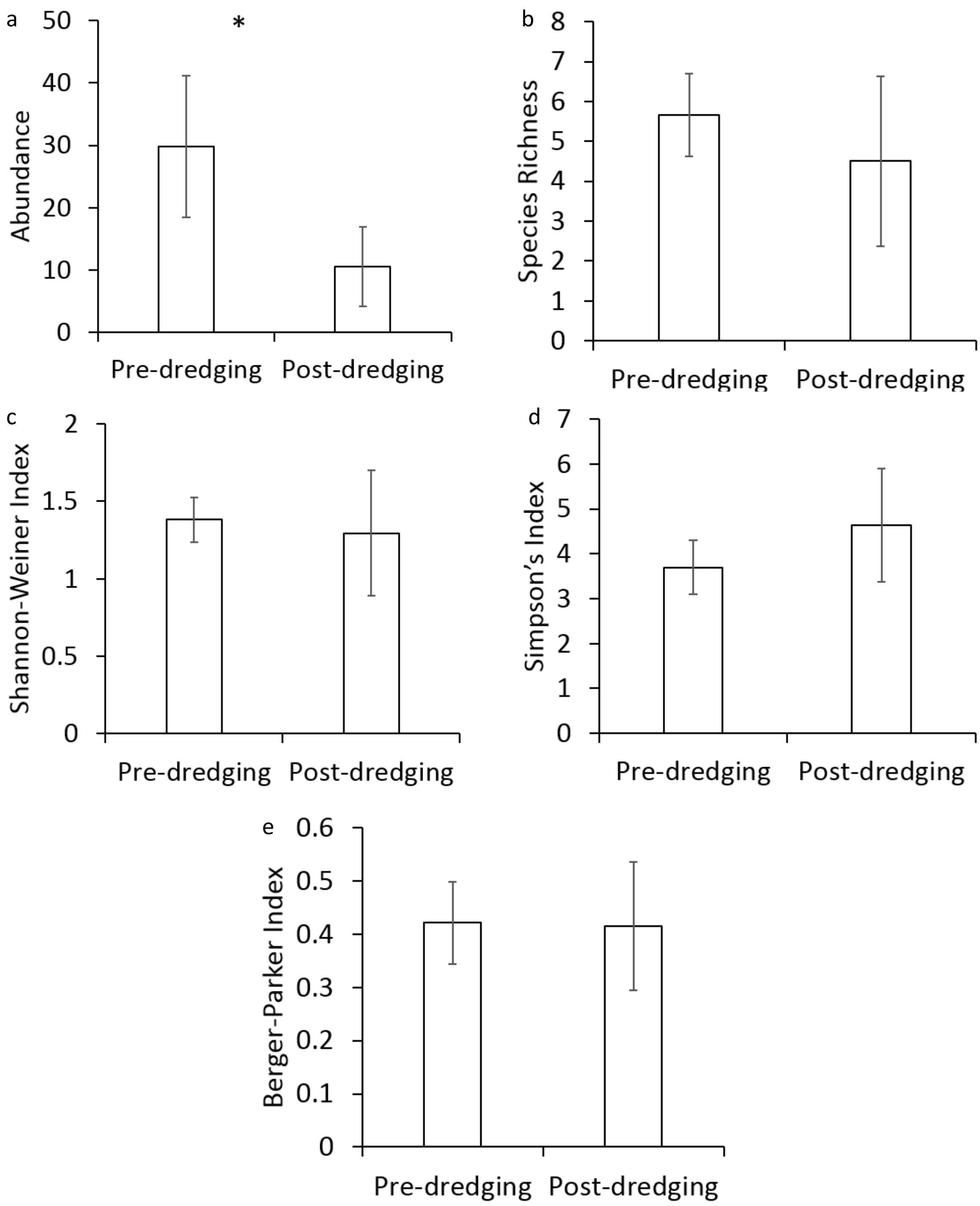


Figure 2: a) Abundance, b) species richness, c) Shannon Weiner, d) Simpson's index and e) Berger Parker data derived from fish sampling at the control site, before and immediately after management. Significant differences indicated by asterisks above bars.

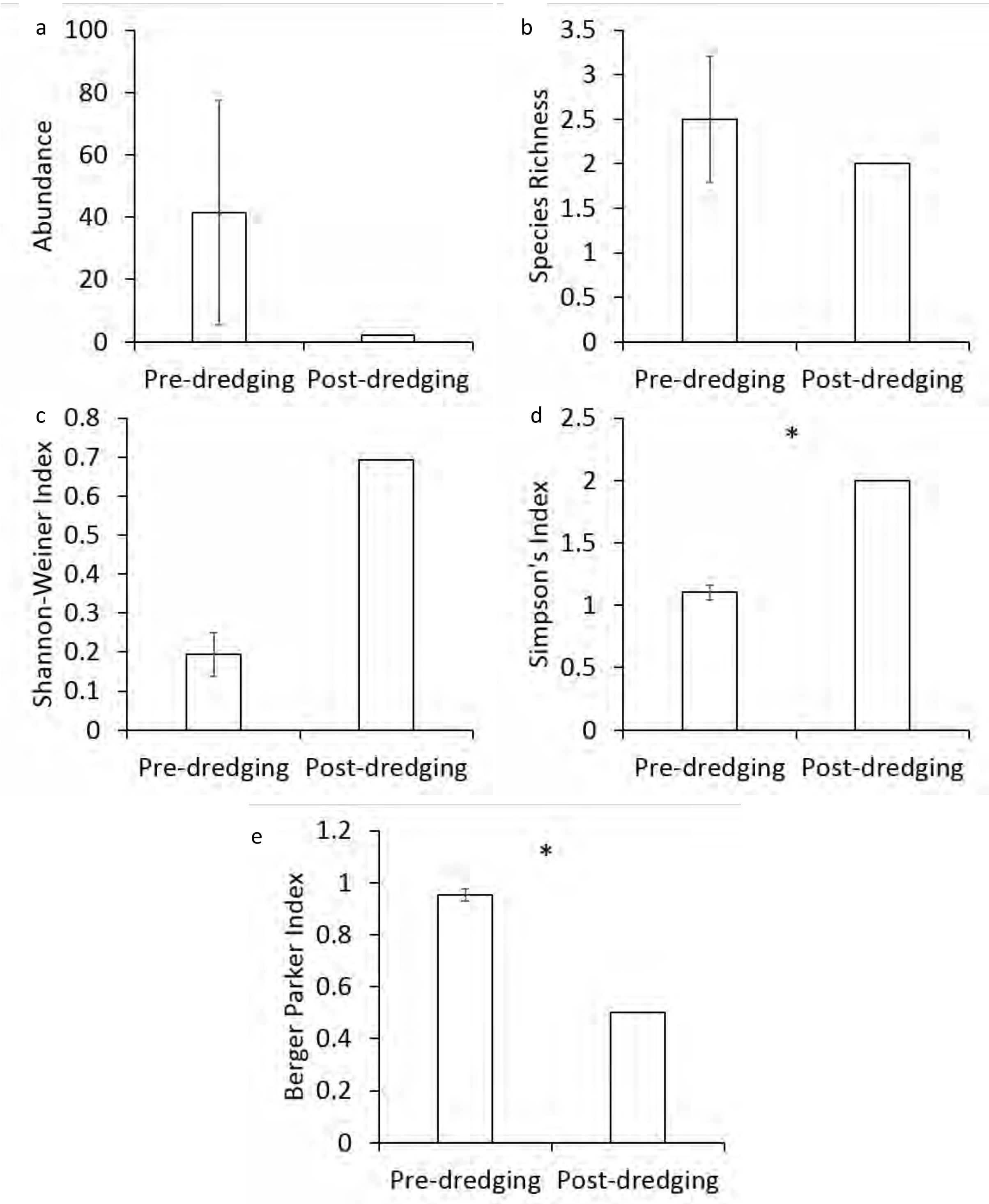


Figure 3: a) Abundance, b) species richness, c) Shannon Weiner, d) Simpson's index and e) Berger Parker data derived from marginal invertebrate sampling at the dredged site, before and immediately after management. Significant differences indicated by asterisks above bars.

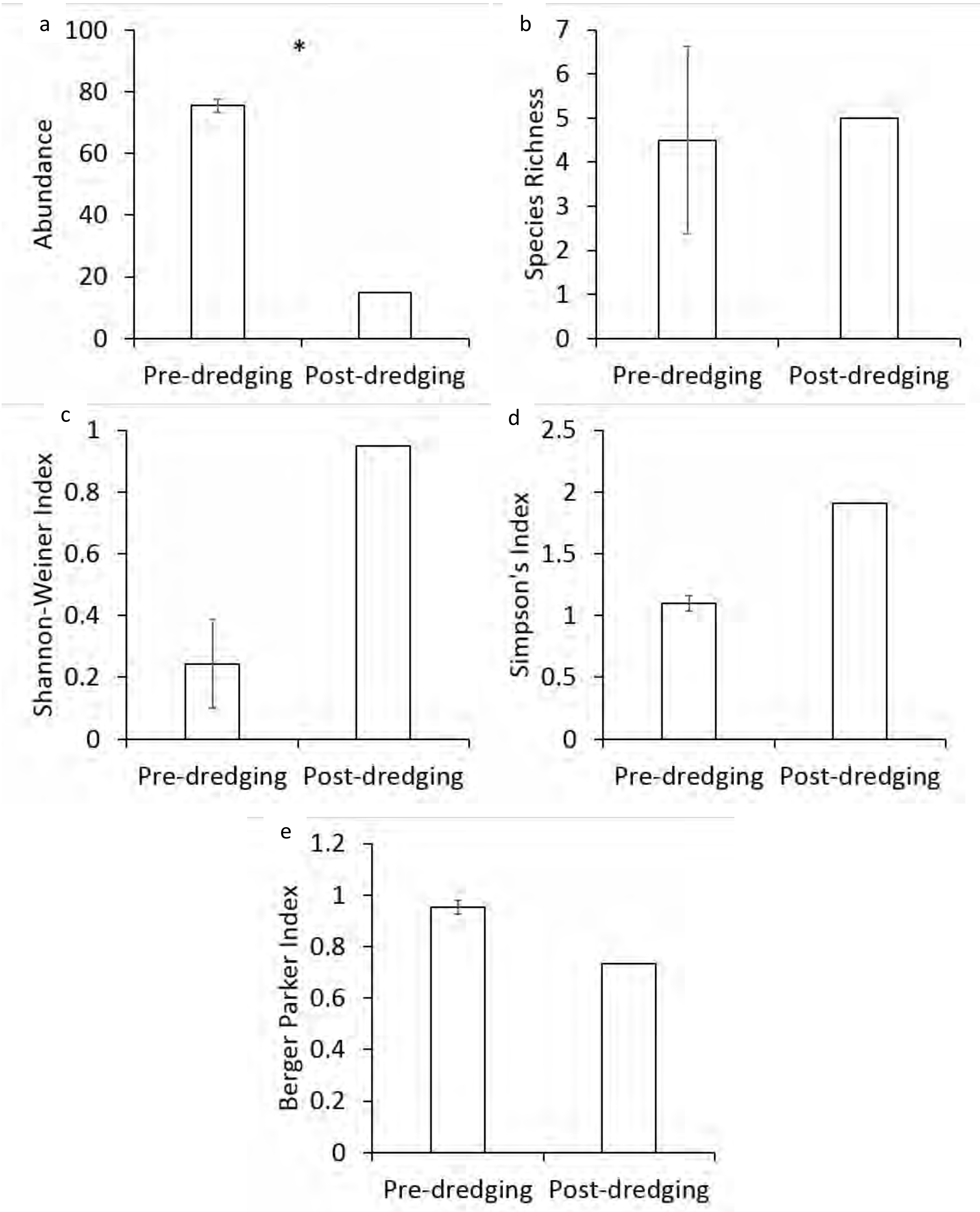


Figure 4: a) Abundance, b) species richness, c) Shannon Weiner, d) Simpson index and e) Berger Parker data derived from marginal invertebrate sampling at the control site, before and immediately after management. Significant differences indicated by asterisks above bars.

7.0 Appendices

Appendix 1. List of species captured during pre- and immediately post-dredging fish sampling.

Thin-lipped Grey Mullet *Chelon ramada*

Common Bleak *Alburnus alburnus*

Roach *Rutilus rutilus*

Gudgeon *Gobio gobio*

Bass *Dicentrarchus labrax*

Pike *Esox Lucius*

Common Bream *Abramis Brama*

Chub *Squalius cephalus*

Flounder *Paralichthys dentatus*

European Eel *Anguilla Anguilla*

Perch *Perca fluviatilis*

Three-spined Stickleback *Gasterosteus aculeatus*

Rudd *Scardinius erythrophthalmus*

Report to: -
Somerset Drainage Boards Consortium
Bradbury House
33-34 Market Street
Highbridge
TA9 3BW

July 2018 – v.6

RESULTS OF A SURVEY FOR HAIRY CLICK-BEETLE *SYNAPTUS FILIFORMIS* ON THE RIVER PARRETT, SOMERSET

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AEcol Ecological Consultants

Unit 14B The Avenue
High Street
Bridgwater TA6 3QE
www.aecol.co.uk
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APPENDIX A. RARITY STATUS CATEGORIES, DEFINITIONS & CRITERIA **36**

Report author & final proof: James McGill PhD.
Review & initial proof: Henry Andrews MSc MCIEEM.

RESULTS OF A SURVEY FOR THE HAIRY CLICK-BEETLE *SYNAPTUS FILIFORMIS* ON THE RIVER PARRETT IN SOMERSET

1. SUMMARY

1.1.1 The River Parrett flows through the counties of Dorset and Somerset in South West England. From its source in the Thorney Mills springs in the hills around Chedington in Dorset, the river assumes a broadly north-western flow through Somerset and the Somerset Levels to its mouth at Burnham-on-Sea.

1.1.2 Dredging is proposed within the Somerset section of the river, upstream from Burrowbridge. This section is known to hold a population of the hairy click-beetle *Synaptus filiformis*.

1.1.3 The UK population of the hairy click-beetle is considered 'Endangered' under pre-1994 criteria defined by the International Union for Conservation of Nature (IUCN) and is listed as a Section 41 Species of Priority Importance under the criteria of the *Natural Environment and Rural Communities (NERC) Act 2006*.

1.1.4 In order to better understand the current status of the hairy click-beetle on the River Parrett, and thereby inform a due-diligence safeguarding strategy to mitigate the impacts of the dredging operation upon the population, AEcol were commissioned by the Somerset Drainage Boards Consortium to establish the status of the species within seven locations where there are historic records.

1.1.5 The survey was performed by AEcol in-house entomologist, Dr James McGill, on three dates, comprising: 21st, 22nd and 23rd May 2018 and recorded 26 adults from 21 locations along the River Parrett between 500 m downstream of Oath Lock and 250 m downstream of Burrowbridge. The species was found to be associated with shallowly sloping tidal terraces, where dense stands of reed canary-grass are subject to flooding on the highest tides. Of an overall seven locations in which the species has historically occurred, it was recorded at three in 2018.

1.1.6 Bank reprofiling can be predicted to have a significant impact upon the hairy click-beetle population. This is based on the unmitigated dredging plans. Mitigation is proposed to ameliorate these effects, although the methods are untested and their efficacy is unknown. Therefore, a surveillance programme is also recommended to attempt to assess the effect of the dredging impacts on the species status in the longer term and explore the possibility of capturing larvae in baited traps.

Section 1 – End

2. BACKGROUND

2.1.1 Dredging is proposed within the Somerset section of the River Parrett, upstream from Burrowbridge. This section of the river is known to hold a population of the hairy click-beetle.

2.2 The hairy click-beetle

Description

2.2.1 The adult hairy click-beetle is typically 9-12 mm in length and covered with greyish pubescence. It is fully-winged. An image of an adult is provided at Photo 1.

Photo 1. Adult hairy click-beetle © W.Urwin

Ecology

2.2.2 Hairy click-beetle larvae are thought to be herbivorous root-feeders (although the possibility that they might be omnivorous has not yet been excluded) and in Britain, all records of adult hairy click-beetle have been made in association with reed canary-grass *Phalaris arundinacea* and common reed *Phragmites australis* (Foster *et al*. 2007). Based on a study by Mendel (2003a) it is thought that, as adults are active in May and June, eggs are laid at this time. Pupation takes place in late summer or early autumn of the second or third year after the eggs were laid and the larvae spend 2-3 years around the roots of the host grass. Adults emerge in early autumn but remain in the soil until the following May or June.

Phase 1 habitats occupied

2.2.3 All records of hairy click-beetle have been made in *F2.1 – Swamp, marginal and inundation / Marginal and inundation / Marginal vegetation*. However, within this broad habitat type the species is restricted to tall vegetation encompassing the probable larval food-plants, growing along rivers with brackish influence.

Conservation status

2.2.4 The UK population of the hairy click-beetle is considered 'Endangered' under the pre-1994 criteria defined by the International Union for Conservation of Nature (IUCN) (see Appendix A for full criteria) and is listed as Section 41 Species of Priority Importance under the criteria of the *Natural Environment and Rural Communities (NERC) Act 2006*.

Distribution

2.2.5 Hairy click-beetle has always had a very limited distribution in the British Isles. Since 1900, published localities have been limited to five locations, comprising: Walton/Sunbury on the River Thames (Fowler & Donisthorpe 1913 – N.B. not recorded since); the River Severn in Gloucestershire (Alexander 2007); the River Wye in Monmouthshire (Mendel 2003b); Rusland Pool in Cumbria (Read 2004, Foster 2007); and the River Parrett in Somerset (Payne 1977).

2.2.6 All Somerset records of the species occur on the River Parrett. The River Parrett flows through the counties of Dorset and Somerset in South West England. From its source in the Thorney Mills springs in the hills around Chedington in Dorset, the river assumes a broadly north-western flow through Somerset and the Somerset Levels to its mouth at Burnham-on-Sea. The upper tidal limit of the river is at Oath and it may be that this delineates the upper range of the hairy click-beetle.

2.2.7 Based on previous records, the potential range occupied by hairy click-beetle on the banks of the River Parrett in Somerset extends over approximately 4.5 km between Oath (the upper tidal limit of the River Parrett) at Ordnance Survey grid reference ST 38309 27880, and Burrowbridge at ST 35717 30521.

2.3 Instruction

2.3.1 In order to better understand the current status of the hairy click-beetle on the River Parrett, and thereby inform a due-diligence safeguarding strategy to mitigate the impacts of the dredging operation upon the population, AEcol were commissioned by the Somerset Drainage Boards Consortium to establish the status of the species within seven locations in which it has been historically thought to occur, and other sections of the river within the range of these records.

Section 2 – End

3. DESK-STUDY

Pre-existing species information

3.1.1 The Environment Agency supplied seven locations on the River Parrett where hairy click-beetle has been encountered, comprising: -

1. Red Hill junction;
2. Stathe Cottage;
3. Stathe Bridge: -
    a. West bank; and
    b. East bank.
4. Parrett Cottage;
5. Parsonage Farm;
6. Walkeys Farm; and
7. Riverside Road.

3.1.2 The locations that the species has occurred in historically are shown at Figure 1.

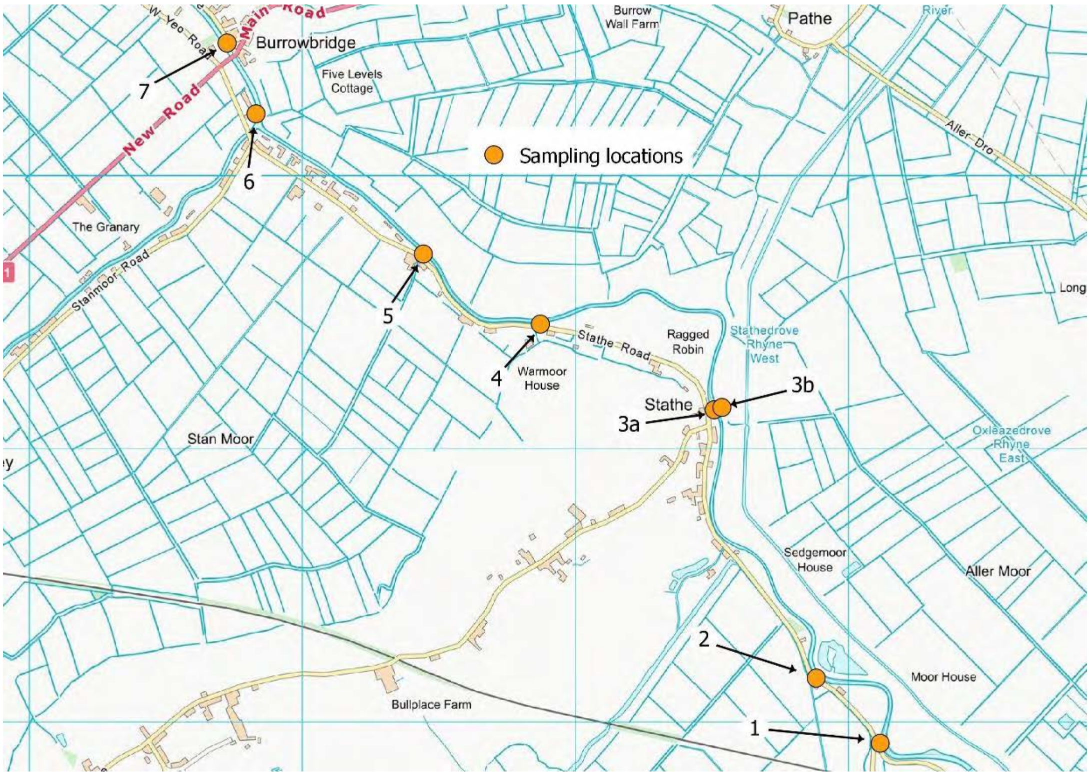

Figure 1. Locations in which hairy click-beetle records have been historically made on the River Parrett.

3.1.3 The Environment Agency performs surveillance at locations 6 and 7 annually but has only recorded individual beetles at location 6 within the past nine years. Unfortunately, the data provided were incomplete and lacked the name of the recorder and the dates the species was encountered. No meaningful negative data was provided (i.e. when surveys might have been performed and the species not encountered). However, Somerset Environmental Records Centre may hold additional data.

Section 3 – End

4. STATUS ASSESSMENT

4.1 Surveyor

4.1.1 The status assessment was performed by AEcol's in-house entomologist, Dr James McGill.

4.1.2 James has completed surveys of terrestrial and freshwater invertebrate assemblages for Ecological Impact Assessment, and Biodiversity Action Plan (BAP) species surveys, and his doctoral thesis investigated outcomes of conservation management and habitat creation for assemblages of invertebrates associated with Open Mosaic Habitat on Previously Developed Land (McGill 2018).

4.2 Objectives of the status assessment

4.2.1 Status assessment objectives were threefold, comprising: -

1. Establish presence/absence of hairy click-beetle at the locations along the River Parrett where it has historically been recorded;

2. Where access was practicable, establish the status of the species across a wider area, including the dredging zone where possible. The overall sampling area extended from 250 m upstream of the Parrett/Tone confluence, 250 m along the Parrett downstream of the confluence, and 200 m upstream of the dredging location. Where access for sweep net survey was not practicable, the habitat was to be assessed visually;

   and

3. Provide advice on mitigation to protect known populations of hairy click-beetle during the dredging programme.

4.3 Sampling methods

4.3.1 In accordance with recommended best practice guidance, as set out by Mendel (2003a) and Foster *et al*. (2007), the status assessment methods comprised: -

- Sweep-netting targeting hairy click-beetle adults; and
- Soil sampling targeting hairy click-beetle larvae.

Sweep-netting

4.3.2 Sweep-netting involves passing a sweep-net through vegetation in a figure-of-eight motion (Drake *et al.* 2007). The net was 50 cm in diameter and 50 cm in depth, made of stout canvas, to sample dense stands of reed canary-grass.

4.3.3 Sweep-net samples were taken continuously along the river bank through reed canary-grass, keeping the net low in the vegetation while walking at a moderate pace. The invertebrates captured were inspected every 10 sweeps. If any hairy click-beetles were swept, a grid reference was recorded at the middle of the route travelled during the previous 10 sweeps.

Soil-sampling

4.3.4 Soil-dwelling invertebrates can be sought by crumbling and sieving the organic soil horizons. As research has identified dense reed canary-grass above the frequently flooded area of soft silt in the lower channel as productive for hairy click-beetle in the soil (Mendel, 2003a), soil sampling was performed in the locations in which the species has historically been recorded. 'Soil-pits' were excavated by digging up soil around the roots of reed canary-grass to a depth of 25 cm. The spoil was crumbled by hand, searched by eye on a sheet, and sifted through a sieve with 0.5 cm mesh. An area of 0.5 m^2 was searched at each soil sampling location. This took approximately 30 minutes for each sample.

4.3.5 At six of the seven localities with previous records of hairy click-beetle, soil-pits were excavated in the reed canary-grass zone in the same area as adults were encountered, or, if no adults were encountered, in the densest stands of reed canary-grass available. There were no excavations on the Stathe Bank near Oath Lock (Sample location 1), due to a lack of accessible reed canary-grass. Therefore, in order to complete the full complement of seven soil samples, the banks described in Section 6.2.1 were substituted for the Burrowbridge bank of the River Parrett immediately upstream from Stathe Bridge.

4.3.6 The 7.9 km on the River Parrett that was sampled for the occurrence of hairy click-beetle in May 2018 is shown at Figure 2.

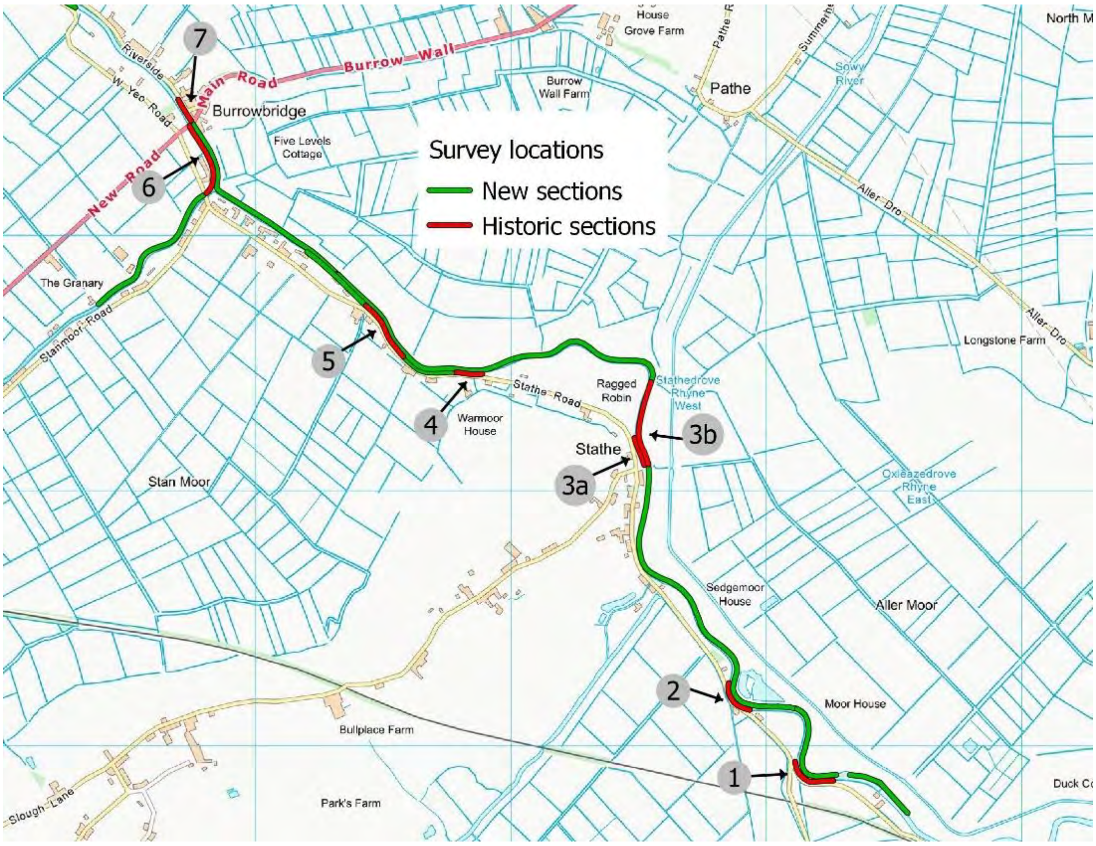

Figure 2. Locations on the River Parrett that were sampled for the occurrence of hairy click-beetle in May 2018.

4.4 Survey dates & weather conditions

4.4.1 The emergence of the adults was confirmed on 18th May 2018. Emergence having been established, the seven locations with historic records and the wider area were sampled on 21st, 22nd and 23rd May 2018. Table 1 sets out the date and weather conditions for each survey.

Table 1. Date and weather conditions for each visit.

DATE	WEATHER CONDITIONS			
	Temp (°C)	Wind (BFT)	Rain (MM)	Cloud (8THS)
21/05/18	21	0	0	0
22/05/18	21	0	0	0
23/05/18	23	0	0	0

4.5 Identification

4.5.1 Adult hairy click-beetle can be recognised in the field based on a combination of size, shape, pubescence, and the enlarged fourth tarsal segment on each leg.

4.6 Constraints

4.6.1 Due to lack of public access, it was not possible to sample all sections of the river bank that would be affected by the proposed dredging. While this prevents conclusive confirmation of the species status in some situations, the suitability of habitat was established based on captures elsewhere and this was used to predict the suitability of sections that could not be physically accessed. On balance, it is concluded that the assessment is adequate to inform a due-diligence safeguarding strategy.

Section 4 – End

5. STATUS ASSESSMENT RESULTS

Data

5.1.1 Twenty-six adult hairy click-beetle were swept from 21 locations between Oath and Burrowbridge in May 2018. Of the seven locations in which historic records have been made, three held the species in 2018 and numerous additional records were also made. Table 2 and Figure 3 summarise this data.

Table 2. Locations with adult hairy click-beetle.

SAMPLE LOCATION	GRID REFERENCE	QUANTITY	STAGE	DATE	BANK
Historic location 3	ST 37485 29213	2	Adult	18/05/18	West
Historic location 3	ST 37511 29306	1	Adult	21/05/18	East
New location	ST 37539 29070	1	Adult	21/05/18	East
New location	ST 37538 29015	1	Adult	21/05/18	East
New location	ST 37527 28934	1	Adult	21/05/18	East
New location	ST 37553 28675	1	Adult	21/05/18	East
New location	ST 37779 28420	1	Adult	21/05/18	East
New location	ST 37786 28417	2	Adult	21/05/18	East
New location	ST 37797 28408	1	Adult	21/05/18	East
New location	ST 37877 28197	1	Adult	21/05/18	East
New location	ST 37923 28162	3	Adult	21/05/18	North
New location	ST 37934 28161	1	Adult	21/05/18	North
Historic location 3	ST 37532 29385	1	Adult	22/05/18	East
New location	ST 37057 29525	1	Adult	22/05/18	North
New location	ST 36919 29477	1	Adult	22/05/18	North
Historic location 5	ST 36557 29555	2	Adult	22/05/18	South
Historic location 5	ST 36520 29606	1	Adult	22/05/18	South
New location	ST 35783 30394	1	Adult	23/05/18	East
Historic location 7	ST 35716 30495	1	Adult	23/05/18	East
Historic location 7	ST 35717 30494	1	Adult	23/05/18	East
Historic location 7	ST 35714 30499	1	Adult	23/05/18	East

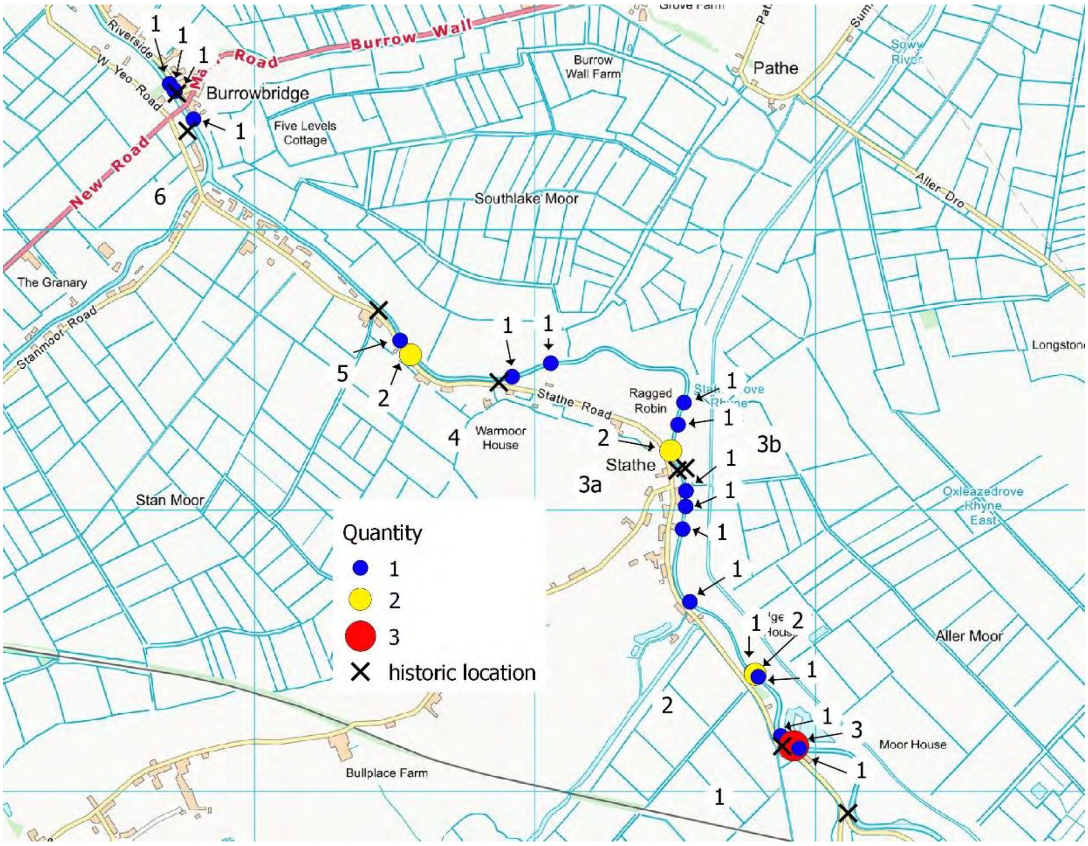

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Figure 3. Locations on the River Parrett where adult hairy click-beetles were recorded in 2018, and historically.

Section 5 – End

6. HABITAT ASSESSMENT RESULTS

6.1 General river channel character

6.1.1 The river channel divides into three or four zones, depending on the bank management regime. These comprise: -

Zone 1: Closest to the river is a zone of soft silt, which reed-sweet grass is growing into and beginning to stabilise. The substrate is semi-fluid and floods regularly, daily or less regularly depending on height.

Zone 2: Above Zone 1 there is a 1-3 m wide band of reed-sweet grass, the extent mostly determined by the profile of the bank. This is consolidated by reed canary-grass roots, organic litter and flood refuse. The largest stands of reed canary-grass develop on gently sloping terraces that are above the neap tide level, but which are still flooded on the highest tides.

Zone 3: Above Zone 2 there is a 2-5 m wide band of tall ruderal vegetation, particularly stinging nettle *Urticia dioica*, as well as broad-leaved dock *Rumex obtusifolius* and common comfrey *Symphytum officinale*.

Zone 4: Above Zone 3 the vegetation is mown on many sections of bank and comprises short turf.

6.1.2 This zonation is modified by grazing, which reduces reed canary-grass to a 50 cm strip at the water margin. Above this is a mixture of bare ground, short turf and occasional ruderal species.

6.2 Overall summary of habitat suitability

6.2.1 Based on observations of habitat where hairy click beetles were recorded, and absent, it is possible to characterise typical habitat for adult hairy click beetle as gently sloping tidal terraces with dense, wide stands of reed canary-grass (Zone 2). These locations are shown on Figure 4.

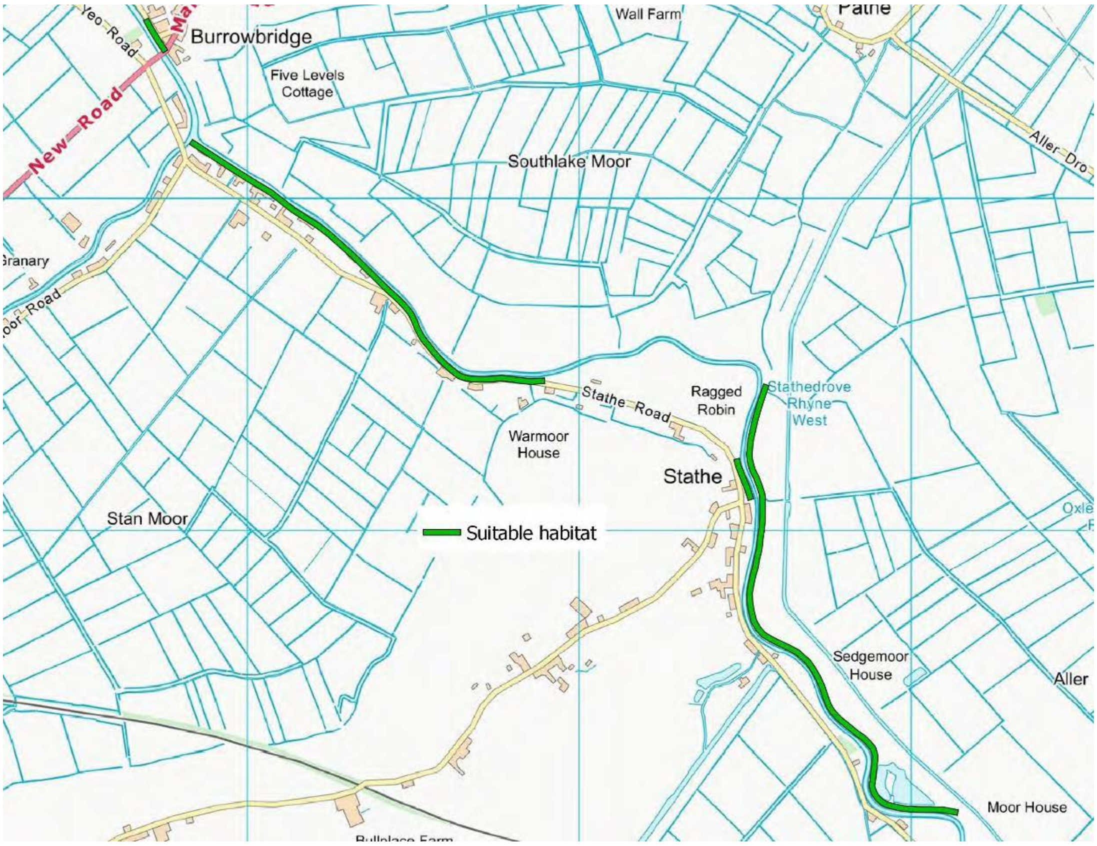

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Figure 4. Suitable habitat for hairy click beetle on the banks of the River Parrett in 2018.

6.3 Sample Location 1 – Red Hill junction

6.3.1 Sample Location 1 comprised a 200 m section of the River Parrett bank upstream from the junction of Stathe Road and Red Hill. This was surveyed from the Stathe bank, from ST 38113 27940 to ST 38262 27865. Despite historic records, in 2018 the habitat comprised little in the way of reed canary-grass on a steep lower channel face (*c.* 45^{o}) and is not typical of the vegetation structure with which the species is associated. No hairy click-beetle adults were recorded.

6.4 Sample Location 2 – Stathe House

6.4.1 Sample Location 2 comprised a 200 m section of the River Parrett bank upstream from Stathe House. This was surveyed from the Stathe bank, from ST 37853 28256 to ST 37937 28145. As with Sample Location 1, this is a locality with previous records of hairy click-beetle, but the habitat composition and structure were materially identical to Location 1 and no adults or larvae were recorded. Photo 2 illustrates the character of the habitat present in Sample Location 2.

Photo 2. River Parrett Sample Location 2 upstream from ST 37870 28182; showing a steep substrate, poor habitat structure and reed canary-grass limited to a narrow fringe on the water margin.

6.5 Sample Location 3 – Stathe Bridge

6.5.1 Sample Location 3 was surveyed on both the west and east banks.

Sample Location 3a – West bank

6.5.2 On the Stathe bank, Sample Location 3 comprised a 120 m section of the River Parrett bank downstream from Stathe Bridge from ST 37524 29098 to ST 37483 29210. The habitat here broadly accords with that known to be exploited by the species, comprising a monotypic 2-3 m belt of unmanaged reed canary-grass growing on a shallow lower channel face with a gentle *c.* 10-20º slope (see Photo 3). This is a locality with previous records of hairy click-beetle, and in 2018 two adults were swept in one 10 m stretch. In addition, three possible hairy click-beetle larvae were exposed at 20 cm depth in a soil pit.

Photo 3. River Parrett Sample Location 2 downstream from ST 36557 29555; where two adult hairy click-beetle were swept.

Sample Location 3b – East bank

6.5.3 On the Burrowbridge bank, a 400 m section downstream from the Stathe bridge from ST 37538 29099 to ST 37557 29471 was surveyed. The habitat here broadly accords with that known to be exploited by the species, comprising a monotypic 2-3 m belt of unmanaged reed canary-grass growing on a shallow lower channel face with a gentle *c.* 10-20^{o} slope. This is a locality with previous records of hairy click-beetle, and in 2018 two adults were recorded but no larvae were encountered in a soil-pit.

6.6 Sample Location 4 – Parrett Cottage

6.6.1 Sample 4 comprised a 100 m section downstream from War Moor towards the confluence with the River Tone from ST 36889 29461 to ST 36778 29464. Here the habitat is typical of that known to be exploited by the species and comprises a monotypic 2-3 m belt of unmanaged reed canary-grass growing on a shallow lower channel face with a gentle *c.* 15-30° slope. Despite historic records of hairy click-beetle, no adults or larvae were recorded.

6.7 Sample Location 5 – Parsonage Farm

6.7.1 Sample Location 5 comprised a 250 m section of the River Parrett bank downstream from War Moor towards the confluence with the River Tone from ST 36571 29527 to ST 36197 29937. Here again, the habitat is typical of that known to be exploited by the species and comprises a monotypic 2-3 m belt of unmanaged reed canary-grass growing on a shallow lower channel face with a gentle *c.* 15-30° slope. This is a locality with previous records of hairy click-beetle, and in 2018 three adults were recorded but no larvae were encountered in a soil-pit.

6.8 Sample Location 6 – Walkeys Farm

6.8.1 Sample Location 6 comprised a 280 m section upstream of Burrowbridge from ST 35741 30425 to ST 35805 30164. Although the lower channel face is shallow with a *c.* 20° slope and has good quantities of reed canary-grass, much of the vegetation has been cut close to the river channel and is therefore not typical of the habitat structure exploited by hairy click-beetles. Despite annual records of hairy click-beetle from Environment Agency surveillance between 2010 and 2016, no adults or larvae were recorded. Photo 4 illustrates the habitat present.

Photo 4. River Parrett Sample Location 6 downstream from ST 35795 30341; the reed canary-grass had recently been cut close to the river channel.

6.9 Sample Location 7 – Riverside Road

6.9.1 Sample Location 7 comprises a 250 m section of the River Parrett bank downstream of Burrowbridge from ST 35749 30449 to ST 35602 30641. This sample was surveyed on the Burrowbridge side alone. The habitat here comprised a 3-4 m belt of unmanaged reed canary-grass dominated vegetation with common reed, growing on a shallow lower channel face with a *c.* 20-30^{o} slope. This is a locality with previous records of hairy click-beetle, and three adults were recorded in 2018, but no larvae were encountered in a soil-pit. Photo 5 illustrates the habitat present in 2018.

Photo 5. Sample Location 7 downstream from ST 35720 30493; where three adult hairy click-beetle were swept.

6.10 Other locations on the River Parrett

River Parrett upstream from Oath Lock

6.10.1 A 300 m section of the Burrowbridge bank upstream of Oath lock from ST 38275 27886 to ST 38659 27639 was surveyed. This section is grazed and had a different character to the river downstream from the lock, with reed canary-grass largely replaced by reed sweet-grass *Glyceria maxima*. No adult hairy click-beetles were recorded.

River Parrett to Oath Lock

6.10.2 A 430 m section of river bank to Oath Lock was surveyed on the Burrowbridge side, from ST 38119 28143 to ST 38275 27886. The habitat here comprises dense ruderal vegetation on the upper bank, and scattered reed canary-grass along a largely bare 1-1.5 m strip above the river channel (see Photo 6). No adult hairy click-beetles were recorded.

Photo 6. River Parrett downstream from ST 38143 22977; unmanaged bank with poorly developed reed canary-grass zone.

River Parrett at Oath

6.10.3 The Stathe bank of the River Parrett between ST 37937 28143 and ST 38113 27943 was visually inspected from adjacent sections, and the opposite bank. This section was heavily grazed by cattle, with limited growth of reed canary-grass (see Photo 7) and the habitat is not typical of that known to be exploited by hairy click-beetles.

Photo 7. River Parrett upstream from ST 37946 28141; heavy poaching from cattle grazing, with limited growth of reed canary-grass.

River Parrett upstream from Stathe Bridge

6.10.4 A 1.3 km section of river bank upstream from the eastern end of Southlake Moor was surveyed on the Burrowbridge side, from ST 37538 29099 to ST 38119 28143. The habitat here comprises a monotypic 1-3 m belt of unmanaged reed canary-grass growing on a shallow lower channel face with a *c.* 20-30^{o} slope (see Photo 8). Fourteen adult hairy click-beetle were recorded, but no larvae were encountered in a soil-pit.

Photo 8. River Parrett downstream from at ST 37923 28162; where an adult hairy click-beetle was swept.

River Parrett at War Moor

6.10.5 Access permissions that would have allowed the survey of the totality of the bank at War Moor were not gained. As a result, the Stathe bank was not fully surveyed. However, a visual assessment found a 350 m section between ST 37483 29210 and ST 37473 29501 held a monotypic 2 m belt of unmanaged reed canary-grass, which is typical of habitat known to be exploited by hairy click-beetles. The remaining 600 m downstream between ST 37473 29501 and ST 36889 29461 was grazed by horses, poached, and held only scattered reed canary-grass.

River Parrett adjacent to Southlake Moor

6.10.6 A 2.2 km section of river bank upstream from Burrowbridge was surveyed on the Burrowbridge side, from ST 35811 30348 to ST 37550 29427. The habitat throughout was heavy poached due to cattle grazing on Southlake Moor, and reed canary-grass was present as a fringe less than 1 m wide, with culms grazed down, and large patches of bare ground and compacted soil (see Photo 9). Two adult hairy click-beetles were recorded opposite the western half of War Moor, one of which was covered in mud.

It is likely that its underground overwintering site was compressed by cattle trampling. This is in contrast to the other 25 adult specimens during this survey which had pristine pubescence. There is no information available about the effects of cattle trampling on hairy click-beetle larvae, although there is some research about other invertebrates. Numbers of larvae for the soil-inhabiting cranefly *Molophilus ater* were lower in trampled peat along a footpath than in adjacent untrampled ground (Bayfield, 1979). Two out of fourteen soil cores produced adults, compared with nine out of fourteen from undisturbed ground (Bayfield, 1979). It seems likely that hairy click-beetle larvae might be killed by heavy compaction from grazing, as click beetle larvae in the present survey were found at shallow depths (*c*. 10-20 cm).

Photo 9. River Parrett downstream from ST 37194 29553; poaching from cattle grazing, with limited growth of reed canary-grass.

River Parrett between Stathe and the River Tone confluence

6.10.7 Access permissions that would have allowed survey of a 400 m stretch of the River Parrett bank between Stathe and the River Tone confluence on the Stathe bank were not obtained. However, the habitat between ST 36197 29937 to ST 35839 30175 was assessed from the opposite bank and comprised a monotypic 2-3 m belt of unmanaged reed canary-grass, growing on a shallow lower channel face with a *c*. 20-30^{o} slope.

The upper bank had been cut recently by the Environment Agency. Given the presence of hairy click-beetle downstream in Burrowbridge, and upstream towards War Moor, presence is entirely possible in this section as the habitat was typical of that known to be exploited by the species.

River Parrett below King Alfred Inn

6.10.8 A 100 m section of the River Parrett bank upstream from Burrowbridge was surveyed on the Burrowbridge side, from ST 35754 30436 to ST 35811 30348. The habitat here comprises diverse ruderal vegetation and a 1-2 m belt of unmanaged reed canary-grass. The lower channel profile is steep (*c.* 45^{o}), with a slightly shallower mid-slope (*c.* 35^{o}) (see Photo 10). One adult hairy click-beetle was recorded.

Photo 10. River Parrett downstream from ST 35784 30389; where an adult hairy click-beetle was swept.

River Parrett downstream from Saltmoor pumping station

6.10.9 A 200 m stretch of the River Parrett bank downstream from Saltmoor pumping station from ST 35286 30894 to ST 35166 30967 was surveyed from the Saltmoor side. The habitat comprisd a 2 m belt of unmanaged reed canary-grass and common reed on a shallow lower channel face with a *c.* 25-40^o slope. Although the habitat composition and structure are typical of that known to be exploited by hairy click-beetles, no adults were recorded.

River Parrett downstream from Saltmoor Farm

6.10.10 A 200 m stretch of the River Parrett bank downstream from Saltmoor Farm from ST 34962 31252 to ST 34867 31366 was surveyed from the Saltmoor side. The habitat comprised a 2 m belt of unmanaged reed canary-grass with common reed on a shallow lower channel face with a *c.* 25-40^o slope. Although the habitat composition and structure are typical of that known to be exploited by hairy click-beetles, no adults were recorded.

6.11 River Tone

River Tone upstream of confluence with River Parrett

6.11.1 A 620 m stretch of the River Tone bank upstream from the confluence with the River Parrett was surveyed on the north side, from ST 35793 30158 to ST 35390 29747. The habitat comprised a monotypic 2-3 m belt of unmanaged reed canary-grass growing on a shallow lower channel face with a *c.* 20-30^o slope, with the upper bank cut by the Environment Agency (see Photo 11). Although the habitat composition and structure are typical of that known to be exploited by hairy click-beetles, no adults were recorded.

River Tone downstream of confluence with River Parrett

6.11.2 The habitat on the south bank of the River Tone between ST 35798 30144 and ST 35396 29721 comprised a monotypic 2-3 m belt of reed canary-grass growing on a shallow lower channel face with a *c.* 20-30^o slope. Although the habitat composition and structure are typical of that known to be exploited by hairy click-beetles, access permissions had not been gained and no survey was performed. The status of the species in this location therefore remains unknown.

Photo 11. River Tone downstream from ST 35617 29955; with a 2 m belt of reed canary-grass left unmanaged, after cutting on the upper bank.

Section 6 – End

7. IMPACTS OF PROPOSED DREDGING & BANK REPROFILING

7.1 Dredging / reprofiling programme description

<u>Timing</u>

7.1.1 A one-off dredging programme on the River Parrett is planned by the Somerset Drainage Boards Consortium in September and October 2018, including bank reprofiling.

<u>Extent</u>

7.1.2 Dredging is proposed in the sections of channel shown on Figure 5. There are two options: -

1. Option 1 – Maximum flood risk benefit of works; and
2. Option 2 – Single bank only mitigation.

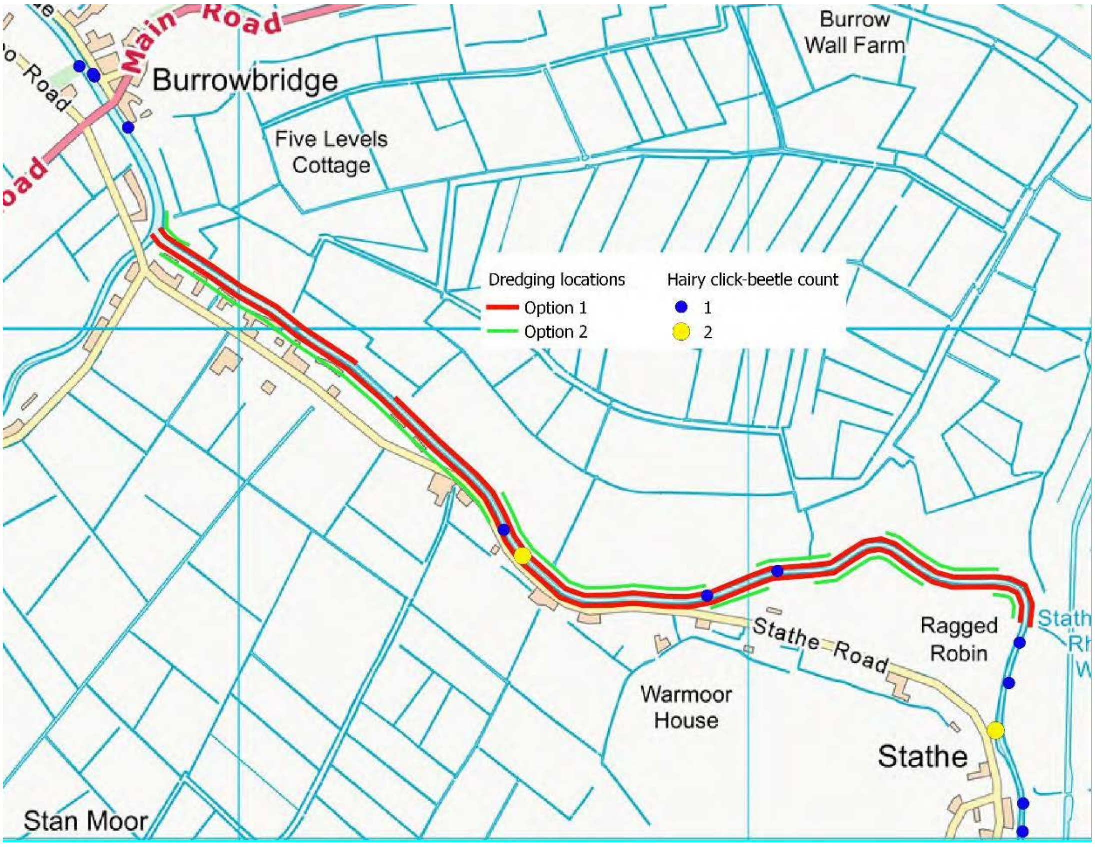

Figure 5. The sections of the River Parrett where dredging is proposed, and the locations where hairy click-beetles were recorded in 2018.

7.2 Potential impacts of proposed dredging on hairy click-beetle

7.2.1 Any maintenance operations affecting the reed-sweet grass zone have potential to affect the hairy click-beetle.

Habitat loss

7.2.2 The potential loss of habitat depends on the precise dredging locations. Option 1 would result in the loss of 39% (1,320 m) of the habitat typical of that known to be exploited by the hairy click-beetle between Oath and Burrowbridge, at least for as long as it takes reed canary-grass to re-establish on the river bank. The proposed dredging zone is contiguous with areas of limited habitat suitability on the grazed banks of Southlake and War Moors. As a result, the maximum distance from the centre of the dredging zone to habitat typical of that exploited by hairy click-beetle would be 1,025 m.

7.2.3 Option 2 would result in the loss of 28% (948 m) of the habitat typical of that known to be exploited by the hairy click-beetle between Oath and Burrowbridge, at least for as long as it takes reed canary-grass to re-establish on the river bank. As it is proposed to dredge on the Burrowbridge bank around Parrett Cottage, the maximum distance from the centre of the dredging zone to habitat typical of that exploited by hairy click-beetle would be 500 m.

7.2.4 The remainder of the proposed dredging is either on the Burrowbridge bank, or the Stathe bank adjacent to War Moor. The impact on suitable habitat for hairy click-beetle here should be minor, as the vegetation and habitat structure here is not typical of most locations where the species was recorded.

Mortality

7.2.5 Adult hairy click-beetles have wings but have only been observed to fly over 1-2 m. As the dredging will take place in September and October, the risk to adults will comprise those that are in the transformation stages between larvae and adulthood and would emerge in the spring of 2019. The remaining members of the populations will be in the larval stages. All the beetles will therefore be within 20 cm of the ground surface around the succulent roots of reed canary-grass. As a result, the dredging will take place when adults and larvae are vulnerable, although it is more likely that adults might find an alternative hibernation site in autumn or spring than winter, when temperatures are lower.

7.3 Constraints to mitigation

7.3.1 There are two significant constraints to defining effective mitigation, comprising: -

1. A paucity of knowledge regarding the need for intervention, which encompasses: -
    a. A lack of data in respect of how long it takes reprofiled banks to re-vegetate;
    b. Whether the soils left by reprofiling are in fact suitable for reed canary-grass; and
    c. What the migration distances over which hairy click-beetles might travel to re-colonise habitat following recovery actually are.
2. A paucity of knowledge regarding the efficacy of mitigation action.

7.3.2 At present, it is unknown how long following reprofiling it will take before the vegetation composition and structure is typical of that exploited by the hairy click-beetle. Similarly, it is unknown whether the soils and substrate that is left by the reprofiling will be suitable for colonisation by reed canary-grass, or whether the grass needs a degree of silting before it can spread to dredged areas.

7.4 Recommendations for mitigation during works

7.4.1 Due to the constraints identified at Subsection 7.3, recommendations for mitigation in respect of the September and October 2018 dredging and reprofiling are limited to 'common sense' recommendations alone.

<u>Excavated material</u>

7.4.2 It is planned to place spoil on the landward side of the Burrowbridge bank on Southlake Moor. This will not affect any hairy click-beetle that might be present in the Burrowbridge bank on the channel side, although the reed canary-grass zone here is poorly developed.

7.4.3 Where reed-sweet grass is removed, it is likely to contain live hairy click-beetle larvae and adults. As the larvae recorded in the present study and previous research (Mendel 2003a) were within 20 cm of the ground surface, the impacts upon them might be mitigated by digging out turves of vegetation at a depth of at least 50 cm. Material might then be placed upright on the bank to maximise the likelihood that it may continue to grow and therefore support the larvae that depend upon it. In order to guard against frost penetration, the turves should be as large as possible and placed against each other in as large a mat as is practical. Turves with reed canary-grass should not be buried beneath other dredgings.

Livestock fencing

7.4.4 If practical, bank sections and any excavated turves should be fenced to keep cattle out, in order that the substrate is undisturbed and the reed canary-grass has the best chance of re-establishing.

7.4.5 Fencing might also be reinstated on the Stathe bank of War Moor, to restrict access of horses to a smaller section of the river channel. This might help the vegetation and habitat structure develop, to resemble most locations where the species was recorded.

Reprofiling

7.4.6 Based on observations of reed canary-grass and hairy click-beetle at the River Parrett, reprofiling should seek to create shallowly sloping tidal terraces, maximising the zone that is subject to flooding on the highest tides.

Cutting

7.4.7 The cutting regime could be altered on the Stathe bank between Burrowbridge and the Saltmoor road bridge. There are recent records of hairy click-beetle on the bank here and it was found directly opposite below the King Alfred Inn. As no dredging is planned on this section, it should be managed to maximise habitat suitability for hairy click-beetle and thereby provide a robust donor population for the dredged and reprofiled sections. This should follow the prescription adopted on the River Tone upstream of the confluence with the River Parrett, where 2-3 m beside the channel is left uncut when the upper bank is mown.

Pilot larval translocation

7.4.8 Although soil sampling has been largely ineffective in the present study, and previous research (Mendel 2003a), it is possible that a more efficient method could be developed to capture larvae, such as the use of baited stocking or pitfall traps. These have been used in surveillance of other click beetle species in agricultural fields (Morales-Rodriguez *et al.* 2017). If trapping could be developed to be successful for live larvae, it would open-up the possibility of removing the species from habitat before dredging takes place. Larvae could be relocated to areas which will not be impacted by dredging, potentially strengthening the population in these areas.

7.5 Recommendations for defining robust mitigation.

7.5.1 The presence of the beetle and the need for dredging and reprofiling provide an opportunity for data-collection that might be used to inform mitigation action more widely in the UK. It is therefore recommended that the following be performed in order to define robust mitigation for future dredging and profiling operations: -

1. Data-collection and review;
2. Vegetation surveillance; and
3. Hairy click-beetle surveillance.

Data-collection and review

7.5.2 The first stage of the mitigation design should be to contact the bodies responsible for the maintenance of the water-courses upon which other populations of hairy click-beetle are known to occur, to see whether they have already defined effective mitigation methods. Regardless, an information network should be established to share knowledge across all populations of the species, in order to ensure rapid transfer of information and the best possible safeguarding.

7.5.3 The second stage should be to collect and collate all data in respect of the lifecycles, propagation, methods by which they spread to new areas, and environmental requirements for both: -

1. Reed canary-grass (to include Ellenberg Indicator Values etc.); and
2. Hairy click-beetle.

7.5.4 Understanding the life-cycle and propagation will inform the time of year when dredging and reprofiling is likely to be least damaging. Understanding the method of spread might lead to more effective ways of safeguarding the beetles (i.e. by using displacement to encourage mobile adults to migrate to areas outside the Zone of Influence of the dredging) and will give an insight into how the grass may again recolonise the reprofiled substrate. This information might also give some idea over what distance the beetles might move to recolonise habitat as it recovers, and what length of hostile ground might represent a barrier to movement. Understanding the environmental requirements will enable an assessment to be made as to what soils and substrate will support reed canary-grass, and which will not. Comparisons might also be investigated in respect of reprofiled banks where livestock do and do not have access.

7.5.5 A basic principle management for invertebrates is rotational management, where "*only a fraction of a site is managed in any one operation*" (Kirby 1992). However, there is no universally applicable ideal plot size, as this is defined by the objectives of individual management schemes (Kirby 1992).

7.5.6 Having reviewed the ecology of reed canary-grass and the hairy click-beetle, the most effective mitigation method would be a dredging programme that was performed in a zoned rotation. The number, width of zones and dredging interval would be defined by the length of time it takes the reed canary-grass to recolonise the reprofiled substrate and the beetles to recolonise the vegetation.

Vegetation Surveillance

7.5.7 Following the dredging and reprofiling it is recommended that the stretch of the River Parrett be divided into surveillance zones as follows: -

1. Undisturbed banks where hairy click-beetle were recorded in 2018;
2. Undisturbed banks where hairy click-beetle were not recorded in 2018;
3. Dredged and reprofiled areas where hairy click-beetle were recorded in 2018; and
4. Dredged and reprofiled areas where hairy click-beetle were not recorded in 2018.

7.5.8 Two replicates of each zone with as similar angles of slope as possible should be chosen and surveillance performed to record the following: -

1. Species composition of vegetation (using DAFOR);
2. Vegetation height;
3. Presence of livestock; and
4. Density (defined on two levels, comprising: a) thick (no bare ground visible through sward); and, b) thin (ground visible through sward).

7.5.9 Surveillance should continue for a minimum of five years or until a reed canary-grass dominant sward with a thick density has been recorded in any un-grazed zone that was subject to dredging and reprofiling in autumn 2018. During this time, the feasibility of hydroseeding of reed canary-grass on the reprofiled banks might also be explored.

Hairy click-beetle surveillance

7.5.10 It is recommended that hairy click-beetle surveillance be performed annually in all vegetation surveillance zones for five years, or until the species is encountered (whichever is sooner) to assess recolonisation by hairy click-beetle in any reprofiled habitat.

7.5.11 Particular consideration should be given to how the migration distance of the species might be established. This information would be of significant value in determining the width of rotation zones.

7.5.12 If the surveillance results are negative, consideration should be given to reintroducing larvae following the maturation of the habitat on reprofiled banks, subject to the development of an effective translocation methodology.

Section 7 – End

8. CONCLUSION

8.1.1 The hairy click-beetle occurs along the River Parrett in Somerset between 500 m downstream of Oath Lock and 250 m downstream of Burrowbridge. The species is associated with shallowly sloping tidal terraces, where dense stands of reed canary-grass establish and are subject to flooding on the highest tides.

8.1.2 Of an overall seven locations in which it is suggested that the species has historically occurred, it was only recorded in three in 2018, although fifteen new locations were also discovered.

8.1.3 The proposed dredging can be predicted to have a significant negative impact upon the hairy click-beetle population in the sections affected. Mitigation is proposed to ameliorate these effects. However, the mitigation methods are untested and their efficacy is unknown. Therefore, a surveillance programme is also recommended to attempt to assess the effect of the dredging impacts on the species status in the longer term and explore the possibility of capturing larvae in baited traps.

Section 8 – End

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APPENDIX A. RARITY STATUS CATEGORIES DEFINITIONS & CRITERIA.

For the purposes of evaluating invertebrate faunas and priorities for conservation action, invertebrates are attributed various rarity status categories, the meanings of which are given below. Definitions and criteria are taken from Drake *et al.* (2007).

A1. RED DATA BOOK

A1.1 Red Data Book Category 1 RDB1 – ENDANGERED

Definition

A1.1.1 Taxa which are in danger of extinction in Britain, and whose survival is unlikely if the causal factors continue operating.

A1.1.2 Taxa included in this category comprise: -

- Taxa whose numbers have been reduced to a critical level or whose habitats have been so dramatically reduced that they are deemed to be in immediate danger of extinction; and
- Taxa which are possibly extinct.

Criteria

A1.1.3 The criteria for selection into Red Data Book Category 1 comprise: -

- Species, which are known or believed, to occur as only a single population within one 10km square of the National Grid.
- Species, which only occur in habitats known to be especially vulnerable;
- Species, which have shown a rapid and continuous decline over the last twenty years and are now estimated to exist in five or fewer 10 km squares.
- Species which are possibly extinct but have been recorded this century but which if rediscovered would need protection.

A2. REFERENCES

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SOMERSET LEVELS DRAINAGE BOARDS CONSORTIUM

River Parrett

Oath to Burrow Bridge Ecology Surveys: Great Crested Newt Desk Top Study

Please refer to Appendix 6C of the ES

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River Parrett

Oath to Burrowbridge: Benthic Macroinvertebrates

Please refer to Appendix 6F of the ES

[1] Taken from "Draft Fish Habitat Technical Note", Johns Associates, 2018.

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Oath to Burrowbridge Ecology Surveys

Phase 1 Habitat and Invasive Plants

Assessment

Please refer to Appendix 6B of the ES

SOMERSET LEVELS DRAINAGE BOARDS CONSORTIUM

River Parrett

Oath to Burrow Bridge: Ramsar Invertebrates

Please refer to Appendix 6F of the ES

SOMERSET LEVELS DRAINAGE BOARDS CONSORTIUM

River Parrett

Oath to Burrow Bridge Ecology Surveys: Fish Habitat

Please refer to Appendix 6G of the ES

River Parrett Oath to Burrowbridge Dredge

Soils Screening Report

On Behalf of

Somerset Drainage Boards Consortium

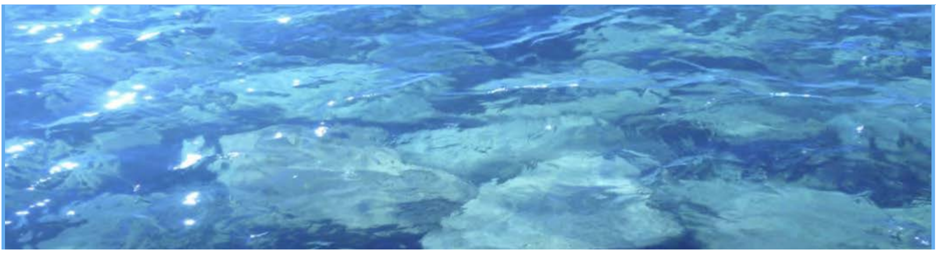
PLEASE REFER TO APPENDIX 2B OF THE ES

SOMERSET DRAINAGE BOARDS CONSORTIUM

Dredging Trials Monitoring Programme November-December 2016

Report AmbSDBC02

March 2017



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Executive Summary A trial dredging project and associated programme of environmental monitoring was successfully undertaken over the period November 2016 to February 2017. A primary objective of the project was to improve our understanding of the natural sedimentary regime of the upper Parrett estuary, in order that any sediment management strategy that may be developed is optimally designed to work with nature. The principle finding is that a seasonal alternation of sedimentary processes is found in the upper estuary. There is a spring/summer/ autumn influx of marine fine sediment (moving in suspension), concentrated over a few hour period around high water on the highest spring tides. At these times of strong sediment delivery, suspended solids concentrations in the upper estuary water can reach 25 g/l. At all other times ebb flow reinforced by river flow scours sediment back down towards the sea. High river flow through the winter prevents the penetration of even the highest spring tides into the upper estuary, thus preventing winter accumulation of marine sediment. At times of river dominated flow, suspended sediment rarely exceeds 0.5 g/l. The seasonal balance between the (scouring) fluvial/ebb influence and the less frequent high spring flood tide supply of marine sediment (accumulation) dictates the net sedimentation situation. There may be significant inter-annual variability in this balance due principally to different peak river discharge conditions between the years. In 2016-17 winter river flow causes persistent scour that deepened the whole upper estuary channel system by 10-20cm. Spring/summer/autumn spring tide influx of mud must produce accumulations deeper than this, to produce the long-term net year by year build-up of mud that is seen in the upper estuary reaches. The sediment that builds up comprises primarily coarse silt, with some clay and finer silt, and up to ~15% fine sand. The bed sediment that forms under these conditions is remarkably dense and strong compared with normal estuarine mud.

Nature acting by itself establishes a slowly varying equilibrium relationship between these processes of erosion and deposition. However optimum channel-section scour is only attained after a long period of river flow erosion. This is the crux of the problem from the flood prevention stance, as the natural clearance of the channel section only takes place during and after the occurrence of overbank flooding. Dredging is therefore being undertaken to take the estuary cross-section area out of 'regime' (equilibrium) so that it is ideally prepared to effectively conduct out to sea the highest occurring floods. This channel cross-section area enlargement will however encourage sediment deposition, both by reducing the effectiveness of fluvial/ebb scour, and by encouraging inland penetration of the sediment rich marine water under high spring tidal action. Optimising dredging effectiveness maximises the cost benefit of this activity. To achieve this three analyses have to be made.

1. Hydraulic modelling that can identify the downstream point beyond which dredging has little effect on floodwater transmission (definition of minimum dredge reaches)
2. Establish the optimum timing for the dredging operations (e.g. inter-annual frequency)
3. Identification of dredge method that operates most cost effectively.

Point 1) is not addressed in this study, but the information generated here will feed into the analysis. Point 2) requires a long-term monitoring system to be set up to provide diagnostic information on the inter-annual variability of the net sediment flux through the upper estuary, which is a recommendation of this study. Point 3) was a major objective of this study. Two experimental dredging systems were trialled, a WID (Water Injection Dredger, high productivity) and a Farrell (cutter on an hydraulic arm, high precision). If it transpires that accurate shaping on the channel cross sections is a primary concern, with large amounts of side-slope cutting, then the Farrell is the best tool. If simple deepening of the thalweg is required, the high productivity of the WID makes it the best method. Both methods simply discharge the cut spoil into the water column to become dispersed by natural processes.

During the study much effort was put into measuring the processes of sediment dispersion downstream from the dredger, to ensure that the dispersing flows did not simply redeposit the dredged sediments further downstream. The processes of sediment dispersion varied between the method, and also according to whether marine (tidal) or fluvial processes were dominant at the time (river discharge).

Under low river flow conditions, the WID can only work for a limited period on the early ebb tide, due to the poor water depth and landward flow at other times. Under these conditions the high productivity of the WID system tended to swamp the low volume of water passing the dredger, producing a dense fluid mud layer on the bed downstream of the dredger, often persisting all the way through the monitored reaches. For this reason and also for the very low dissolved oxygen conditions sometimes seen in the bed layer, the use of the WID at times of low river flow is unlikely to be the most practical option.

Both with the WID under higher river flow conditions, and with the Farrell (lower productivity), less dense plume conditions were generated. The water column real-time monitoring undertaken showed that most of the time the dredged spoil was washed seawards through the monitored channel reaches. Bathymetric surveys showed that natural river scour prevented the long-term accumulation of any of the dredged mud as far north as Black Bridge, just downstream of the M5 motorway. Given that the lower reaches of the estuary contain a large reservoir of mud that feeds the process of (spring tide) pumping of mud into the upper estuary, it is probably not important to be concerned in detail about the ultimate sink sites of the dredged material.

Through all the channel reaches from Burrowbridge to the M5 motorway, between November 2016 and February 2017, it was calculated that some 32,000m^3 of mud was dispersed seaward. Only some of these reaches were dredged and logically applying non-dredged area losses to all the reaches it can be calculated that river action alone would have removed some 24,000m^3, thus attributing 8,000m^3 to the dredge activity. The winter of 2016-2017 did not see particularly high river flows, and significant inter-annual variability in the capacity of the river to scour itself should be expected. Critically, using a WID/Farrell system for dredging must be seen as a method of supplementing the natural processes of scour, and should aim to take place a) as early as possible in the winter (to maximise post-dredge river scour) and b) always at times of high river flow (to ensure optimum initial dispersion). In the same vein, spillways and sluices should be designed and operated to maximise the natural scouring power of the Tone and Parrett freshwater discharges

No serious environmental concerns emerged during the monitoring that was undertaken.

The conclusions of the study noted that an alternative to dredging (enhancing scour) might be the reduction of the supply of fine sediment to the upper estuary reaches (reducing accumulation). Although such an option would not normally be open, the plan to build a tidal barrier across the lower Parrett estuary, if operated correctly, could be a practical and economically attractive alternative solution to the maintenance of the upper estuary channel flow capacity. It is recommended that this possibility be carefully investigated.

Other recommendations made involved improved future monitoring (river flow gauging, bathymetric survey methods, sediment flux monitoring), the potential usefulness of uncovering archived data on the Parrett mud system held at HR Wallingford, and the need for further consideration/study to provide a better understanding of optimum channel profile shape and dimensions for both maximising flow capacity and minimising sedimentation.

Dredging Trials Monitoring Programme November-December 2016

1. Introduction

1.1. Background

As part of long-term planning for flood management on the Somerset Levels, the role of the River Parrett (Figure 1) as the prime western drainage conduit to the sea is under consideration. The river runs between artificial levees in its lower course, restricting its capacity for natural channelling of flood waters. The same reaches are affected by tidal action, the estuarine flow feeding sediment into the zone from the large and dynamic mud reservoir of the upper Bristol Channel. Historically the combined problem of confined channels and high sedimentation rates has been addressed by human intervention, through an active programme of dredging. This cost was affordable in the days of cheaper labour and navigational use of the Parrett, the latter ceasing between the 1930s (to Burrowbridge) and 1971 (closing of Bridgwater docks). Since closure, dredging activity has significantly reduced, this change and the resulting silting of the river channel potentially being an important contributory factor to the severe flooding seen across the Levels in the last decade.

Alleviation of the flooding problem on the Somerset Levels is the responsibility of the newly formed Somerset Rivers Authority (SRA), working closely with the UK Environment Agency (EA) and the local drainage boards (Somerset Drainage Boards Consortium, SDBC). The SDBC has taken on responsibility for the channel dredging aspects of the project.

Pioneer[1] dredging of key sections of the lower Parrett south of the M5 (from about 2km south of the motorway, Figure 1) in 20014-16 used backhoe technology, with diggers reaching from the banks or mounted aboard floating pontoons. Spoil was taken ashore, and used to widen/heighten the levees or to spread on agricultural land. This dredging method proved very expensive, and rates at which natural processes refill the excavated zones dictate that a more economical form of dredging has to be found if the practice is to be sustainable. Confirmation of this situation, and exploration of the potential for future cost-effective (sustainable) maintenance dredging strategies are both therefore required.

To this end a programme of experimental dredging and monitoring of effects was undertaken during November and December 2016 [2]. The trials were run by the SBDC, and this report addresses the monitoring undertaken during this project. The monitoring focussed on the ~2km of channel between Burrowbridge and Westonzoyland, which contained the <1km Experimental Dredge Zone (EDZ) as shown in Figures 1 & 2.

[1] Pioneer term used instead of the normal capital or maintenance classification to denote dredging of deposits which are not natural, but which have laid undisturbed for decades.

[2] The main period of experimental dredging and monitoring finished on 2nd December 2016. After this date the presence of the dredging plant in the estuary was taken advantage of to deepen a further <1km section of channel between the EDZ and Westonzoyland, Figure 2. This dredging was only partially monitored.

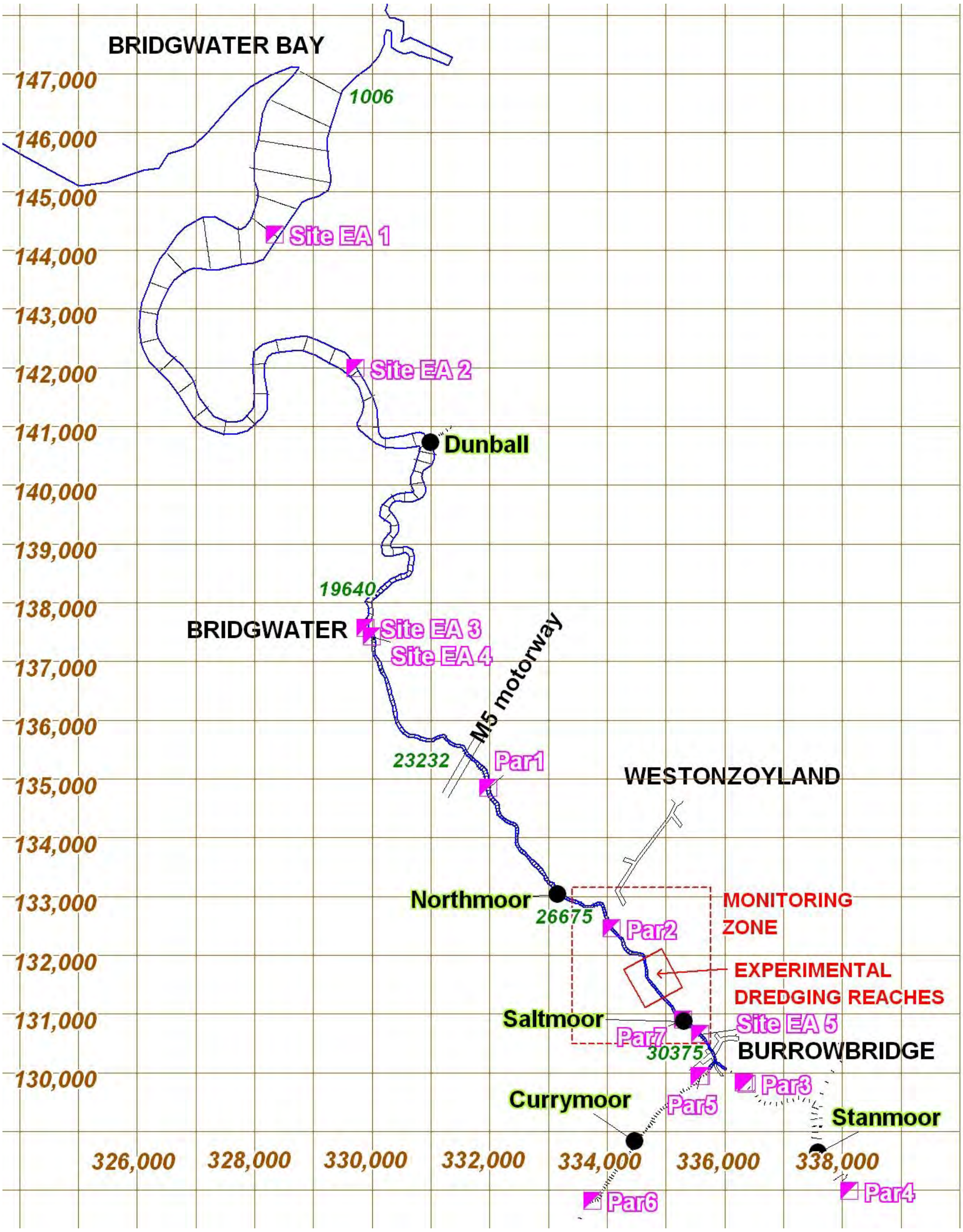

Figure 1. Locations

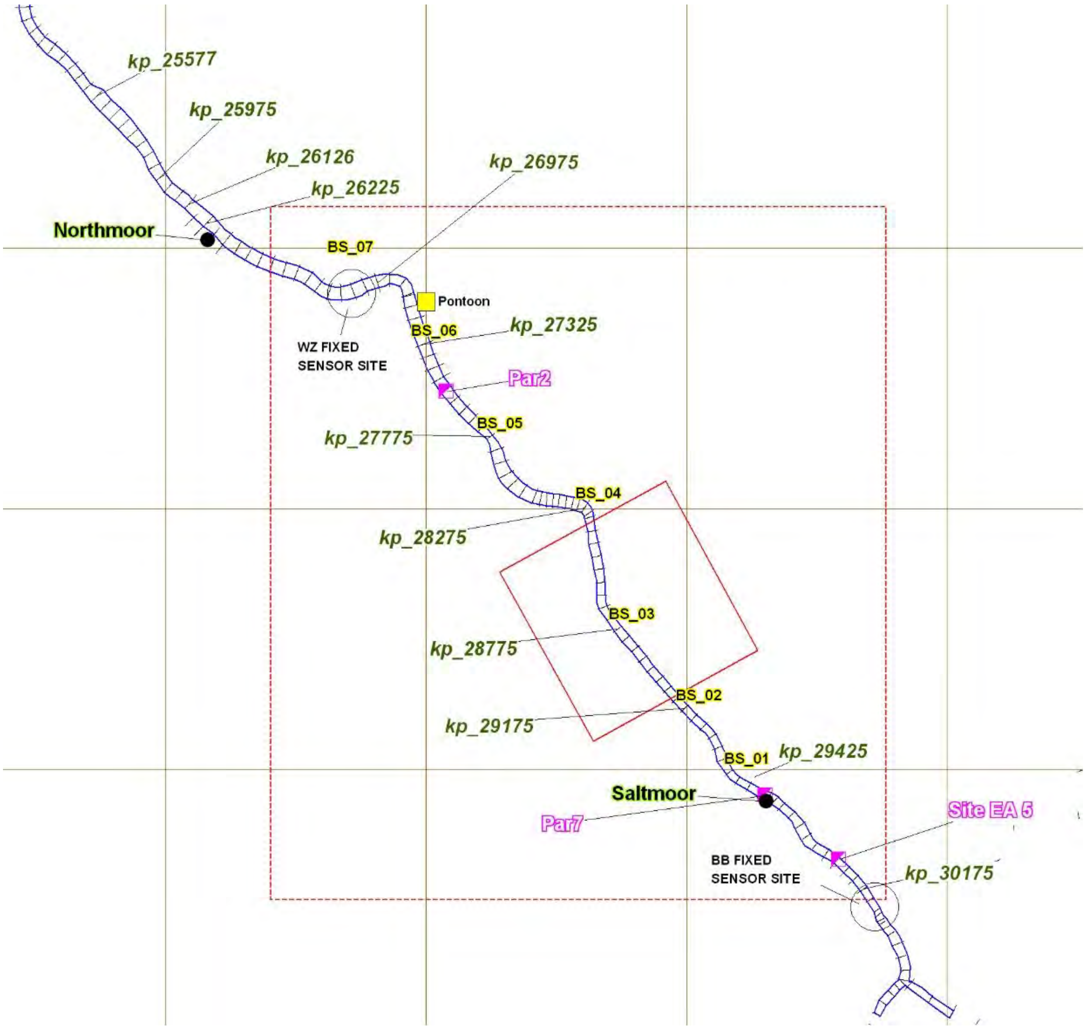

Figure 2. The monitoring zone

Figure 3. The BORR with the WID T-pipe pumping but elevated above the water surface.

The experimental dredging used two methodologies neither of which involved transport of spoil away from the river for disposal/reuse. The dredging created dense suspensions of the excavated material, which were naturally carried seawards by the (ebbing) tidal flow, augmented by the river discharge. The dredging was undertaken by Van Ord UK Ltd, using the vessel BORR (Figure 3).

Water Injection Dredging (WID). A T-pipe with downward pointing nozzles is fastened to the end of a pipe that can be lowered below the dredger, the inboard end being connected to a low pressure (~1bar) pump which forces water into the T-bar. The T-bar is lowered to be a short distance above the bed, parallel to the bed, and water is injected at low pressure into the bed while the vessel moves slowly along. The bed is stirred up into the lower water column, creating a dense suspension, which is carried away by the ambient flow. The WID method lacks precise dredge control, but is capable of very high productivity when bed sediments are unconsolidated and fine.

Farrell Dredging. A circular cutter rotates in a plane parallel to the bed, and is connected to a pump which sucks up water and sediment cuttings into a pipe. The pipe terminates at the water surface alongside the dredger, the dense slurry being discharged into the surface layers of the ambient flow to be dispersed naturally. The cutter head is on the end of a jointed hydraulic arm, which (via computer/GPS control) can be moved from side to side across the watercourse providing a precision trimming facility. Farrell dredging provides a very accurate cut but progresses more slowly than the WID method.

The methodology and dredge hardware used is described more fully in Appendix 1 (Van Ord specifications).

1.2. Monitoring Objectives

The monitoring programme has five broad objectives, most of which are addressed in this report:

1. Provide further understanding of the natural processes of water and sediment movement through the upper estuary of the River Parrett, in the form of a conceptual model [3] of the system, that will inform future planning and sediment-management-strategy development.
2. Protect the environment[4] from adverse effects during the trials and to enable assessment of any potential environmental impacts of long-term adoption of these methods.
3. Measure the effectiveness (productivity and precision) of the dredging plant (addressed in detail elsewhere).
4. Identify and quantify the processes of sediment dispersion downstream from the dredger
5. Identify the short term changes effected by the dredging (channel morphology and sediment composition)
6. Trial optimum methodologies for a long term monitoring programme.

A future (seventh) objective will be a longer-term assessment of the changes effected by the trials (Objective 5 after many months). This will be principally concerned with the rates at which sediment deposits re-accumulate in the trial-dredged reaches (bathymetry surveys and visual observations).

[3] A conceptual model provides a descriptive framework for the organization of knowledge about the elements and interrelationships within a system, serving as a guide for observation and interpretation. Importantly, conceptual models can define the envelope of reality that mathematical models (of the necessarily simplified system) must reproduce.
[4] See report: Parrett and Tone Hydrodynamic Maintenance Dredging Trials 2016. Environmental Impact Assessment (including HRA and WFD). Parrett Internal Drainage Board (on behalf of the Somerset Rivers Authority) 17 October 2016 (final version)

1.3. Secondary Data Sources

A substantial amount of research has been undertaken in past years, examining water and sediment flow in the River Parrett and linked environments. The key reports relied upon through the monitoring study are as follows.

The Unit of Coastal Sedimentation based in Taunton studied fine sediment circulation of the inner Bristol Channel in the 1970s and 1980s. They identified a system of settled muds, stationary suspensions and mobile suspensions, with mud moving between these states according to the lunar cycle of tidal energy. From the point of view of influence on the Parrett estuary sedimentary system their findings can be summarised in the following two report[5] extracts.

The turbidity maximum extends from Watchet in the Bristol Channel to well above "The Shoots," which is the upstream limit of this study. As a direct result of the energy cycles and availability of erodible fine sediment, the suspended solids concentrations are high and variable ranging from <O. 1 to >200 g l^{-1}. Based on water volume and suspended sediment mass computations in this region, preliminary estimates (unpublished) show that on spring tides of the order of 17 million t of fine sediment is suspended in the water column whilst on neap tides some 50% of this sediment settles to the bed to form dense stationary layers.

The plan distribution of average suspended solids data shows a zone of marked lateral concentration gradient along the main channel of the Severn between "The Shoots" and the Holm Islands and extending across the Inner Bristol Channel to the English coast near Watchet. This suspended solids front occupies a narrow zone at the surface and bed on spring and neap tides. The concentration on the English side of the front was consistently higher, >4.0 g l^{-1} at the bed on spring and neap tides, than on the Welsh side, where it is generally <0.5 g l^{-1}.

The same studies showed that Bridgwater Bay contains some 500M tonnes of mud as settled deposits, some of which are eroding and others accreting, and which must play an important source and sink roles in the regional fine sediment circulation system. These fluid and settled mud deposits are likely to be the primary source of the sediments that are mobile in the Parrett estuary.

HR Wallingford have undertaken several studies of the River Parrett system. The first study (unreported as data went into a physical modelling exercise) was conducted in 1977/78 in relation to proposals to construct a tidal barrier at Dunball, and involved field studies of water and sediment flow conditions between the estuary mouth and Bridgwater. These results are partially reported in a 1986 study[6] looking at dredging options for the Parrett, when some further field measurements were taken from Bridgwater to the tidal limits. Later studies of the Parrett undertaken by HR Wallingford [7] [8] [9] have not involved field measurements. Two further general HR Wallingford reports [10] [11] contain useful references to some of the above data as well as describing the latest thinking on mud suspensions.

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[5] KIRBY, R. , and W. R. PARKER. 1983. Distribution and behaviour of fine sediment in the Severn Estuary and lnner Bristol Channel, U.K. Can. J. Fish. Aquat. Sci. 40 (Suppl. 1): 83 - 95.
[6] HR Wallingford 1986. River Parrett Dredging Study. Report EX 1428.
[7] HR Wallingford 2016. Somerset Levels and moors Flood Action Plan. Dredging Study for the Rivers Parrett, Tone and Brue. Report MCR5576-RT001-R02-00
[8] HR Wallingford 2001. River Parrett Flooding Appraisal of Possible Solutions. Phase 1. Review of Agitation Dredging. Report EX 4433
[9] HR Wallingford 1996. River Parrett Dredging research Strategy. Report EX 3480.
[10] HR Wallingford 1993. Impact of Climate Change on Water Quality. Report SR 369
[11] HR Wallingford 2012. Methods for Predicting Suspensions of Mud. Report TR104.

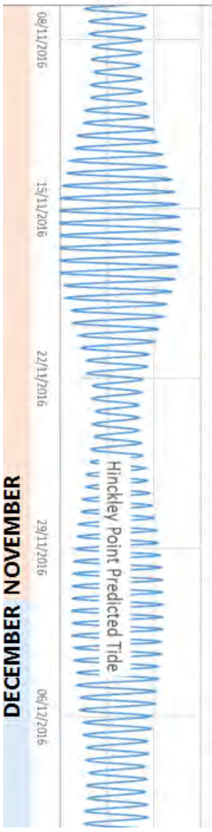
In 2008 and 2009 the Environment Agency commissioned studies to examine the flux of sediment through the upper estuary, undertaken by Partrac Ltd/Black & Veatch. For two one-month periods (mid-November to December 2008, mid-August to September 2009) instrumented frames were placed at seven sites in the Parrett low-water channel in the reaches above the M5 motorway (sites identified in Figure 2). Although some data were lost due to frame failure, clogging with weed etc, some good baseline information was captured [12] on current velocities, sediment transport and channel morphology.

Sediment samples from the bed of the Parrett at five sites (Figure 1) were analysed for particle-size characteristics in both March and August 2016.9 (EA data). A laser sizing system was used.

2. Methods

2.1. Dredging timetable

Tide



Date		Dredging Activity	Monitoring Activity	
7	M			
8	Tu			
9	W	*Jetty and pontoon installed*		
10	Th		BS	*Initial bed sediment survey*
11	F	*Dredger launched at Dunball*		
12	Sa			
13	Su			
14	M	*Dredger on site. Berth dredged.*	1	*Pre-dredging WQ survey*
15	Tu	*1 hour WID. South reach*		
16	W	*1.25 hours WID. South reach*	2	*1st dredger plume survey*
17	Th	*1.25 hours WID. South reach*		
18	F	*2.5 hours WID. South reach*	3	*2nd dredger plume survey*
19	Sa			
20	Su			
21	M			
22	Tu			
23	W	*Farrell fitted*		
24	Th	*Farrell fitted*		
25	F	*2.5 hours Farrell dredge. North reach*	4	*3rd dredger plume survey*
26	Sa	*Spuds adjusted*		
27	Su			
28	M	*6 hours Farrell dredge. North reach*	5	*4th dredger plume survey*
29	Tu	*6 hours Farrell dredge. North reach*		
30	W	*4.5 hours WID . North reach*	6	*5th dredger plume survey*
1	Th	*2 hours Farrell dredge. North reach*		
2	F			
3	Sa			
4	Su			
5	M		7	*Post-dredging WQ survey*
6	Tu	*Processing*		
7	W			
8	Th		BS	*Final bed sediment survey*
9	F			

Table 1. The dredging and monitoring timetable.

Dredging and monitoring activities are detailed in Table 1. Before the 20th November, low river discharge dictated that dredging could only take place for a few hours on the early ebb after high water (HW) spring tides. After that date the river discharged increased to the point that dredging was possible at most times.The experimental dredging was undertaken along two reaches of the estuary, totalling about 800m, between Kp [13] 28300 and 29100 (BS02 to BS04 in Figure 2). The

[12] Partrac Ltd. March 2009 & September 2009 SEDIMENT BUDGET REPORT (River Parrett/Tone) Reports P1022.05.D021v01 & P1022.05.D026v01

[13] A system of kilometre posts (Kp) starting at the estuary mouth (Steart Island) and following the thalweg has been in use for previous Parrett estuary projects and is relied upon here.

northern part of this section (separated by the bend) was undertaken using the WID method alone, the southern part using the Farrell cutter but also with the WID for one day.

As an extension of the planned experimental dredge, from 12-16th December the channel between the north edge of the EDZ and the pontoon at Westonzoyland (Figure 2) was dredged using combined Farrell (side slope) and WID (channel floor) methods. Thirty-three hours of active dredging took place, with up to 11.5 hours of dredging in one day (river level was high enough to enhance ebb flow). On the final day (16th) the WID method was used to undertake a single 'cleansing' path all the way from Burrowbridge to Westonzoyland.

2.2. Bathymetry

A standard set of transects have been used for estuary bathymetry surveys over the years. These are spaced 50m apart through the upper estuary, the spacing widening in the lower estuary (Figures 1 & 2). The profiles are identified by their Kp chainage (in metres) from the estuary mouth [13]. A secondary profile numbering system is also in use, identified by profile number north of the confluence of the Tone and the Parrett. As the latter site is located at Kp 30575, this secondary profile identifier can be derived from the equation:

Profile number =1+((30575-Kp)/50) The EDZ therefore contains profile 30-45.

AP Land Surveys Limited conducted a set of surveys along these transects in October 2016. The survey was restricted to upstream of Kp 25575 (profiles 1-101). These data have been used as baseline information for the dredge monitoring. The surveys were undertaken on foot or in a small boat using a pole mounted RTK DGPS. AP Land surveys conducted a post-dredge survey at some of the profiles during late December 2016. Every profile inside the EDZ (30-45) was resurveyed and every third profile outside the EDZ between profiles 1 and 87.

Storm Geomatics were commissioned to undertake a pre-dredge survey of the estuary reaches between Black Bridge (downstream of M5 motorway) and Burrowbridge using combined multibeam (below water level) and scanning laser (above water level) techniques. The survey was however completed on the 16th and 17th November, at which time dredging had just started. The survey was undertaken by Shoreline Surveys Ltd using an Odom Teledyne MB2 (200kHz) multibeam (nominal accuracy $\pm$0.05m) and a Velodyne Puck VLP-16 Laser (nominal accuracy $\pm$0.01m). Positioning during data capture used a Trimble SPS 855 GNSS receiver using corrections from the Trimble VRS NOW service. A post-dredge survey of the same reaches, using just the multibeam, was undertaken during the week of the 13th February 2017.

For completeness the spring 2014 (pre pioneer dredge) bathymetry dataset has been included in the analyses. This (pole and ADCP method) data set comprises most of the estuary.

All data were entered into a (MapInfo) GIS system and gridded for analysis.

2.3. Fixed-point Autonomous Sensors

WATER QUALITY sensors (two) were installed on the 20th October 2016 and were retrieved on the 16th January 2017. The sensors were located near Westonzoyland (WZ, downstream end of monitoring area) and at Burrowbridge (BB, upstream edge of monitoring zone) as shown in Figure 2. They monitored conditions in the surface ~0.5m of the water column, the BB sensor being suspended from a bridge and the WZ sensor mounted in an anchored floatation system. Data were logged at 15 minute intervals and transmitted via the internet to cloud storage/PC access. Each unit contained a YSI 6600 V2 Sonde with the following sensors:

Optical Backscatter (turbidity) with a wiper Type 6026. This optical sensor was withdrawn in approximately 2002 and is characterized by relatively small optics, a factor that results in minimal penetration of the light beam into the sample which allows an improved ability to cope with higher turbidity conditions than more modern (standardised) sensors. All optical backscatter systems suffer from the limitation of continuing to provide (spurious) data above a maximum turbidity condition. This limit is be pre-defined by the manufacturer in terms of NTU but due, to the natural variability in TSS (total suspended solids) and NTU relationships, the limit can be difficult to identify in the field. The upper limit of the 6026 sensor is 4000 NTU.

Temperature & conductivity. Salinity is calculated from these two values using a standard formula.

Dissolved oxygen, which is automatically combined with temperature and conductivity data to be reported both as an absolute value and % saturation.

The sensors functioned very well throughout the monitoring period, being subject to downtime due to stranding and weed clogging for only a few days in total (worst case was the dissolved oxygen sensor at Westonzoyland which failed on the 4th January 2017 and was not replaced). Comparison with manual profiled data showed good correspondence of values, but it is recognised that although there is only weak vertical variability in water temperature and salinity, strong vertical gradients in turbidity and dissolved oxygen occurred at key times, which these near-surface sensors did not see. Turbidity calibration information for the sondes are provided in Appendix 2.

WATER LEVEL data was provided by the EA and Proudman Oceanographic Laboratory (POL). The EA maintain sensors at five sites pertinent to the survey (Figure 1). Data are logged at 15 minute intervals and are logged and accessible via the internet. POL maintains the tidal stage recorder at Hinkley Point at the western extremity of Bridgwater Bay, data again being available via the internet. As there is a slow and range-dependent progression of the tidal wave along the narrow Parrett estuary (with associated variability in high water times), all tide times have been referred to low water at Hinkley Point.

2.4. Manned Water Quality Surveys

A manned water sampling system was used from a boat on seven days of the nineteen day monitoring period (Table 1). The system was deployed from the Van Ord support vessel CHALLIS 2 (Figure 4). Although monitoring was successfully achieved using this vessel, its length, beam and draught were too large for the environment, restricting its ability to turn in the narrow channel (reducing the periods of time monitoring could be continued for) and propeller disturbance was potentially a major source of local turbidity.

The CHALLIS 2 had a small derrick at the stern which allowed deployment of a water profiling system. Water depth during the survey was always less than 5m, allowing the profiling system to be hand-hauled. The system contained the following equipment:

A Valeport 'Owen' Water Sampler (Figure 5). This is a 1m long 5cm diameter tube that is suspended horizontally in the water column, a system of fins keeping it aligned into the flow. Feet fitted to the base of the sampler allow it to securely rest on the bed for sampling 10cm above the bed when required. On release of a messenger down the supporting rope the tube can be automatically closed, trapping a water sample. The Owen tube can be quickly brought into the vessel and supported vertically in a metal frame, allowing a settling test to be undertaken. The latter is achieved by initially withdrawing a water sample from the base of the tube (total concentration) then taking subsamples at 10cm depth from the top of the tube at 5 and 10 minute intervals. Comparison of the TSS content of the three subsamples shows the rates at which the coarser elements of the suspended solids are settling out. The Owen tube was also used just to take water samples for calibrating the optical turbidity sensors also being deployed.

Two sondes were mounted on the Owen tube as illustrated in Figure 5, sampling as closely as possible the water flowing through the tube.

Figure 4. The CHALLIS 2 workboat showing the derrick used for the Owen tube.

Partech 740 turbidity meter. This sensor was mounted on the port side of the Owen tube (Figure 5). The unit is a short-beam transmissometer, measuring optical attenuation (cf optical backscatter). These systems are capable of measuring turbidity to much higher levels that OBS units, and the 740 reliably measured turbidity up to 20,000 NTU. Importantly the 740 gave a ‘beyond full scale’ signal once light extinction had occurred, unlike the OBS sensors. Unfortunately the 740 had no facility for data logging, simply a cable to a hand-held display unit. Therefore readings were just taken at the surface and on the bed, with note taken at the level at which light extinction occurred (both on ascending and descending casts). Unlike OBS sensors, there is not a near-linear relationship between light attenuation and turbidity.

YSI ProDSS Sonde. This unit was mounted on the starboard side of the Owen tube. The unit is cable-connected to a hand-held display unit, but also data is logged internally. Logging was set to record all data values at 1s intervals, and was simply switched on at the beginning of each survey and off at the survey end. Log time accuracy was checked daily. Surface and bed readings were logged simultaneously with the Partech 740 observations. The sonde contained the following sensors.

- Depth below water surface (by pressure, calibrated to atmospheric pressure)
- Temperature
- Conductivity/salinity
- pH

- Turbidity (OBS) that gave spurious (low) data in turbidity levels above 2000NTU (see Appendix 1)
- Dissolved Oxygen (reported both at absolute concentration and % saturation).

Figure 5. The Owen tube and attached sondes.

ALGIZ 10X handheld ruggedised PC fitted with DGPS (EGNOS). The position system was initiated at the beginning of each survey and logged the vessels location constantly at 1s intervals through the day. The synchronicity of the ALGIS and YSI ProDAA clocks was checked daily, and the two logs combined to provide one data record. Times when the ProDSS was not immersed were simply removed from the record on the basis of water depth (<0.1m).

One simple data collection strategy was mostly used during the monitoring of the dredge plume. All monitoring took place from local HW through the ebb tide. The CHALLIS 2 never anchored, profiling always took place in the channel centre, facing upstream with the skipper using the engine to hold position against the 1-2 knot current. The CHALLIS 2 initially took up station astern of the dredger and a water column profile was taken with the Owen tube and attached sensors. A drogue (moving with the surface ~0.5m) was thrown overboard at the start of the profiling and was carried seawards by the current. Once the profile was complete, the Owen tube was lifted from the water, the boat turned, and the Owen tube lowered back into the water at about 0.8m depth. The boat then slowly motored downstream until it caught up the drogue. The Owen tube was lifted aboard again, the boat turned (on passing the drogue) and the same plug of water (approximately) was profiled again. This process was repeated (about 5 times) before ceasing at the seaward end of the monitoring zone. Thus both point profiling and towed fixed depth observations were made. From time to time a water sample was taken for calibration purposes (the exact closure time of the tube being logged for relation to the sonde data). Up to 5 times per survey a settling test was conducted, mostly immediately astern of the dredger or at the most downstream location (for logistical reasons). Typically three or four such transects were monitored on one ebb tide (transects taking just over one hour to complete).

A simpler approach involving less profiling was adopted during the before and after dredging surveys, when little vertical variability was encountered in the water column. If for logistical reasons the CHALLIS 2 had to spend time alongside the landing Pontoon at Westonzoyland, profiling and continuous (set depth) records were also observed from that static position.

Calibration/settling water samples were filtered in the lab within seven days of collection. Cellulose nitrate 0.2um pore membranes were used. Because of the high TSS concentrations and the absence of saline water (maximum salinity of 3 observed for short time) washing through of filter cakes with distilled water was not undertaken. The highest concentration samples required dewatering using the membranes, then being washed into porcelain weighing boats for weighing (due to the volume of the filter cake). Balance precision was 4dp gram. All results can be seen in Appendix 2.

2.5. Bed Sampling

An estuary bed sediment survey was undertaken at the beginning and end of the monitoring period (Table 1). Sampling was undertaken from a small inflatable boat, allowing navigation of the channel at very low water levels (maximum intertidal exposure). Seven sites were visited, spaced at about 400m intervals through the monitoring zone (Figure 2). At each site the condition of the banks/ intertidal was photographed and samples of the bed sediment were taken from immediately above the water margin on both he left and right banks, and from the channel centre using a small (0.05m^2) van Veen grab (Figure 6).

The shear-strength of the intertidal mud at the water's edge (dry) was measured using a shear vane designed for normal estuary mud [14]. This instrument (Figure 6) measures the shear resistance of the surface 10mm of an intertidal mud deposit, and can be used in the range 1-1.3kPa. In the event, and surprisingly, many of the sediments tested exhibited strengths greater than 1.3 kPa.

[14] P. Bassoullet, P. Le Hir 2007 In situ measurements of surficial mud strength: A new vane tester suitable for soft intertidal muds Continental Shelf Research 27 (2007) 1200–1205

Figure 6. Inflatable dinghy, grab and shear vane used for the bed surveys.

With most samples it was possible to collect the mud undisturbed by inserting a 100ml volume core. This set-volume sample allowed determination of the *in-situ* bulk/dry density of the deposits.

Particle size analysis was undertaken for all samples. Sediment was initially wet sieved at 63um. The coarser fraction was dried at 105^{o}C then dry sieved (0.5 phi sieve interval). The fine fraction was quantitatively subsampled using a stirrer/syringe system. One fraction was dried to determine total weight <63um, ground and stored for possible future use. Another fraction was pre-treated with hydrogen peroxide to remove organics, dispersed with sodium hexametaphosphate and the particle-size determined using the pipette method. This methodology is based on BS1377, adapted for marine rather than soil conditions. Silt and clay content analysis is based on sedimentation principles (cf optical measure of grainsize used in laser analysis). Mineralogy of the sand fraction was examined under the microscope.

3. The Receiving Environment

3.1. Morphology

The estuary channel through the monitoring zone is a sinuous channel (Figure 2) of simple cross-section, the sinuosity taking the form of short and straight reaches separated by often sharp bends, reflecting its man-made origin. The channel thalweg varies between +3 and +1.5m ODN through the zone and the bank crestline stays constant around 8m ODN (Figures 7 and 8). Much of the riverbank is artificial levee. Through the monitoring zone the width between bank crests generally increases from 30 to ~45m, and the cross-section area from about 85 to 120m^2. There is however considerable variation in these dimensions through the zone, with narrower, smaller area profiles tending to occur on bends. The low water channel is a metre or so deep at times of low river flow, with a zone of periodically inundated mud and vegetation (Figures 3, 4 and 8) extending upwards on either bank for some 5m vertically. This zone is invaded to some level by the tide for short periods over spring tides, but only reaches bankfull levels during severe river floods.

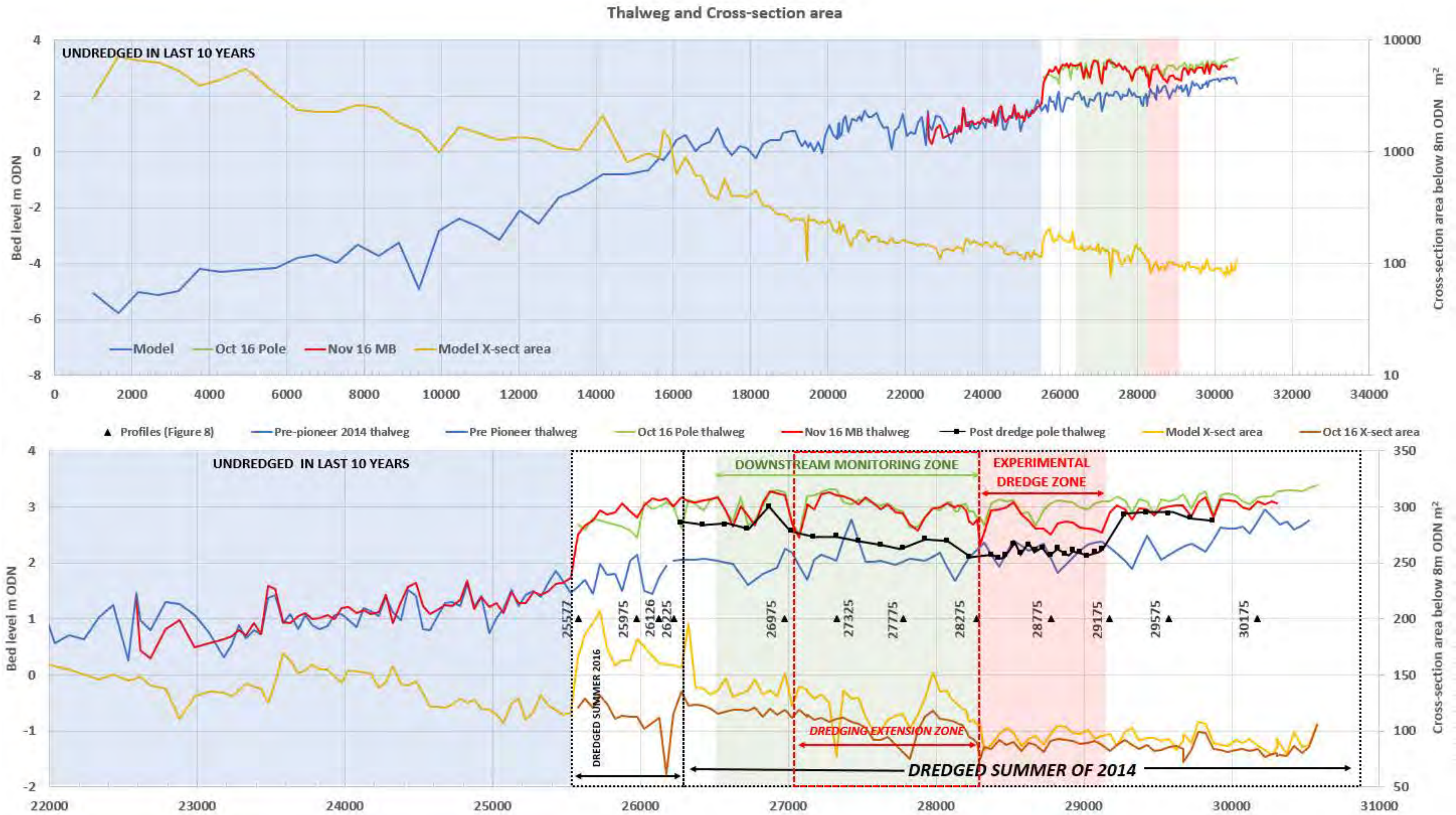
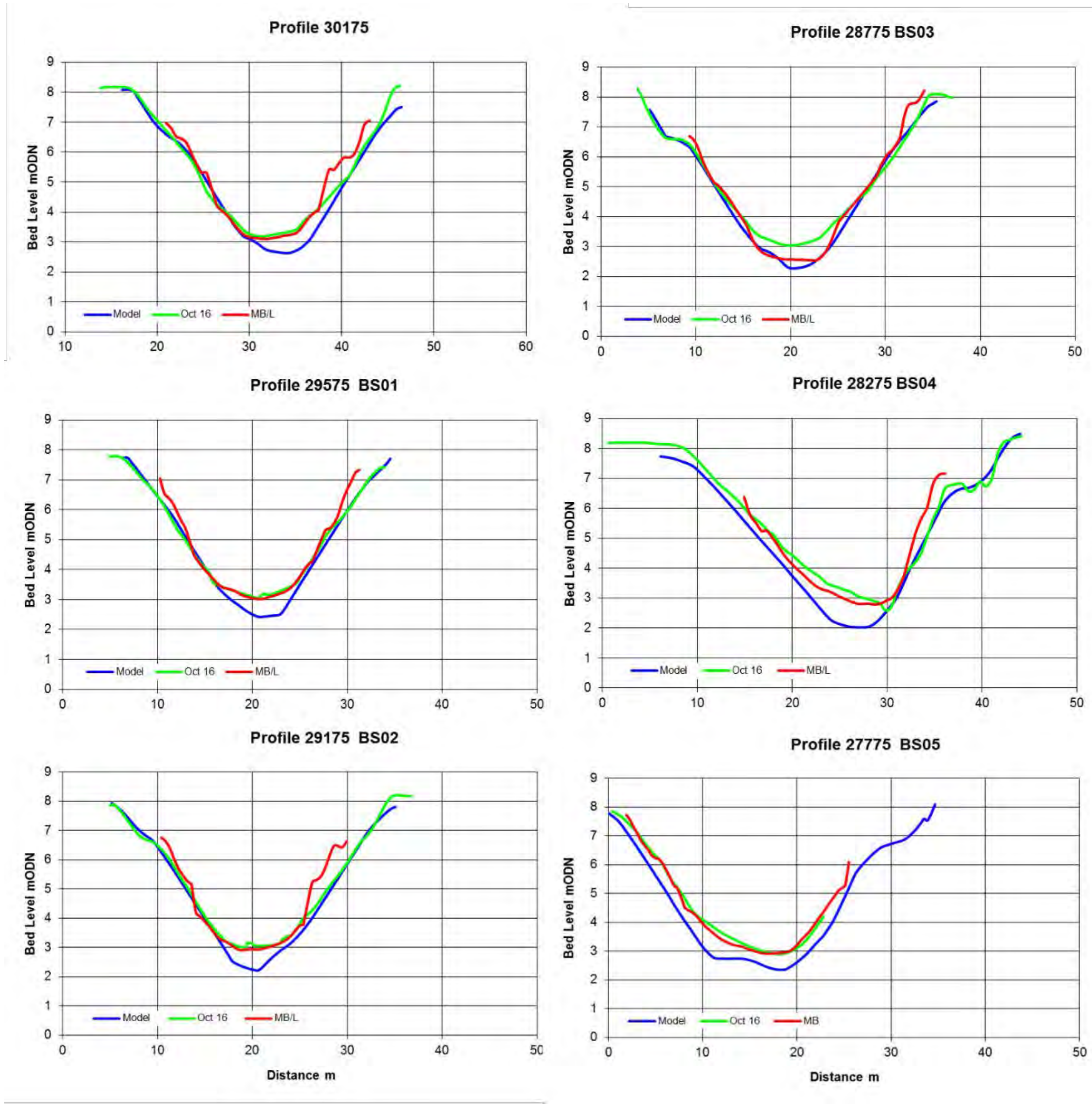


Figure 7. Long-sections of the Parrett estuary from various surveys. Top: whole estuary. Bottom: Upper reaches, including the EDZ and monitoring zone. For the 'Model' cross-sectional area data, all points including and upstream of kp 25577 (prof.101) are based on design profile data, below this point the 2014 survey data are used (explaining the marked apparent change at that kp). Cross-section areas are measured to bankfull (~+8mODN) levels.



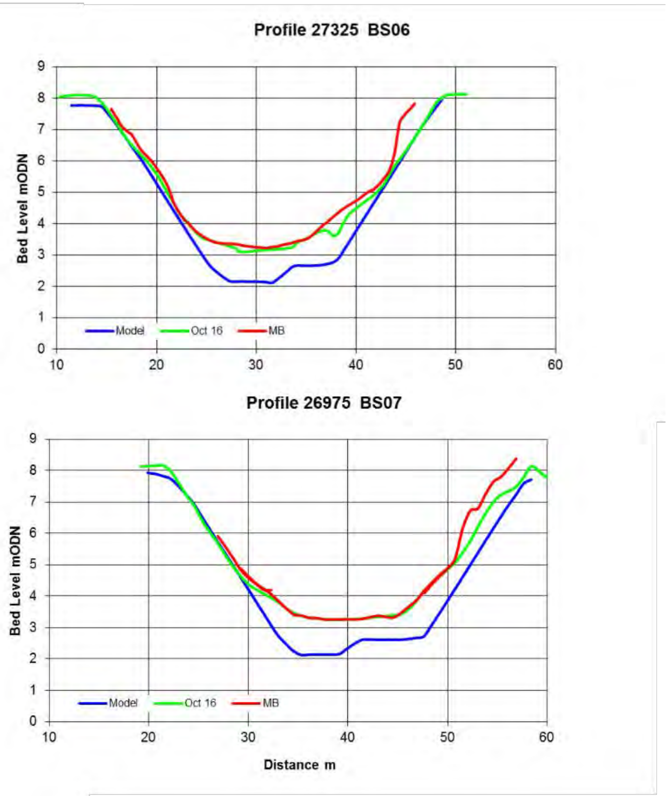


Figure 8A. Channel profiles within the monitoring zone. Note the ‘model’ profiles are based on design, not survey data (optimum condition).

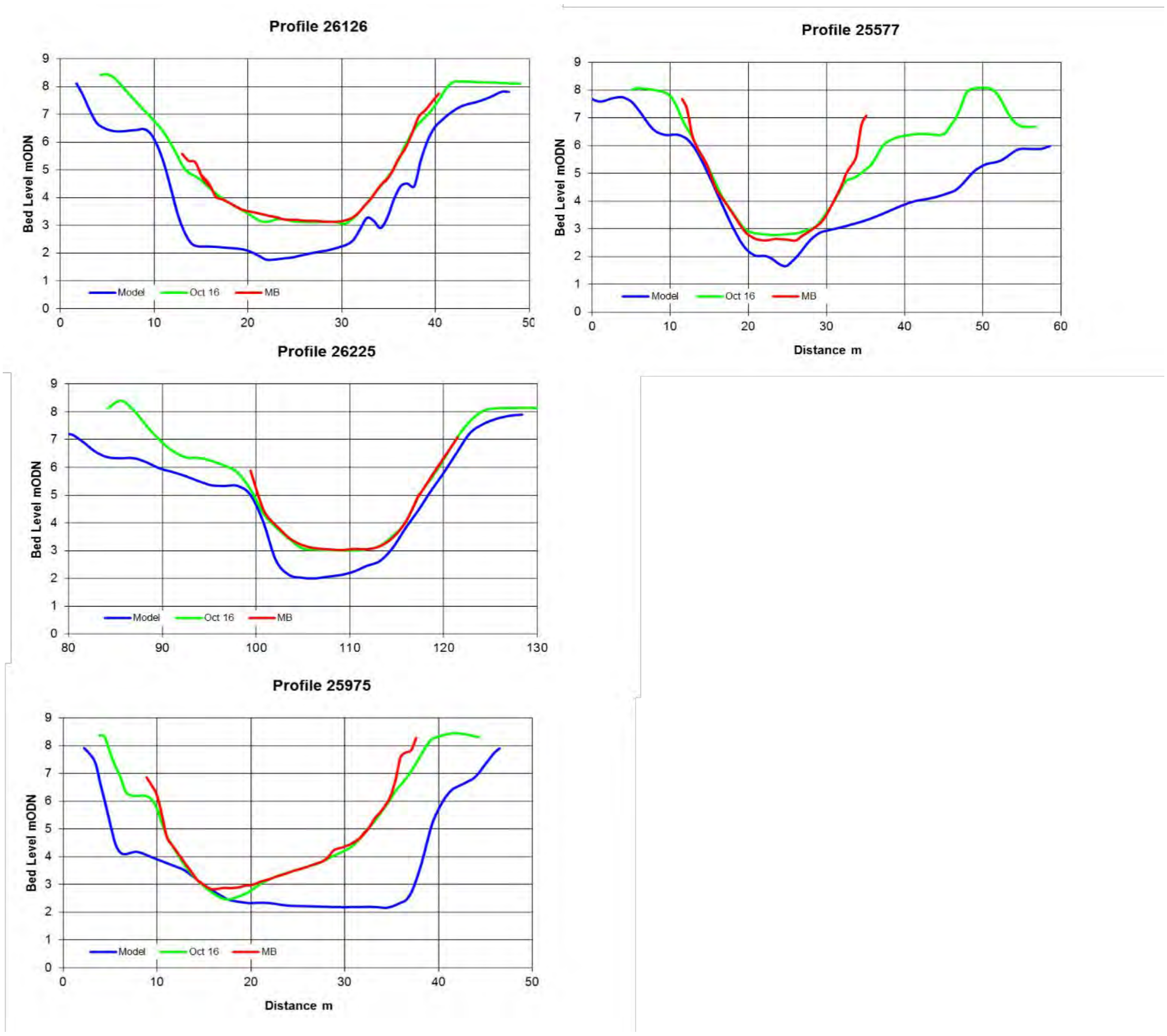


Figure 8B. Channel profiles in the reaches immediately downstream of the monitoring zone.

Rock armour reinforces outer bends, and dredging and other maintenance works ensure that the river does not laterally migrate out of the confining levees. The cross-sectional area of the channel does vary through time however, being subject to natural seasonal and inter-annual fluctuations in bed level in response to alternating cycles of erosion and deposition. Bathymetric (pole) surveys undertaken at 6 monthly intervals from April 2015 to October 2016 through the monitoring reaches (Figure 9 [15]) show a clear pattern of deposition (reduction of the cross-sectional area) through the summer months and scour (enlargement of the cross-section) through the winter months. The channel was largely free of dredging activity during this period, though the changes seen (primarily net deposition, Figures 8 and 9) probably reflect response to the unnatural widening of the channel sections resulting from the pioneer dredge activity in the summer of 2014 [16].

[15] Data and figure provided by R Kidson, SDBC.

[16] There is evidence that although the pioneer dredging increased the cross-sectional areas of the channel, the thalweg depth actually decreased by ~0.5m in the northern parts of the dredged reaches, reducing the thalweg gradient. R Kidson, SDBC, *pers com.*

In Figures 7 and 8, the red (November 2016 multibeam) profiles generally agree well with the green October (pole survey) data below +5m ODN, the deepening between surveys seen in the upper reaches of the EDZ reflecting the fact that dredging of this area had already commenced at the time of the November survey. Variations seen above +5m ODN are due to the inability of the laser data to discriminate vegetation from sediment, therefore limiting the combined multibeam/laser technology from mapping complete profile cross-sectional areas.

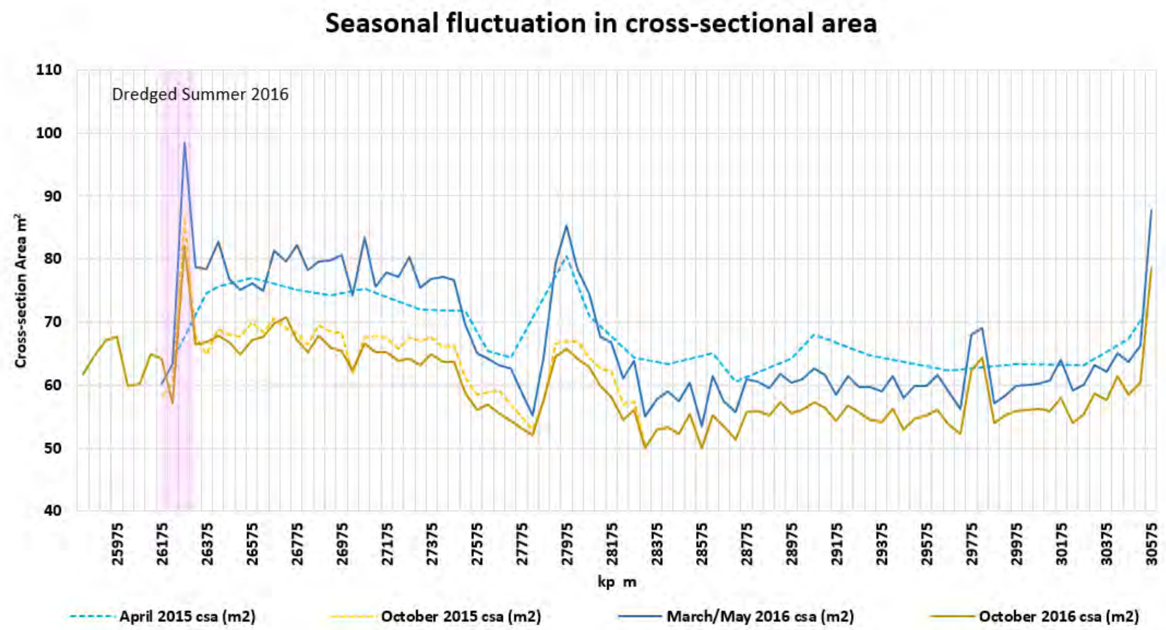


Figure 9. Natural seasonal fluctuations in channel cross-section.

3.2. Bed Sediment Characteristics

Clay and fine-silt sized sediment dominates the mud suspensions of the inner Bristol Channel [4]. Bed sampling and particle-size analyses (PSA) along the Parrett estuary in March and August 2016 (EA data) suggest both a longitudinal variation in the particle-size characteristics of the sediment, and a seasonal variation of those characteristics (Figure 10), viz:

- The sand content of the bed increases landwards, and during the winter. At the mouth sand content is <10%, increasing inland to reach 20-40% at a distance of about 20 km from the mouth, decreasing slightly again towards Burrowbridge, where the sand content was measured at 10% in late summer and 30% in late winter.
- The clay content of the mud fraction tends to decrease landwards, from 20-10% in late winter and 30-20% in late summer, the clay content seeming to build slightly through the summer.
- Coarse silt replaces fine silt landwards, with little apparent seasonal variability. At Burrowbridge, coarse silt is the dominant component of the bed.

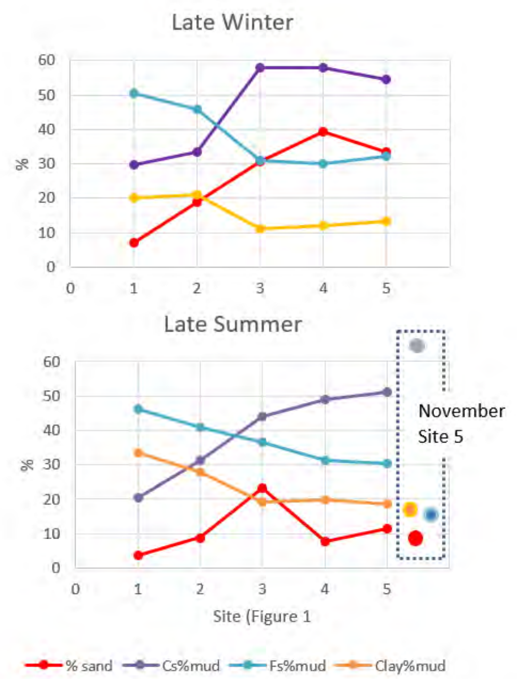
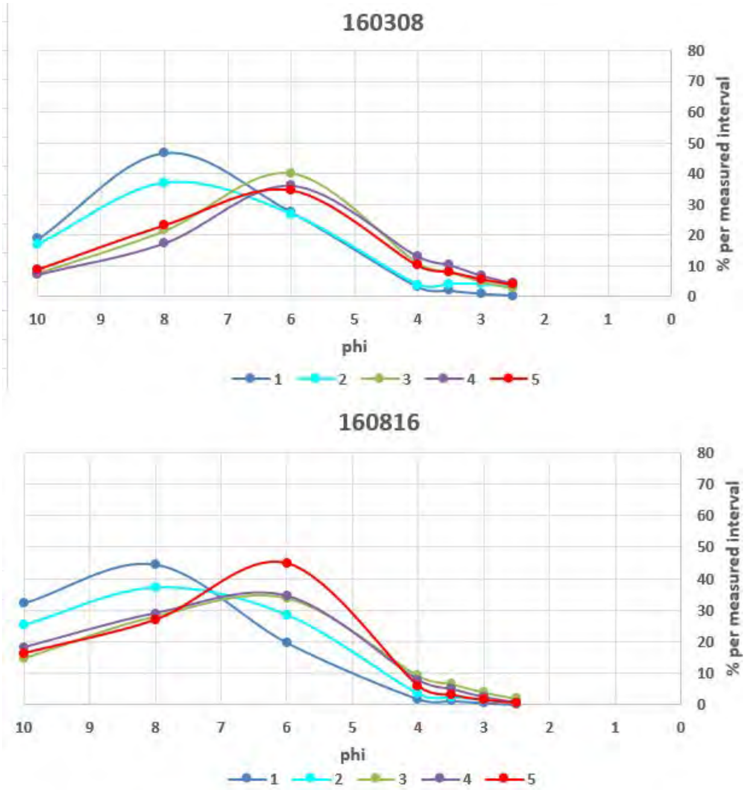


Figure 10. Particle size characteristics of intertidal bed samples along the Parrett Estuary in March (top) and August (bottom) 2016. For site locations see Figure 1. Site 5 equates to the present monitoring zone (upstream end).

%sand = % material >63um in total sample
Cs%mud = % coarse silt (>16um) in the mud (<63um) fraction
Fs%mud = % coarse silt (16-4um) in the mud (<63um) fraction
Clay%mud = % coarse clay (<4um) in the mud (<63um) fraction

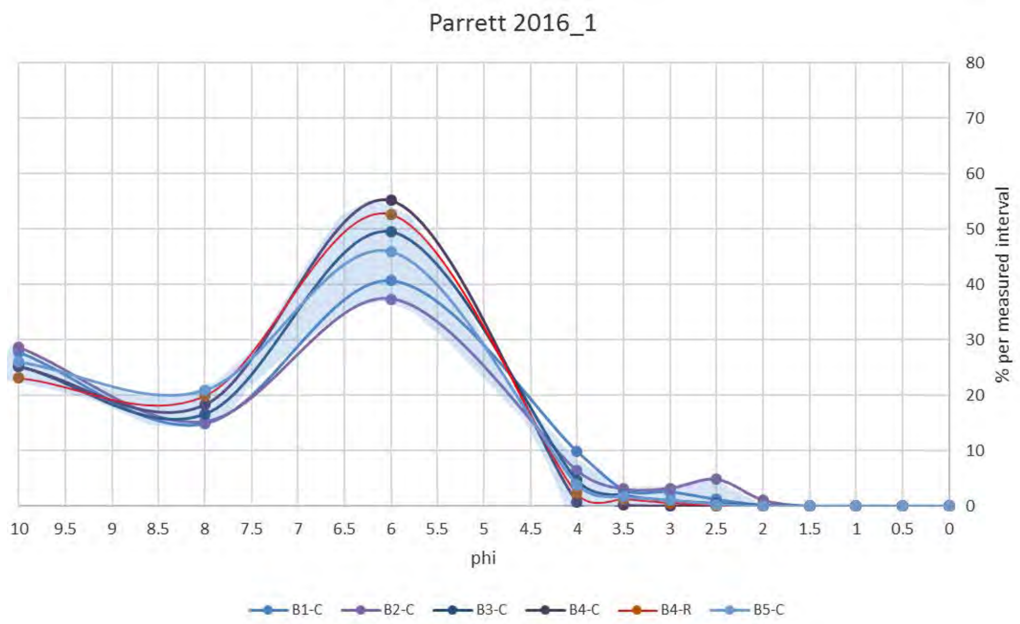
The averages (for the same sediment fractions) of all the 21 samples collected in mid-November at the initiation of the monitoring programme are shown in the lower graph of Figure 10. They correspond well to the EA site 5 data, although showing an even greater dominance of the coarse silt fraction. The latter difference may be an artefact of the different PSA methods used. The EA PSA data are presented as frequency distribution plots in Figure 11.



PHI	mm
1	0.500
2	0.250
3	0.125
4	0.063
5	0.031
6	0.016
8	0.004

Figure 11. 2016 EA data presented as frequency distributions

The frequency distributions for the 21 samples collected at the initiation of the November monitoring are plotted in Figure 12. It can be seen that they correspond well with the EA plots, and they also fall into two distinct groups, corresponding (with slight overlap) to channel centre samples and bank samples (the blue shaded area is the envelope of the plots in the upper graph, for comparison purposes). Summary data for the two groups are given in Table 2. Careful examination shows that within both groups there is a slight increase in the dominance of the coarse silt population (phi=6) from site B1 (landward end of the monitoring zone) to Site B7 (seaward end), contrary to the whole-estuary trend. Otherwise there seems no consistent longitudinal gradient in the bed sediment characteristics through the surveyed zone. Sand is sometimes present as minor fine/very-fine sand particle population, but normally forms just the coarse toe of the silt particle population.



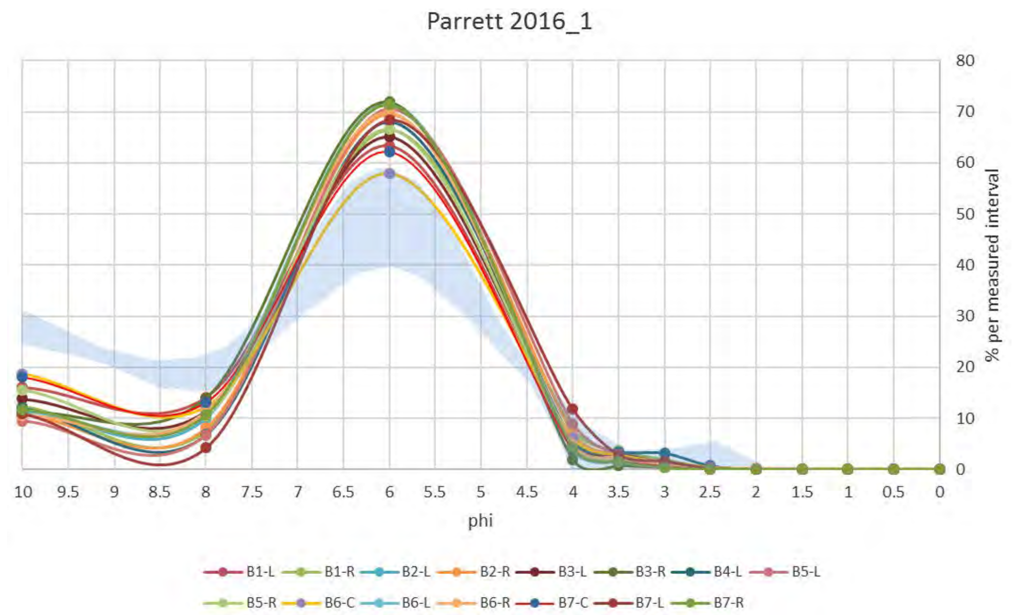


Figure 12. Discrete frequency distribution plots of the PSA data from the initial monitoring bed survey. C=channel centre, L=left bank, R=right bank (looking seawards). See Figure 10 for phi.

BANK GROUP

Field Sample ID	% sand (2mm-63um)	% silt & clay (<63um)	% of siltclay coarser than 16um	% of silt/clay finer than 4um	Dry Density $t\ m^3$	Bulk Density $t\ m^3$	Shear Strength kPa
B1-L	6.5	93.5	67.7	17.2	0.7	1.42	1.50
B1-R	13.8	86.2	77.0	14.3	0.77	1.48	1.50
B2-L	6.9	93.1	76.7	12.5	0.73	1.45	0.90
B2-R	11.7	88.3	78.6	12.2	0.79	1.49	1.50
B3-L	9.7	90.3	72.1	15.3	0.70	1.43	1.08
B3-R	3.1	96.9	74.2	11.4	0.71	1.44	1.50
B4-L	13.1	86.9	78.3	13.9	0.72	1.45	1.50
B5-L	13.1	86.9	81.3	10.9	0.78	1.48	1.50
B5-R	7.4	92.6	71.8	16.8	0.65	1.40	1.20
B6-C	11.0	89.0	65.1	21.1	0.69	1.43	
B6-L	6.1	93.9	76.0	12.0	0.77	1.48	1.50
B6-R	8.4	91.6	76.2	11.5	0.68	1.42	1.20
B7-C	6.6	93.4	66.6	19.4	0.62	1.39	
B7-L	16.5	83.5	81.9	13.0	0.75	1.47	1.10
B7-R	6.3	93.7	76.2	12.4	0.71	1.44	1.05
Average	*9.3*	*90.7*	*74.6*	*14.3*	*0.71*	*1.44*	*1.31*
St Dev	*3.7*	*3.7*	*5.1*	*3.1*	*0.05*	*0.03*	*0.23*

CHANNEL GROUP

B1-C	16.6	83.4	48.8	33.3	0.52	1.33
B2-C	18.7	81.3	46.0	35.2	0.49	1.30
B3-C	8.4	91.6	54.2	27.6	0.49	1.31
B4-C	1.2	98.8	55.9	25.5	0.55	1.34
B4-R	4.3	95.7	55.1	24.2	0.72	1.45
B5-C	7.1	92.9	49.5	28.0	0.54	1.34
Average	*9.4*	*90.6*	*51.6*	*29.0*	*0.55*	*1.34*
St Dev	*6.9*	*6.9*	*4.0*	*4.4*	*0.09*	*0.05*

Table 2. Summary PSA, density and shear strength data for the two sediment groups on the initial survey. Note the shear vane could only read to 1.3 kPa so 1.5 kPa values shown here indicate 'failure not reached'.

Comparing the two (bank and channel) groups it can be seen that there is:

- No variability in the relative sand/mud composition between groups
- A large variation in the relative contribution to the mud fraction of the coarse-silt versus fine-silt/clay fractions, the bank group containing much higher coarse silt and lower clay.
- Higher density in the bank group sediments compared to the channel group. This looks to be a function of the differing silt/clay compositions of the two groups (see density/PSA correlations plotted in Figure 13).

- Three samples do not fall clearly into either group. Sample B4-R is a relict sediment collected from an eroding, armoured outer-bend cliff, and can be explained by not being a product of the present day sedimentary regime. Samples B6-C and B7-C are from seaward end of monitoring zone, where the channel profile widens considerably, and extensive channel shoaling is occurring (Figure 8A). These two samples may therefore flag an important change in the channel floor sediment regime that begins to occur at this chainage.

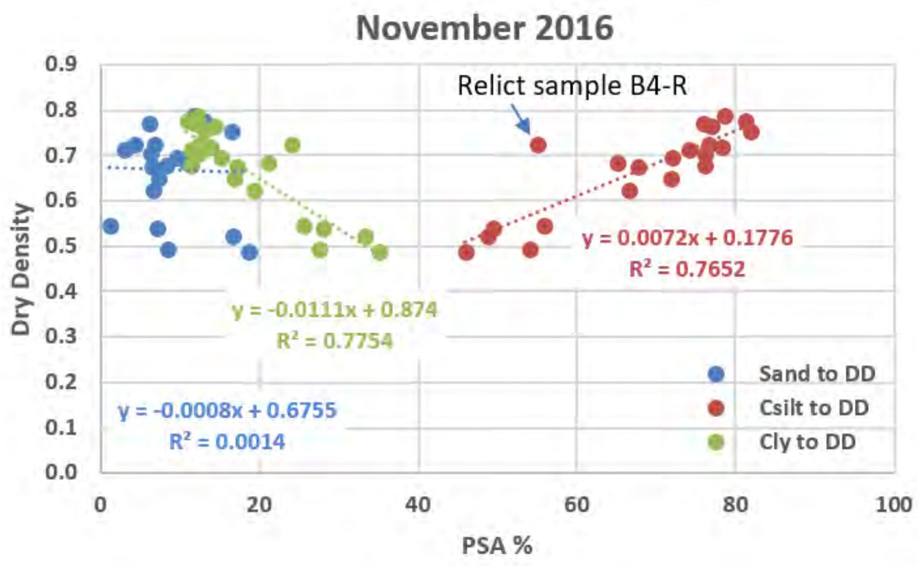


Figure 13. Sediment density to particle-size interdependencies, initial bed survey.

Shear strength data are available for bank data only. The shear vane used could only measure up to 1.3 kPa so values recorded as 1.5 kPa simply indicate that failure did not occur. The values (mean at least 1.3 kPa and lowest value seen 0.9 kPa, Table 2) are surprisingly high for natural estuary mud deposits. Analysis showed no, or very poor, correlation between shear strength and density or any of the PSA characteristics. This lack of correlation suggests that history (consolidation/drying time) is probably the primary control of shear strength. It was not feasible to make shear strength measurements on the inundated channel floor, however the appearance of the grab samples also suggested a high degree of consolidation/shear strength, comparable to the bank values.

The visual observations on the intertidal mud surfaces made during the bed sampling survey are reproduced in full in Appendix 3. The following key features emerged:

- At the landward end of the monitoring zone reeds often come down to the water's edge along much of the length of the banks (Figure 14 A). Bare sediment 'bays' are present between reed zones, and are quite steep in places. The bays become larger and more frequent going seawards. At the furthest seaward extremity of the survey area the reeds are rarely present along the LW mark, and wide, shallower angle bare mud zones typically dominate (Figure 14B).
- At the landward end of the monitoring zone the sediment surfaces are not smooth and tend to be criss-crossed with both lateral (90° to the river axis) and longitudinal features (Figure 14C). The latter probably form as micro-cliffs at the water's edge during higher stage levels, or are very minor slump faces. The origin of the former is unclear; they seem to be degrading features and could either be formed as downslope rain-wash rills, or be the remnants of transverse bedforms (likely a mix of both origins).

Figure 14. Photographs of key intertidal bed features, pre-dredge survey

Figure 15. Site BS04 Left bank, showing transverse ripple marks and micro-cliffing.

- Further south, the transverse bed features become stronger in many places and are clearly ripple marks (Figures 14B & 15, wavelength of about 20cm). Drainage seeping from the bank is guided by, and enlarges, the ripple troughs. The ripples tend to be symmetrical, not suggesting a direction for the formative flow.
- No evidence of active slumping on a large scale (few minor features).

3.3. Fluvial Discharge

Freshwater passes through the region on its way to the sea in a complex fashion involving the main watercourses (Tone and Parrett), sluices and spillways, floodplain water storage areas, bypass channels and pumping stations (Figure 16). As a result of the complexity of this system there is a paucity of data available to describe (statistically and as time series) the throughflow of fresh water.

Water levels are recorded at many sites on the river, the five relied on in this study are plotted (in green) in Figure 1. The recorders at Saltmoor and Northmoor pumping station best represents water levels at the landward and seaward ends of the monitoring zone respectively. Data are available 2012-2017 (plotted in Figure 17). The lower edges of the blue dot zones represent water level attributable to river discharge alone, and show clearly the periods of peak river discharge between December and March each year. The upper edge of the blue dots shows the monthly peaks of the effects of the highest lunar tides, and (in winter time and occasionally during other seasons) the river flood peaks.

All the estuary stage data are plotted in Figure 18 (A, B & C, November 16, December 16 and January 17 respectively). For each month of data at the Northmoor and Saltmoor sites an analysis has been undertaken to determine the Base River Flow (defined as the lowest water level found between one hour before and six hours after LW at Hinkley point, shown in centre graphs of Figure 18). This plot is probably the best available representation of levels representing true river water flow through the Parrett. Some patchy EA river discharge data are available and are used to annotate the base flow in Figure 18A (November, 5-40$m^3 s^{-1}$). During December and January river discharge probably varied between 10 and 20 $m^3 s^{-1}$. It is possible that the slight increases in Base River Flow levels seen (during all three months) to coincide with the periods of spring tides are the result of incomplete escape of tidal waters from the uppermost tidal reaches per tidal cycle, but rainfall events may also be the cause. Minor stage events were recorded in the upper catchment areas on the 9th November and the 10th - 15th December and also in January, possibly explaining these base flow variations. The same graphs show the normal persistence of a low tide steady downstream head of water between the Saltmoor and Northmoor sites, of up to 0.5m at times of low river flow reducing to 0.2m or less at times of higher river flow.

Figure 16. The Parrett and Tone: Drainage routes, spillways, pumping stations and water storage areas. The Severn Estuary is to the north (top).

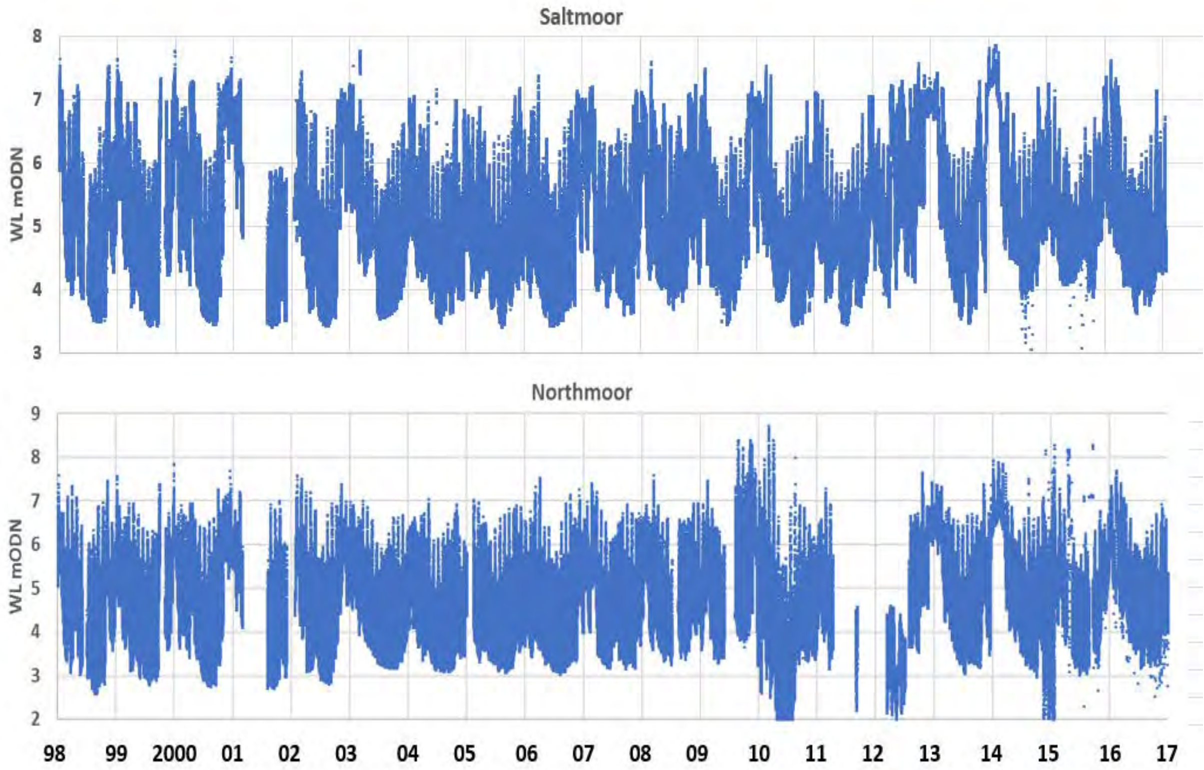


Figure 17. Water levels recorded at Saltmoor and Northmoor Pumping Stations 1998-2017. (These data seem to contain some sensor malfunctions at low water levels).

3.4. Tidal Regime

The Bristol Channel has a very large tide range, with some 14m recorded between the highest and lowest tides. The standard tide levels for Hinkley Point, the gauge at the western edge of Bridgwater Bay, are given in Table 3.

	m CD	mODN
Highest astronomical tide	13.02	7.12
Mean high water springs	11.83	5.93
Mean high water neaps	8.91	3.01
Mean low water neaps	3.59	-2.31
Mean low water springs	0.92	-4.98
Chart Datum (CD)	0	-5.9
Lowest astronomical tide	-0.19	-6.09

/ater Level =
range) + 0.1876

Table 3. Tide levels at Hinkley Point and high water level to tide range correlation equation.

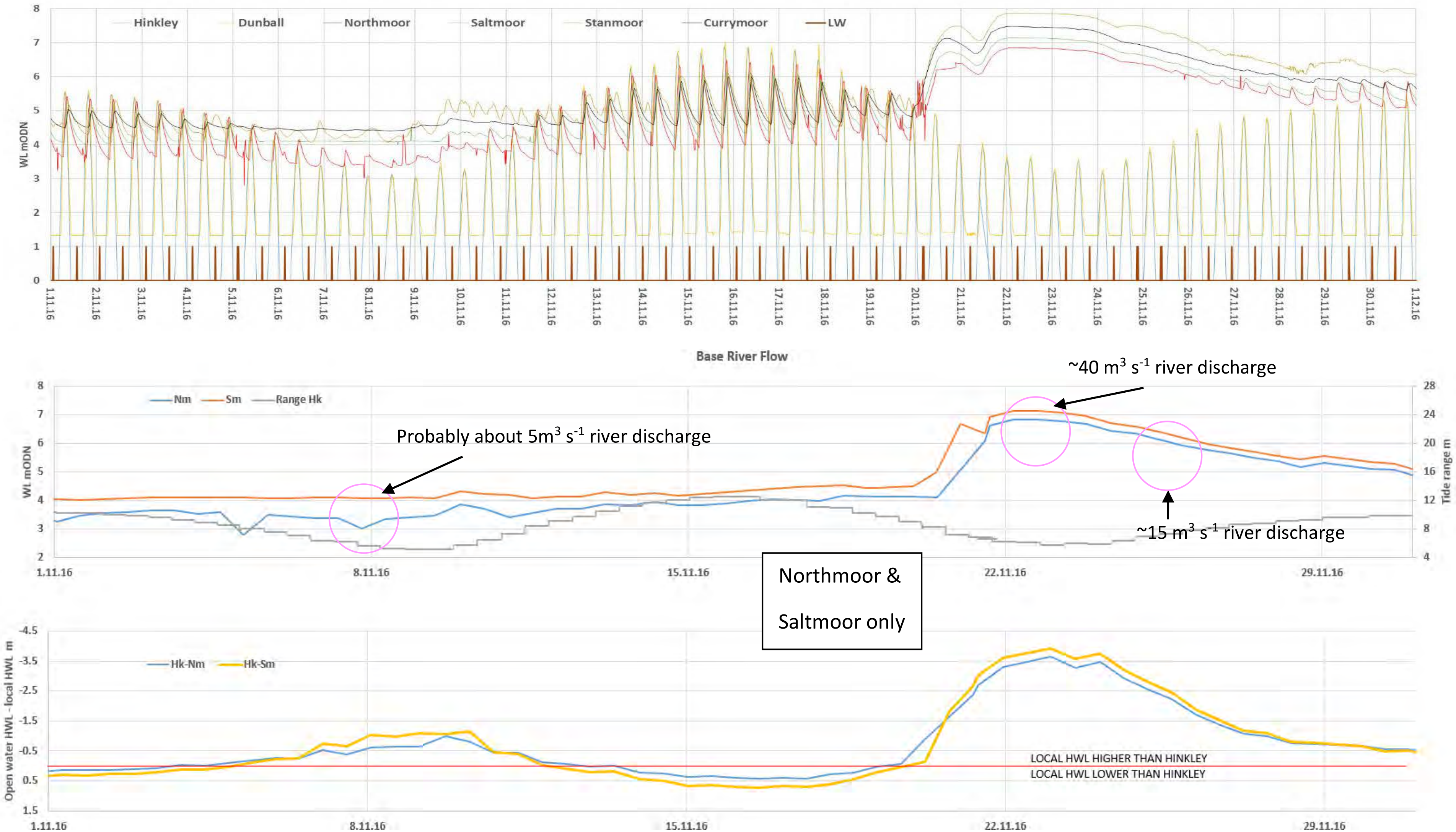


Figure 18A. November 2016 estuary water levels. Top: stage records from all sites. Middle: Base River Flow. Bottom: HW level differences on Hinkley

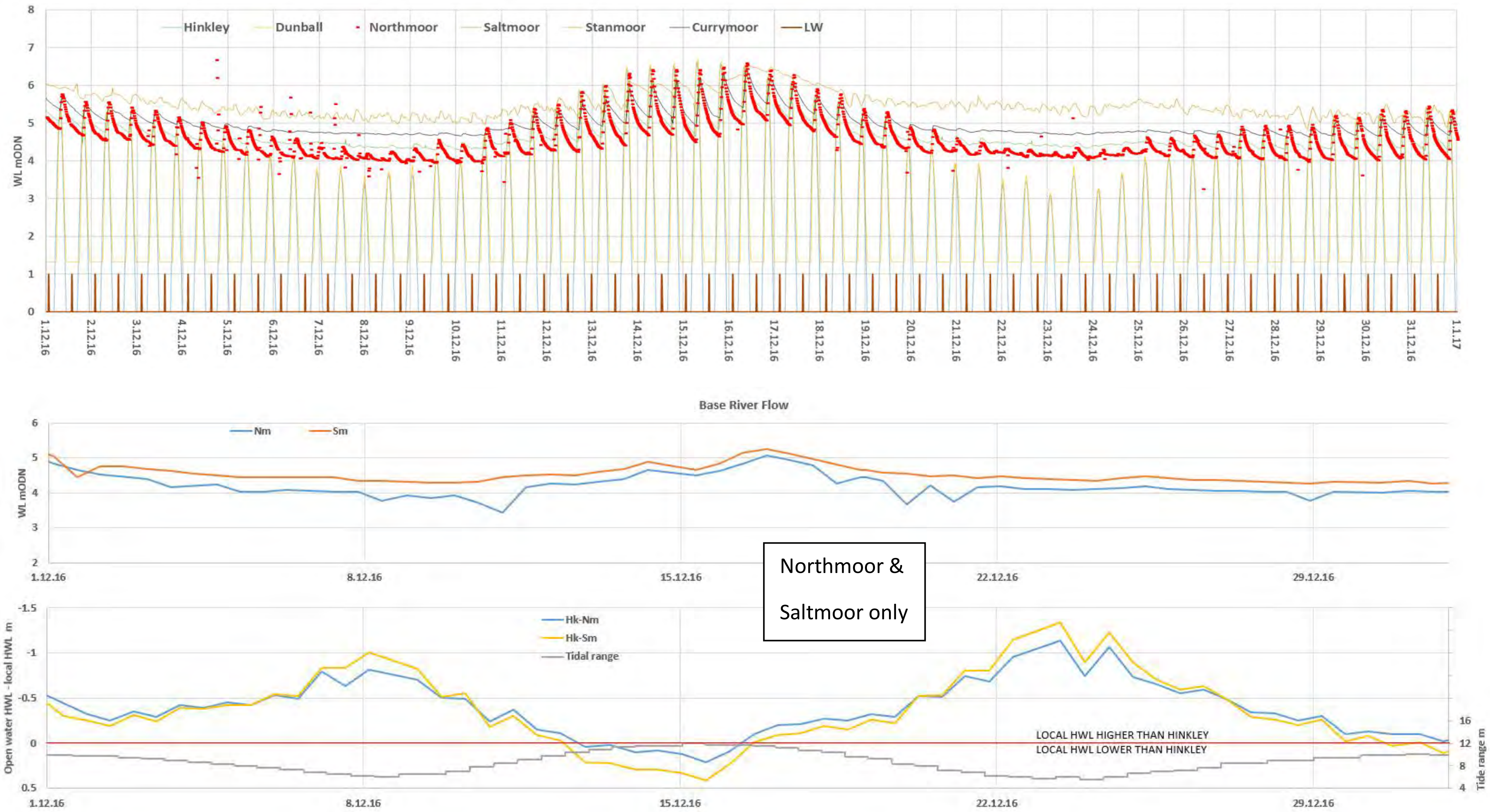


Figure 18B. December 2016 estuary water levels. Top: stage records from all sites. Middle: Base River Flow. Bottom: HW level differences on Hinkley

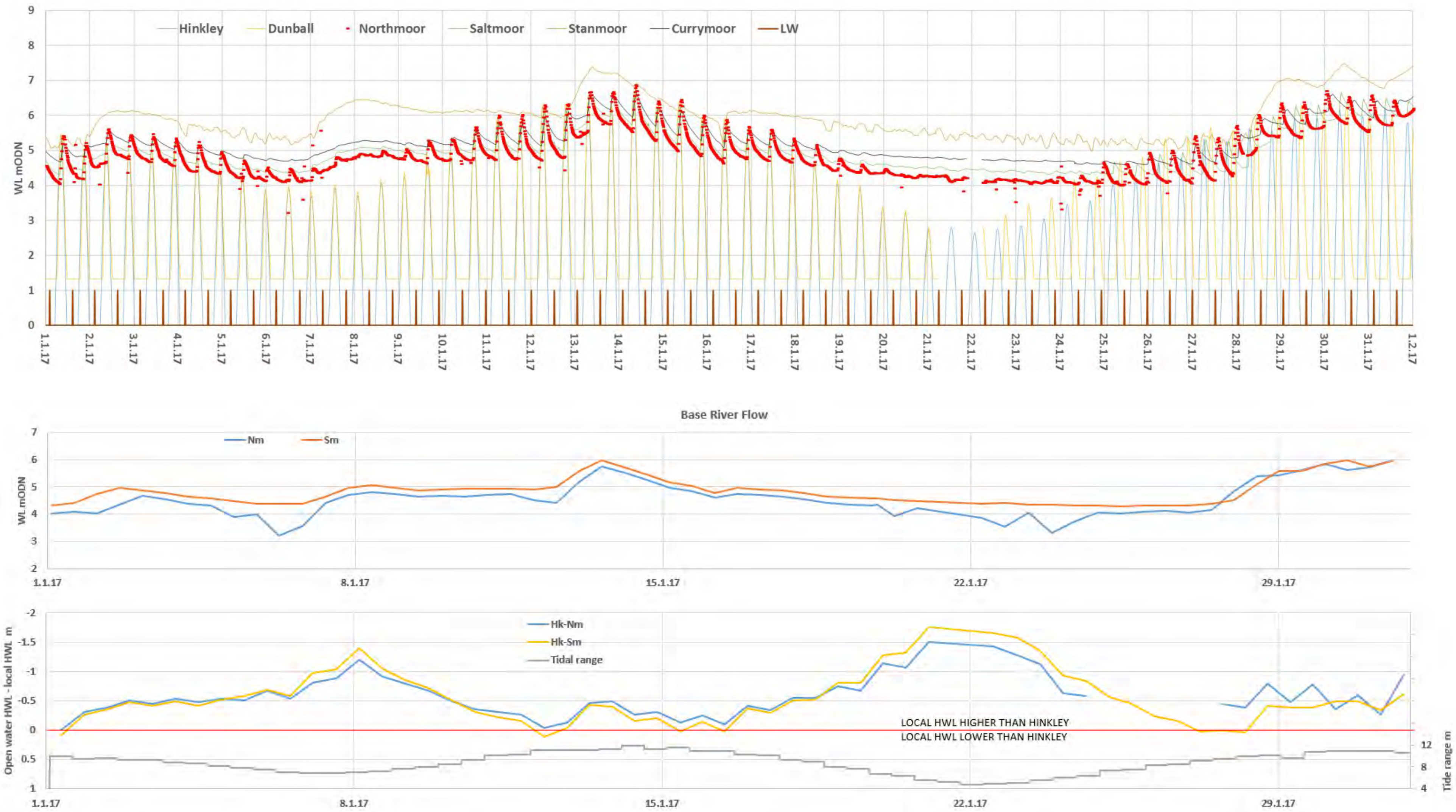


Figure 18C. January 2017 estuary water levels. Top: stage records from all sites. Middle: Base River Flow. Bottom: HW level differences on Hinkley.

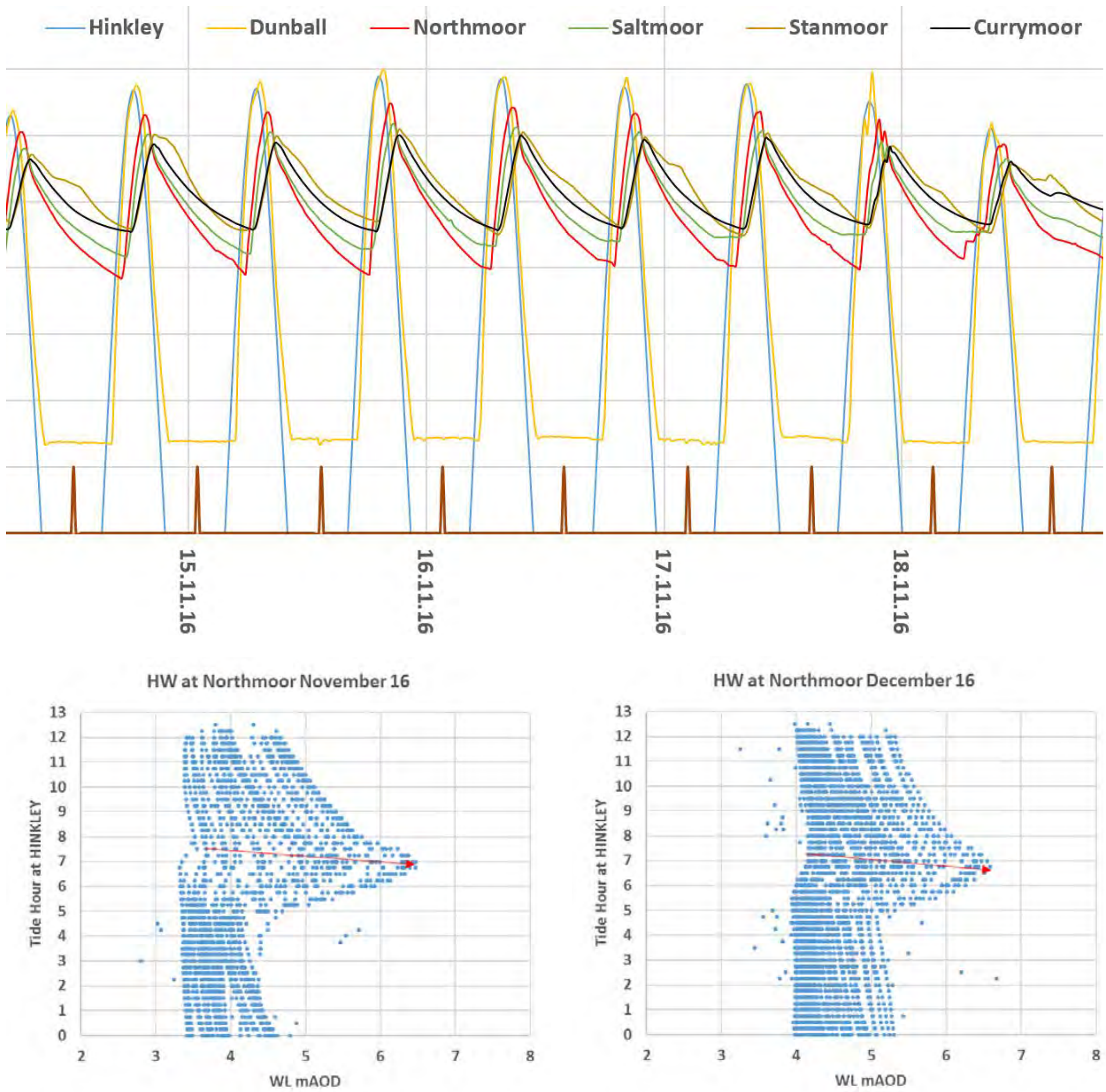


Figure 19. Detail plots of compared levels and timings of the tidal curve in the upper estuary.

Recorded water levels in the estuary through the survey period, November, December 2016 and January 2017 are shown in Figure 18A, B & C respectively. Figure 19 (top) shows an expanded part of the November data plot. The levels seen are a combination of tidal and fluvial effects, less so in December and January when river discharges were lower than the November peak flow..

The combination of high tidal range and a long narrow morphology strongly modifies the form of the tide as it progresses up the Parrett estuary. Figures 18 &19 data demonstrate the following features of the progression:

- The tide-level curve is asymmetrical, with a steeply rising flood limb and a long drawn-out ebb limb. On spring tides the flood typically begins about 2 hours before local HW and the ebb occupies the remainder of the (~12.5 hour) tidal cycle, with the water level still falling until the start of the flood. This situation sometimes generates a small bore at the beginning of the flood, with a ~0.3m high wave progressing upstream.

- There is a lag in the local time of HW as the tide wave moves up the estuary, with a spring tide one hour difference between HW at Hinkley Point and HW at Northmoor, and a 2 hour lag between Hinkley HW and HW at the tidal limits (Stanmoor recorder on the Parrett and Currymoor recorder on the Tone). This lag time can increase by a further half-hour on neap tides (Figure 19 bottom graph).
- As the thalweg bed level at Northmoor is ~+2.5m ODN, and on low flows there is always at least 0.5m of water in the river (water surface at +3m ODN), neap tides (Table 3) are only just felt at this site, and hardly any semidiurnal effects at all are seen at Saltmoor where levels are ~0.5m higher. Low neap tide HW takes the form of a backing up of river flow rather than the passing of the landward-flowing front of the rising tide. The bottom graphs in Figures 17 and 18 show the local high-tide water level (at Northmoor and Saltmoor) compared to the level reached at Hinkley Point. It can be seen that when the tidal range at Hinkley is less than about 8m, the high water condition in the monitoring zone (between the Northmoor and Saltmoor sites) is one of backing up of river water, with the Saltmoor HW level greater than that at Northmoor. At higher tidal ranges the HW level at Northmoor is greater than that at Saltmoor, consistent with the passing of the crest of the tidal wave and some dissipation of its energy between the two sites. This model of the (low river discharge) tidal mechanism and lag times is summarised in Figure 20. High river discharge modifies this model, increasing water levels relative to Hinkley and reducing lag times (to as low as ~30 minutes).

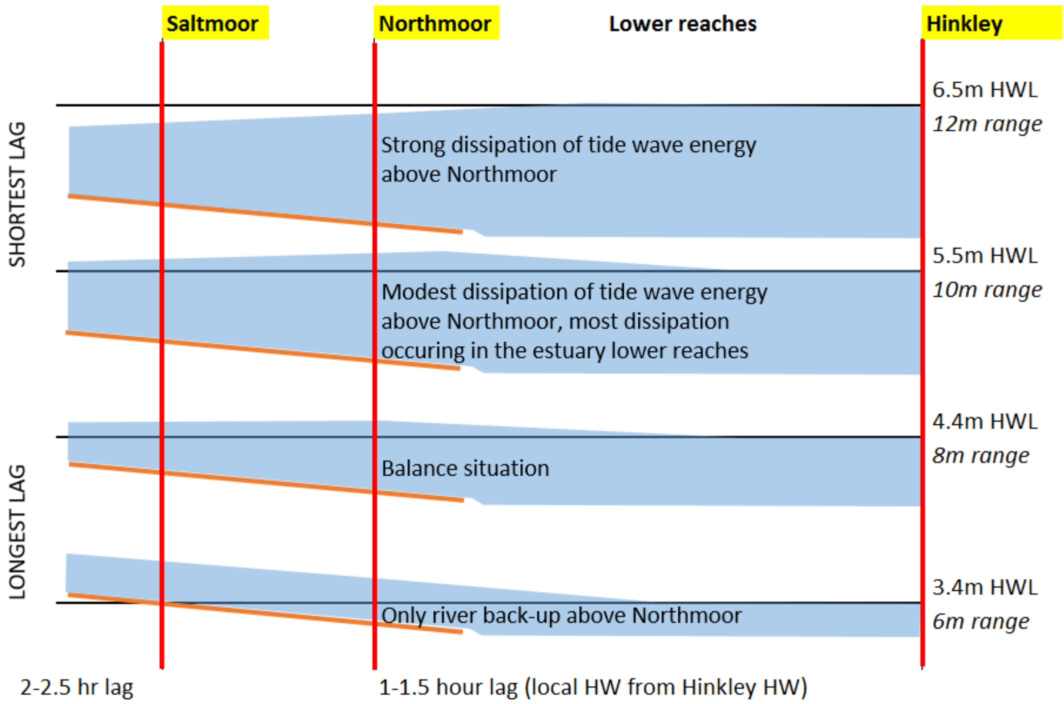


Figure 20. A model of high tide levels reached in the upper Parrett estuary compared to offshore tide levels, illustrating the changed drivers of water level elevation between spring and neap conditions.

In November at the Westonzoyland autonomous near-water-surface WQ sensor the mean and median salinity values were 0.50 and 0.47 respectively. The minimum salinity was <0.01 and was seen at the time of peak river discharge. Higher than the median salinity values were seen once the tidal range at Hinkley rose above about 11m, that is on high springs. The values rose through the flood, peaking at HW, with the greatest value (7.92) coinciding with the highest tide (16th). Manned monitoring was undertaken the same day commencing exactly at HW in the centre of the experimental dredging zone. Values recorded were generally around 1.5, rising to 2.9 near the bed on one cast. At the Burrowbridge permanent sensor site the equivalent mean, median, maximum and minimum salinity values through November were 0.44, 0.47, 1.01 and <0.01 respectively.

In December no manned surveys were taken over high spring tides. The Westonzoyland sensor recorded mean, median, maximum and minimum salinity values of 0.52, 0.47, 2.0 and 0.02 respectively, very similar to the November data except for the maximum value (spring tide maximum ranges were lower in December, Figure 18). The equivalent values from Burrowbridge were 0.51, 0.47, 0.68 and 0.01.

The salinity data collected during November and December (with low river flow for much of the period) indicate that these upper reaches of the Parrett estuary lie above the zone of saline water intrusion. No marked salinity stratification was observed, and maximum values were low (reaching 7 at times of very low river flow and highest annual tide range). Data collected during July and August 2008 at Partrac sites 1-7 (Figure 1) show similar/lower salinity values (Table 4). Maximum tidal range at that time was probably slightly lower than conditions seen in November 2016, and minor freshwater flood peaks were also reported

Site	Salinity (PSU)		
	Minimum	Maximum	Average
Site 1	0.20	3.39	0.30
Site 2	0.20	0.34	0.27
Site 3	0.20	0.41	0.30
Site 5	0.17	0.26	0.23
Site 6	0.17	0.26	0.23
Site 7	0.20	0.31	0.25

Table 4. Salinity statistics July/August 2008 at the Partrac sites (Figure 1).

Tidal currents were not directly recorded during the November-December 2016 monitoring. However average current speeds could be roughly determined from the time it took the drogues to pass though the monitoring reaches during manned monitoring exercises (Section 2.4). Drogue runs were made during a ~3 hour period immediately following local HW. Mean velocity could be determined over a 1.5 to 2km set of reaches. The results are plotted in Table 5. Fastest velocity (1.2 m s^{-1}) was encountered in the period immediately following HW on the day of the highest spring tide and very low river flow. Spring tide/low river flow velocities observed at other times lay in the range 0.56 – 0.96 m s^{-1}. The lowest velocity seen was on the 25th November during the period of peak river flow, when no tidal effects were evident (Figure 17). Both the latter runs showed velocity values of ~0.46 m s^{-1}. These slower flows at higher river stage are consistent with the lower water surface gradient that persists under these conditions (Figure 18 middle graph). During the declining river flood limb velocities increased again to 0.69-0.78m s^{-1}.

These data are very consistent with observations made by Partrac in 2008, at two sites (in and below the monitoring zone, Figure 1) and at 1m above the bed. These data are reproduced in part in Figure 21. The plots show peak velocities at high water, declining slowly through the long ebb period, then dropping to near zero just before the beginning of the flood tide. Ebb values on spring tides were around 0.8m s^{-1}, consistent with the drogue tracking results. On neap tides velocity maxima drops to about 0.6m s^{-1}. At the end of the period shown there was a minor river flood event, during which the strongest velocities were seen (reaching ~1m s^{-1} at site 2, within the monitoring zone). This increase in velocity contrasts with the marked reduction in velocity seen in November during a much more substantive river event. It is possible that this difference relates to differing water-depth to channel cross-section areas between minor and major flood events.

Date *Nov*	**Run**	**Velocity** *m/s*	**Condition**
14	1	0.8	Spring tide, very low river
16	1	1.2	Highest spring tide, very low river
	2	0.62	
18	1	0.56	Spring tide, very low river
	2	0.96	
25	1	0.46	Peak river flow
	2	0.47	
28	1	0.78	Declining but high river flow
	2	0.78	
	3	0.69	

Table 5. Reach-averaged water velocities from drogue tracking.

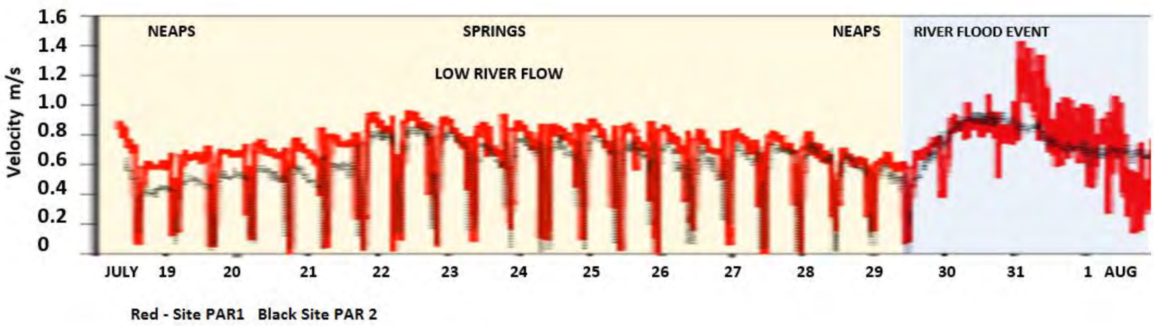


Figure 21. Partrac water flow data for late July 2008 at sites within and downstream of the monitoring zone (Figure 1). Velocities recorded at 1m above the bed.

3.5. Human Activity

As covered in Section 3.3, this system of watercourses is very much under human control. Maintenance bank works and dredging to maintain depths and channel cross-sections is one aspect of that control, with changes occurring over timescales of years and decades. Water diversion however, through use of sluices and pumps, will change on an hourly-through weekly timescale. During the November-December 2016 monitoring period, there was a two day period (21-22nd Nov) when the Parrett spillways overflowed, followed by approximately 7 days, when most of the main Pumping Stations were operational..

3.6. The Natural Sediment Regime

The bed sediment survey undertaken clearly shows that a) cohesive sediment dynamics will dictate the sediment transport processes that occur in this area and b) once in motion, processes of sediment suspension (rather than bedload transport) will dominate. Some rolling of material along the bed (gravel particles, highly consolidated mud clasts/balls) may occur at times of highest flow velocities, but they are likely to play a minor role in the sedimentary regime.

Data on the natural suspended sediment regime have collected as follows.

- Autonomous surface water turbidity recorders (WZ and BB) were deployed on 20th of October and ran until 14th November before dredge works commenced
- The same recorders ran from 19th December until 16th January 2017. The latter data set can be regarded both covering the dredge recovery period and (if there is no noticeable post dredging level of effect) the natural system. These data are initially and cautiously examined here on the basis of the latter premise.
- Manual turbidity profiling was run on the 14th November, the day before dredging commenced, and also on the 5th December, a few days after the completion of dredging. Again the latter day of data may show dredge recovery effects, but are initially examined in this section.
- Partrac data are available from 2008-9.

PRE-DREDGING

The manual turbidity profiling data are considered here first, as they provide insight into how much vertical variation in turbidity is present, and therefore how representative the surface water sensors are of the full situation. The survey was undertaken on the 14th November, with low river flow, tidal range 11.6m (high spring), HW at Hinkley 5:53 GMT (6.26m OD) and HW at Northmoor 07:00 GMT (6.04m). Monitoring began at 8:15 and ran through until 12:30. For the first two hours the vessel was stationary alongside the pontoon at Westonzoyland, during the next 1.25 hours a drogue-track run was made through the monitoring zone, and the final hour saw stationary observations alongside the pontoon again. Observations at a fixed height in the water column (~0.8m below the water surface) are plotted in Figure 22 and profile data in Figure 23.

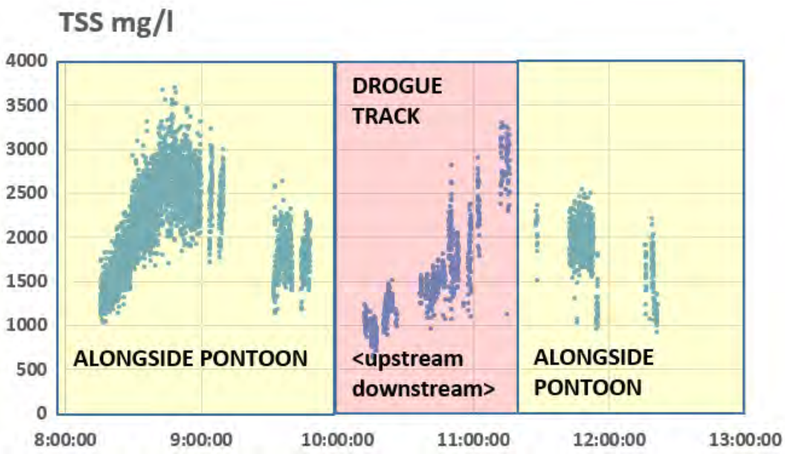
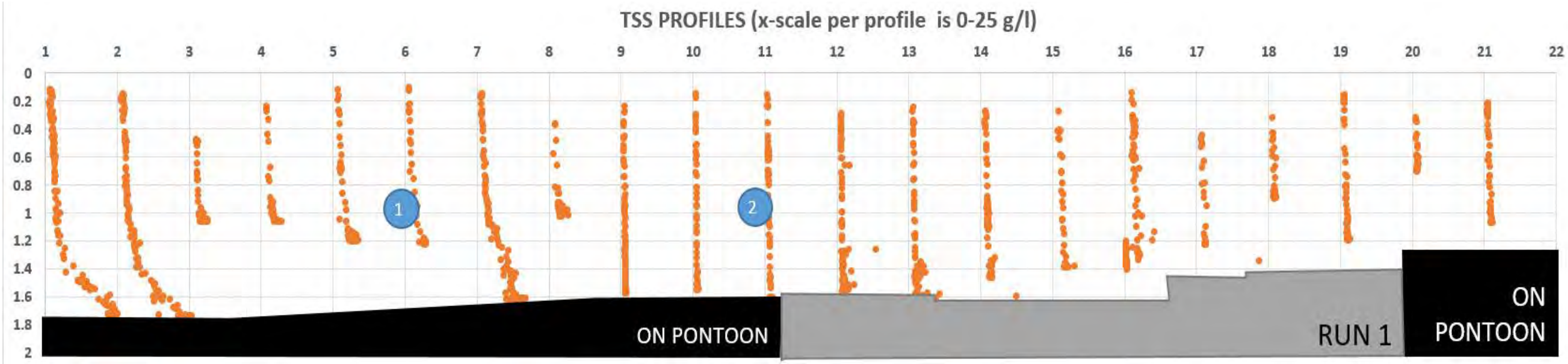


Figure 22. Pre-dredge Total Suspended Solids (TSS) data, 14th November 2016, observations at a set depth (time vs TSS plot).

Mean = 1980 mg/l
Median = 1958 mg/l
Maximum = 3700 mg/l
Minimum = 542 mg/l



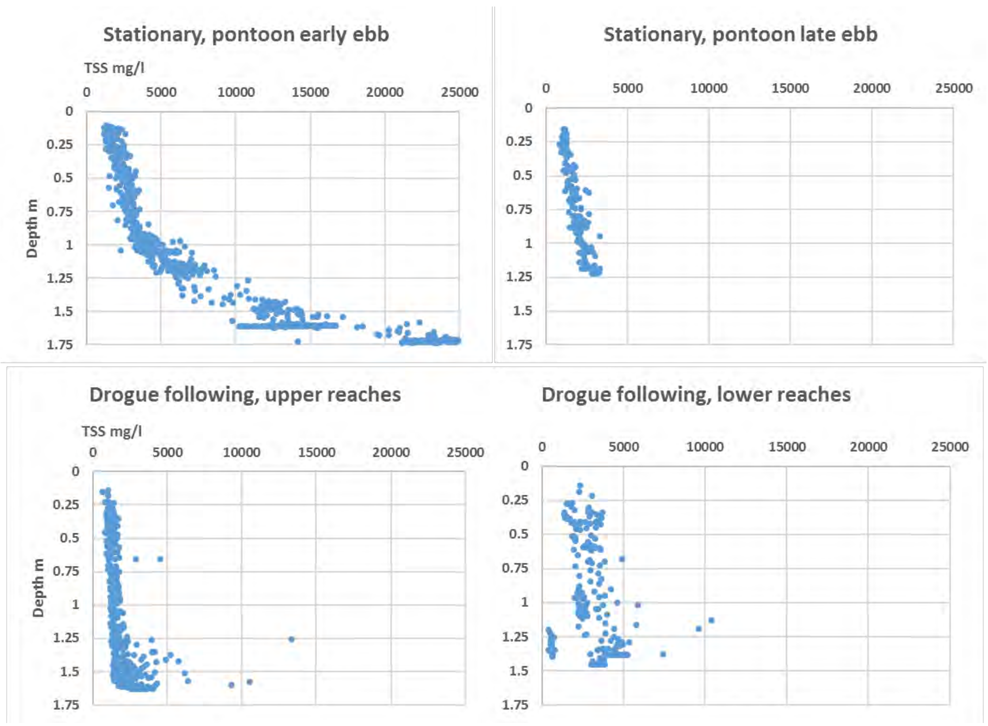


Figure 23. Pre-dredge Total Suspended Solids (TSS) data, 14th November 2016, profile observations (y-axis is depth in metres).

Top: All profiles in time sequence. Middle: All readings while moored alongside the pontoon, divided into early and late ebb datasets. Bottom: All drogue tracking data (following the same plug of water as it moves down the estuary), divided into upper and lower reaches.

Numbered blue circles are water samples taken for TSS calibration.

mg/l	Mean	Median	Max	Min	StDev
Stationary Early Ebb	9369	5973	25654	1171	7560
Stationary Late Ebb	1982	1967	3333	862	586
Drogue upper reaches	2013	1601	37364	652	1953
Drogue lower reaches	2805	2798	46662	391	2799

The key observations arising from this dataset can be summarised as follows.

- Only ebb tide conditions have been observed, and on a high spring tide.
- The mean-median TSS values lie in the range ~2-9 g/l, with minimum values around 500mg/l and maximum values exceeding 25 g/l.
- TSS levels increased through the early ebb, peaking at around 2 hours after local HW then decreased, quickly at first then slowly, through the remainder of the ebb.
- There was a strong vertical gradient in the TSS profile, with near-bed values being between 2 and 10 times higher than the near-surface values.
- During the first part of the ebb, there was a steady increase in TSS towards the bed, consistent with mud erosion occurring from the bed with particles being mixed up into the flow. In certain profiles during drogue tracking (mid ebb) in the upper reaches, the TSS profile gradient was less marked in the upper water column but there was a strong step in the lower profile with high near-bed TSS observed. In strongly flowing water this step feature is suggestive of active bed erosion.
- The set-level drogue following (Figure 22) showed that TSS steadily increased through the monitoring area as the followed plug of water moved through the zone, again demonstrating that erosion was occurring.
- In conclusion, it seems the reaches through the monitoring area were subject to active bed erosion through this spring tide ebb flow, with erosion peaking about 2 hours after local HW. Due to strong vertical TSS gradients, total TSS seen by a near-surface sensor will underestimate the sediment load being carried.

Time-series plots for the WZ and BB autonomous surface water sensors for the pre-dredge period are shown in Figure 24. The TSS data from this plot have been analysed and replotted as tide-hour graphs, grouped by lunar (spring-neap) tidal range (Figure 25). The summary statistics, grouped by spring/neap/higher river flow periods are given in Figure 26. The salient features of the suspended sediment regime that emerge from this late autumn data-set can be summarised as follows.

- The timeseries data (Figure 24) show at first glance that much more sediment is in motion over spring tide period and neaps, and at WZ compared to BB. This observation is quantified in the statistics if Figure 26.
- The spring tide periods at WZ have mean/median values of 300-900 mg/l (figure 26), comparable to the surface values from profiling data (Figure 23). Maximum TSS values as both WZ and BB reach only 10000 mg/l, less than half of near-bed values seen in profiling, due to the vertical variability in TSS. Differences between manned/autonomous datasets will also be due to the fact that both flood and ebb periods are included in the autonomous dataset, but the profiling data only covered the initial phase of the ebb tide.
- Neap tide mean/median values are significantly lower than the spring tide values, have a range of 50-500mg/l (WZ and BB, Figure 26), suggesting that bed erosion is less effective over neap tides.
- The small river flood event seen early in the period (Figure 24, within a neap period) produced a TSS peak but mean/median values were around 500 mg/l at WZ, indicating that minor flood events are not as effective at causing bed erosion as spring tides, but are more effective than neap tides.

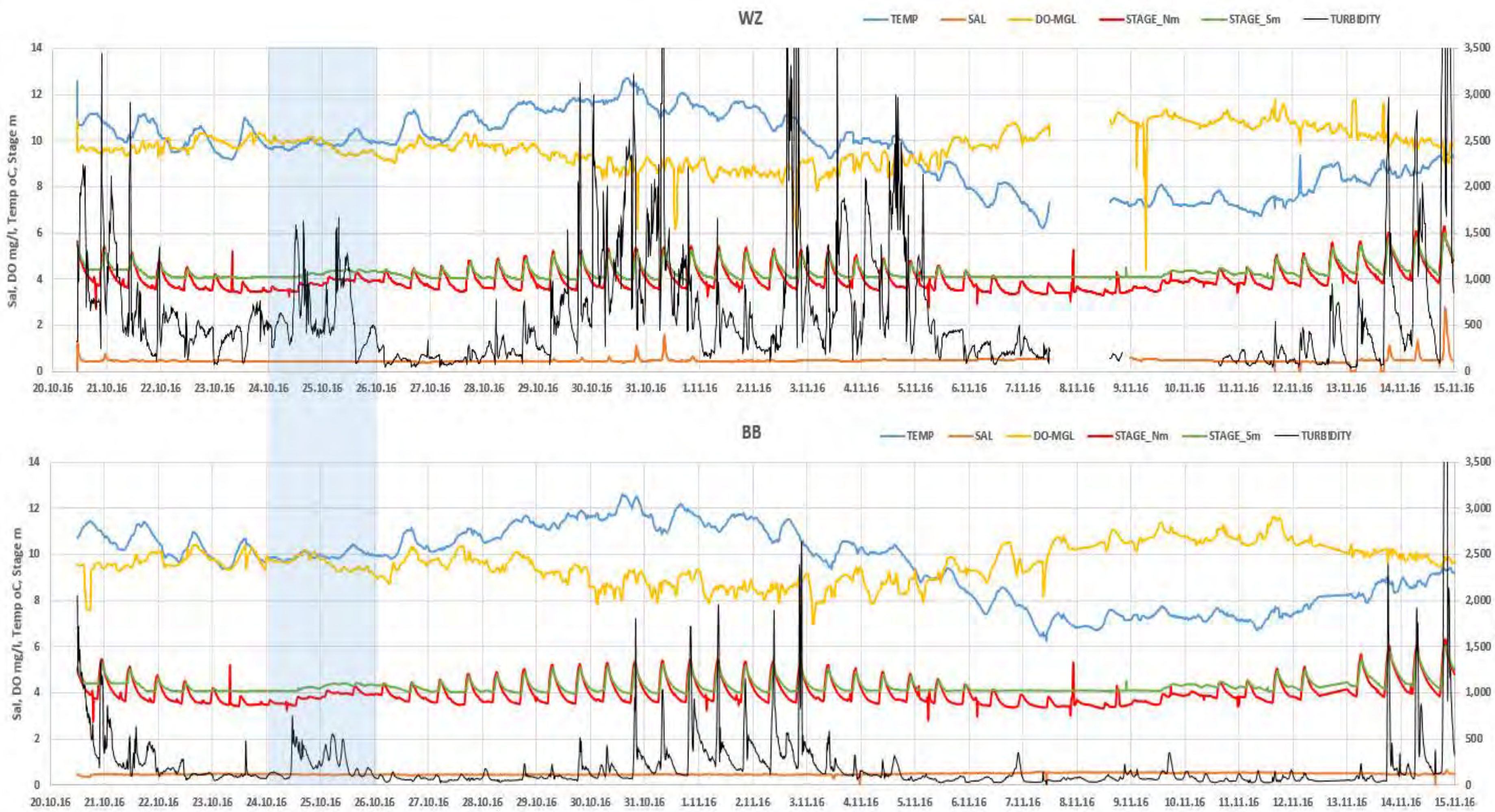


Figure 24. Westonzoyland (WZ) and Burrowbridge (BB) surface water sensor data for the pre-dredge period (20th October to 14th November). Blue shaded area is a minor river flood event.

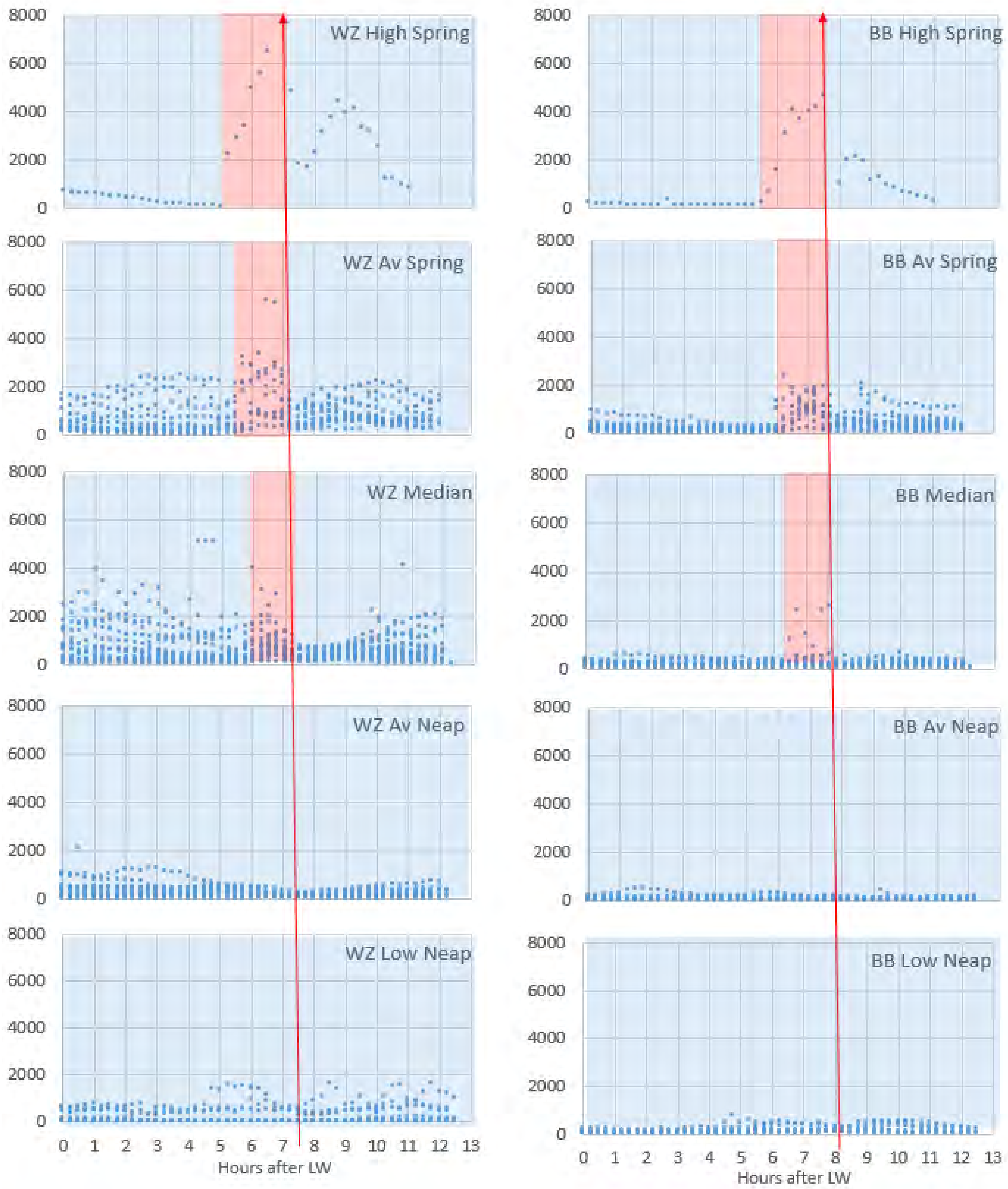
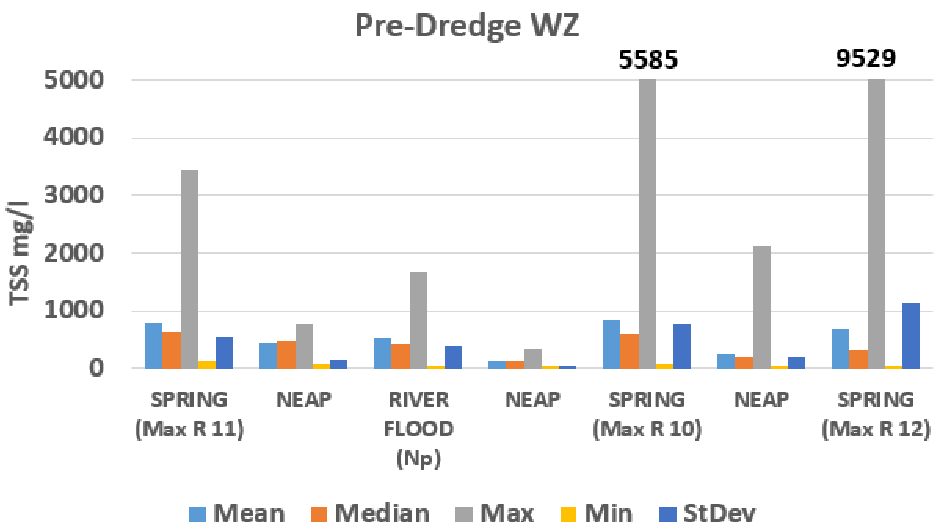


Figure 25. Pre-dredge surface water sensor TSS data (WZ & BB) tide-hour plots grouped by spring-neap condition. The red line is HW. Red shading is upstream water flow, blue shading is downstream water flow. Y axis is TSS mg/l.

The four spring neap groups correspond to tide ranges (top to bottom) >12m, 10-12m, 8-10m, 6-8m and <6m (see Figure 20).

	Mean	Median	Max	Min	StDev
SPRING (Max R 11)	781	627	3443	116	565
NEAP	437	462	769	78	158
RIVER FLOOD (Np)	520	433	1666	54	399
NEAP	122	119	343	53	52
SPRING (Max R 10)	849	594	5585	72	775
NEAP	260	199	2129	61	198
SPRING (Max R 12)	690	302	9529	42	1126



	Mean	Median	Max	Min	StDev
SPRING (Max R 11)	390	243	1835	57	356
NEAP	105	105	476	48	39
RIVER FLOOD	212	170	751	33	150
NEAP	66	62	110	24	22
SPRING (Max R 10)	233	145	2608	32	276
NEAP	73	63	352	6	49
SPRING (Max R 12)	336	91	10254	24	879

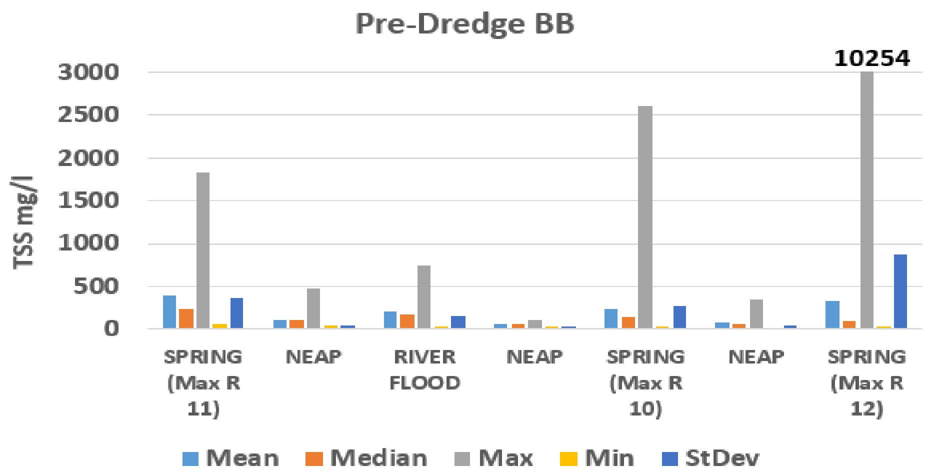
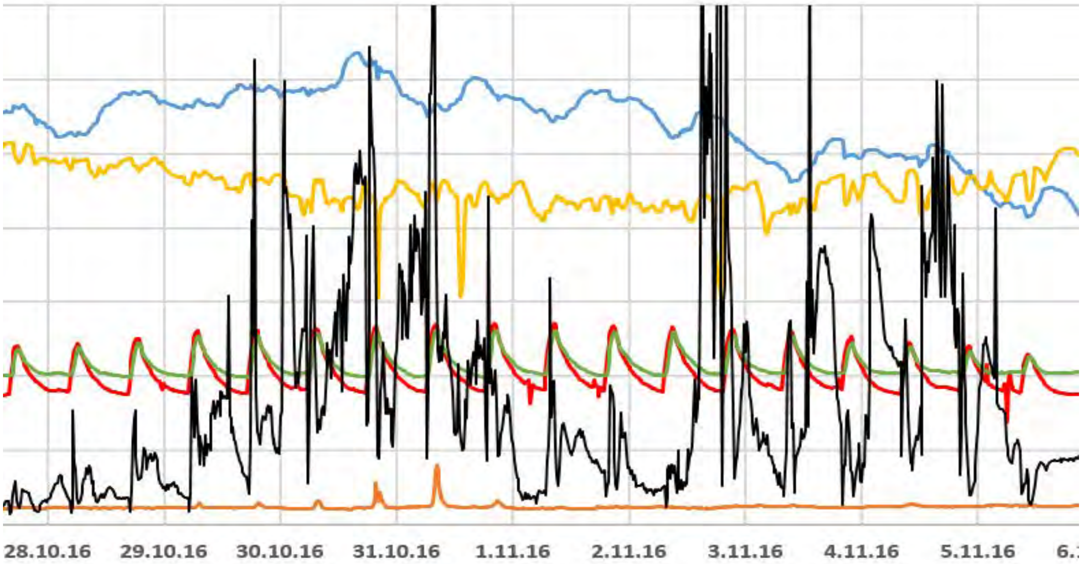


Figure 26. Summary statistics for pre-dredge TSS conditions for WZ (top) and BB (bottom). Neap to spring differentiation is based on 8m range at Hinkley Point. R=range.



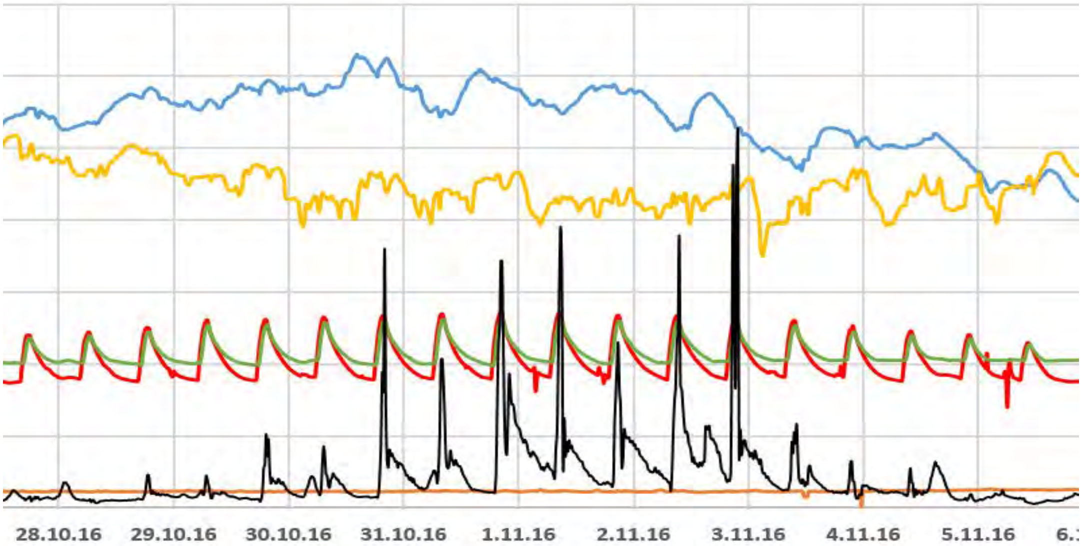


Figure 27. Enlargement of the peak spring tide zone of Figure 24, WZ (top) and BB (bottom).

- Comparing TSS statistics for the WZ and BB sites (Figure 26) the latter values are nearly all substantially lower than the former, typically by a factor of two. At times when water flow is seawards then this difference is consistent with the monitoring zone undergoing erosion. At times when landward flow occurs (short flood tide on springs), the difference is suggesting that substantive accumulation is occurring. The net flux of sediment will be a balance between these two conditions varying with space and time through the zone.
- The tide hour plots (Figure 25) provide some insight into this equilibrium. Through neap tides the flow through the monitoring reaches is nearly always seawards, even at times of low river flow. So sediment can only be carried seawards. But TSS levels are not high (rarely exceeding 1500 mg/l), so the potential for sediment transport is lower. However concentrations at WZ are clearly higher than at BB, so slow erosion through these reaches persists. On spring tides a period (maximum ~2 hours) of strong landward-going flow occurs immediately before HW. However on normal spring tides, the TSS levels seen during this

flood seem little different to those persisting through the much longer ebb period, suggesting that erosion is still the dominant process. Only on the top spring tides is it clear that the TSS concentrations on the flood are greater than on the ebb, with a suggestion that accretion processes may be dominating.

- The presence of this top spring tide situation can be clearly seen in the BB timeseries (enlarged in Figure 27, bottom). Just over the seven tides on the top of springs (not a very high spring period) it is clear that there is a peak of very high suspended sediment concentrations associated with the flood tide, and much lower concentrations on the subsequent ebb. Sediment 'pumped' through this section of the river on the flood that accumulates on the bed do not seem to be strongly eroded through the ebb. This situation will be particularly pertinent to the higher side-bank slopes, not subject to the full length of ebb drainage as they dry out.
- Inspection of the same period data (Figure 27) for the WZ site shows interesting differences. Up until the 31st October a similar pumping mechanism to BB can be seen, with spikes of very high TSS associated with the short flood flow. As at BB, lesser TSS concentration is seen during the ebb, and on several occasions much lower TSS is seen on the early ebb, building through the later ebb, again indicating that only sediment at the level of the channel floor is being actively reworked by the ebb, the deposits higher on the banks staying accumulated. As the peak of spring tides is reached (1st and 2nd November) however the overall TSS levels decrease substantially, although still with flood TSS values greater than the ebb. Then by the 3rd November the overall TSS levels increase again but with no flood TSS peak, most high TSS values being confined to the ebb (seaward erosion). This situation may reflect a sediment exhaustion phenomenon, where first spring tides of each lunar cycle set in motion the available unconsolidated mud in the lower estuary reaches, pushing the sediment towards the upper estuary on the flood. This source body (of recently accumulated sediment) may have a limited volume and become exhausted. This situation would be seen in the upper reaches as a body of high flood-tide TSS concentration that progressively passes upstream through several tides, but fading out before the peak tidal range is reached. On this particular lunar cycle this plug of high TSS water passed through WZ on the flood tides from the 29th to the 31st October, and was evident at BB from 31st October to the 3rd November. The flood concentrations of suspended sediment seen at BB were normally lower than at WZ however, showing significant accumulation through the monitoring zone.

POST-DREDGING

During the period 15th November to 17th December a) substantial dredging was undertaken through the EDZ (and subsequently most of the monitoring zone) and b) a large river flood passed through the drainage basin, peaking on the 22nd November. Both could potentially have modified the suspended sediment regime condition.

A limited series of manual profiling observations were made on the 5th December (three clear days after the EDZ dredge was completed), with moderately low river flow, tidal range 7.9m (high neap/low spring boundary), HW at Hinkley 9.23 GMT (4.39m OD) and HW at Northmoor 10.30 GMT (4.81m). Monitoring began at 9:15 and ran through until 12:30 GMT. For the first hour the vessel was stationary alongside the pontoon at Westonzoyland. Then a slow set-depth (~0.8m below water surface) run was made through the monitoring zone and back (lasting just over an hour, not drogue

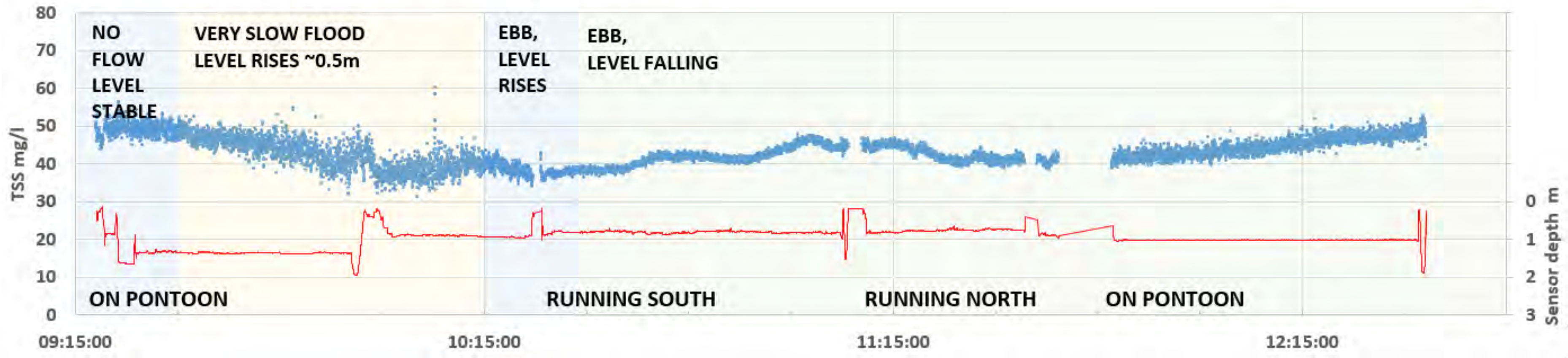


Figure 28. Set-level TSS monitoring, post-dredge survey (5th December 2016). Mean data value is 43 mg/l.

tracking), with vertical profiles at either end. Finally another hour of stationary observations were made alongside the pontoon at WZ. All the data collected on TSS are shown in Figure 28.

At the beginning of the observation period the water level was stable and there was no flow. For about 1 hour before HW time the flow almost imperceptibly move landwards and the water level rose less than 0.5m. The landward flow ceases and a slow ebb current began just before the maximum water level was reached, then the level began to fall and the ebb current slowly accelerated.

TSS concentrations remained almost constant and very low through the ~3 hour period, with values between 35 and 55 mg/l. There was no vertical variation in TSS concentration. TSS levels dropped slightly in the hour before HW, then increased slightly into the mid-ebb. Set-depth TSS concentrations showed a very slight increase in concentration towards BB, indicating some deposition from the flow at that time. This very simple situation is summarised in Figure 28.

The situation seen on the 5th December is totally different to that seen in the pre-dredge surveys, with very low TSS values. This could be an effect of the slightly higher river discharge. Or it could reflect the point in the lunar tide cycle tide (tide range 7.9m), being exactly on the balance point between constant seaward flow (neaps) or a flood tide penetration (springs), the absence of any current creating the clear water. Or it could reflect an exhaustion of erodible local sediment, as a result of both river flood scour and dredging activity. All explanations may play a role.

Time-series plots for the WZ and BB autonomous surface water sensors for the post-dredge period are shown in Figure 29. The TSS data from this plot has been analysed and replotted as tide-hour graphs, grouped by lunar (spring-neap) tidal range (Figure 30). The summary statistics, grouped by spring/neap/higher river flow periods are given in Figure 31. The salient features of the suspended sediment regime that emerge from this late autumn data set can be summarised as follows.

- The timeseries data (Figure 24) show at first glance that there is only slight increase in suspended sediment concentrations between neap and spring conditions at both sites, but that during river flooding events mean TSS concentrations can double and maximum values increase by up to a factor of 3 (Figure 31). The mean/median of all datasets lie in the range 30-60 mg/l, contrasting strongly with the pre-dredge situation when much higher suspended sediment concentrations were seen. At times of modest river flow there is a minor increase in the TSS levels at WZ compared to BB, indicating slight erosion through the study area, but no significant difference during the higher flood event. No flood tide TSS peak is evident on spring tides (compare Figure 30 and Figure 25). All data are summarised in the statistics of Figure 31.
- The spring/neap transition tide periods at WZ have mean/median values of ~50 mg/l (figure 31), compatible with the one day profiling data at about 1m below the surface (Figure 28 mean value of 43 mg/l).
- Although there were no tides of the higher spring range during the post-dredge monitoring period (Figure 30), comparing like energy levels (e.g. tide hour plots for median tides, figure 25 for pre-dredge and Figure 30 for post-dredge) there is huge reduction in the post-dredge TSS levels (by a factor of ~10). This may be simply due to the slightly higher river discharge compared with the pre-dredge period, but the change may be further argument for a control imposed by processes of sediment exhaustion. It is not possible to say from this evidence alone whether the potential exhaustion effect seen in these reaches is largely attributable to just the scouring action of the November river flood, or whether the dredging played an important role.

PARTRAC DATA

The Partrac data (Table 5) appear to show exactly the same (x~10) differences pre and post the first big river flood of the winter, consistent with our data showing that minor increase in river discharge and/or exhaustion effects can dramatically modify the suspended sediment regime in the upper reaches of the estuary.

	Jul-Aug 2009			**Nov-Dec 2008**		
mg/l	*Average*	*Max*	*Min*	*Average*	*Max*	*Min*
Site 1	608	3568	15			
Site 2	219	3567	38	36	39	33
Site 6/7	225	2725	41	22	28	19

Table 4. Partrac summary data for suspended sediment concentrations measured ~1m above the bed for two periods of 20-30 days (spring and neap tides). Site 2 & 7 are in the monitoring zone (Figure 1). NB. There are no data on the NTU-TSS calibration used by Partrac.

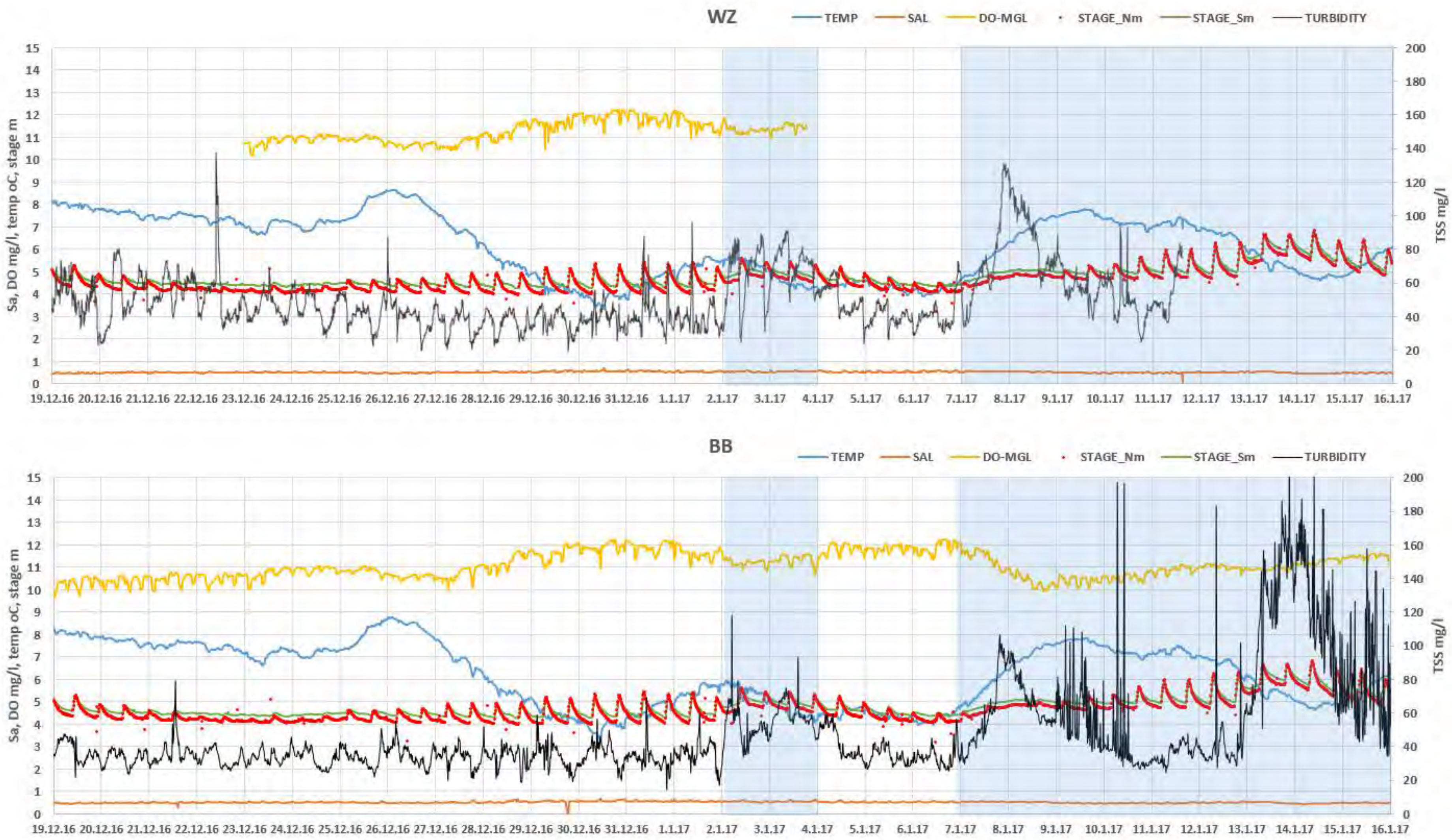


Figure 29. Westonzoyland (WZ) and Burrowbridge (BB) surface water sensor data for the post-dredge period (18th December to 16th January). Blue shaded boxes are minor river flood events. At WZ the DO sensor failed on 3/1./17 and the turbidity sensor on 11/1/17.

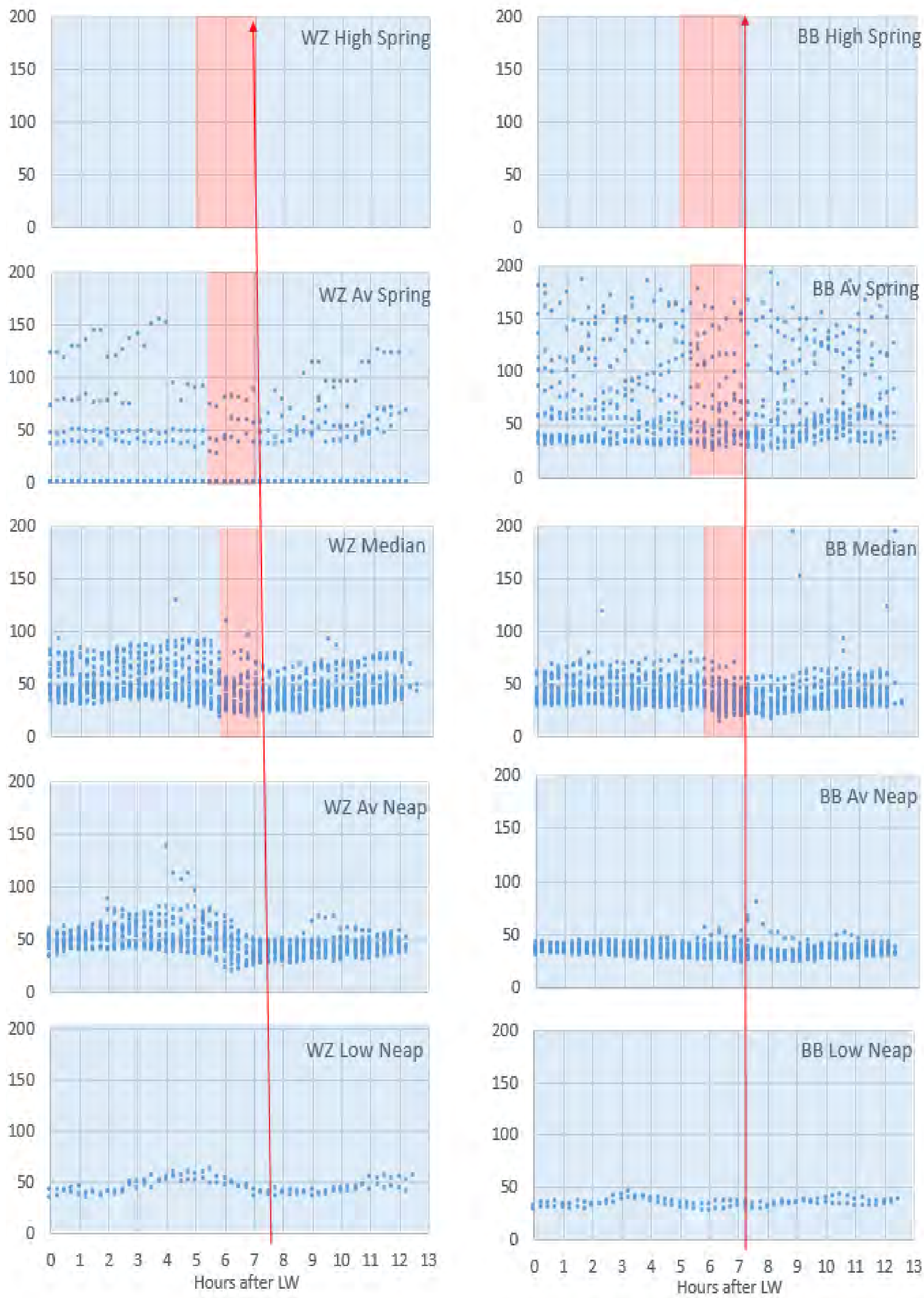
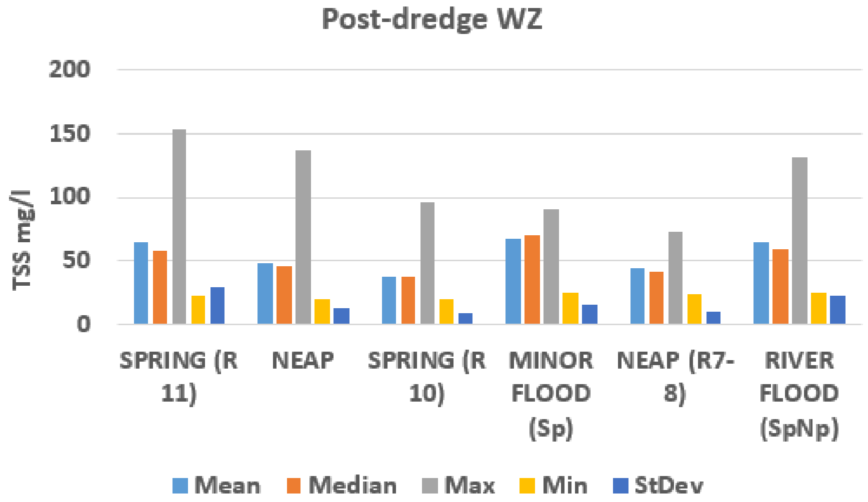


Figure 30. Post-dredge surface water sensor TSS data (WZ & BB) tide-hour plots grouped by spring-neap condition. The red line is HW. Red shading is (potential) upstream water flow (at low river discharge), blue shading is downstream water flow.

The four spring neap groups correspond to tide ranges (top to bottom) >12m, 10-12m, 8-10m, 6-8m and <6m (see Figure 20).

	Mean	Median	Max	Min	StDev
SPRING (R 11)	65	58	154	23	29
NEAP	48	46	138	20	13
SPRING (R 10)	38	38	96	19	8
MINOR FLOOD (Sp)	67	71	91	25	15
NEAP (R7-8)	44	42	73	24	10
RIVER FLOOD (SpNp)	65	59	131	25	23



	Mean	Median	Max	Min	StDev
SPRING (R 11)	44	43	192	22	14
NEAP	34	34	79	22	6
SPRING (R 10)	34	34	68	14	6
MINOR FLOOD (Sp)	55	56	118	29	11
NEAP (R7-8)	37	35	60	25	8
RIVER FLOOD (SpNp)	70	59	201	24	39

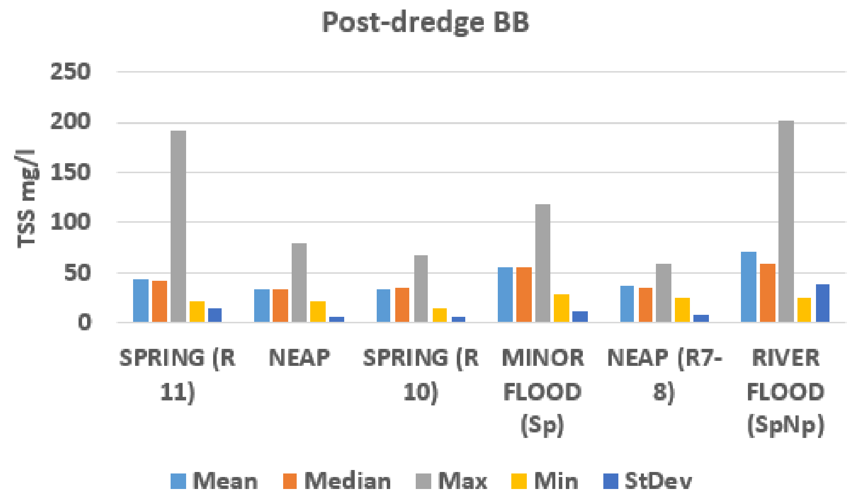


Figure 31. Summary statistics for post-dredge TSS conditions for WZ (top) and BB (bottom). Neap to spring differentiation is based on 8m range at Hinkley Point.

3.7. Water Quality

DISSOLVED OXYGEN. In all the near-surface (autonomous) measurements made the % DO in the water rarely dropped below 80%. The absolute DO value varied with temperature, but not obviously with turbidity, suggesting the latter (at natural concentrations in suspension) is not creating an oxygen demand. Absolute values only fell below 8mg l^{-1} for very short periods of time, suggesting temporary clogging of the sensor head with organic matter. All the manual profiles recorded (outside of the dredging period) also showed similarly high DO levels (no reduction with depth) except one cast, during which DO dropped to 50% on reaching the bed rose to normal values again on moving back to the water surface. There was no high turbidity associated with this event, again likely to be a spurious reading.

AMMONIA. Ammonium as N (NH4-N) concentrations generally remained below 0.5 mg l^{-1}. Small spikes in ammonia measurements (up to 3 mg l^{-1}) were observed during high spring tides. These fluctuations were closely correlated to conductivity and are a consequence of the ammonia probes being sensitive to sodium and potassium, rather than representing a real change in ammonium concentrations.

4. Geomorphometric Change

4.1. Rates and Patterns of Change

The pre-dredge morphology of the channels is described in Section 3.1 (Figures 7 & 8). Post-dredge conditions were measured using three methods:

- During dredging, control surveys were undertaken by Van Ord by running single beam echo sounder longitudinal lines run along the thalweg within the dredge zones
- Immediately after the cessation of dredging (during December) some sections were resurveyed using the pole method.
- In mid-February a multibeam acoustic survey was undertaken (re-run of the initial survey).

The three survey methods gave very comparable results. The patchy Van Ord data were difficult to combine into clear graphics, and have not been used in the analysis, beyond checking consistency. The other two data types were gridded in the GIS system to create 3-D surfaces, from which volume changes and illustrative cross-sections could be prepared (Table 5, Figures 32-34).

All the data collected showed overall scour to have occurred between October/November and December/February. Some localised accumulation occurred, notably on the lower side-slopes of the banks ('berms'), but erosion prevailed.

The multibeam survey covered the greatest channel extent, from the M5 motorway to Burrowbridge (Figure 1). Some 32,000m^3 of sediment was eroded from the channel floors and lower slopes of this section of the estuary between the November and February multibeam surveys. The estuary channel through this area has been divided into seventeen reaches of about 500m (nominal) length. These seventeen reaches can be divided into five groups (Table 5) on the basis of their modification between the two multibeam surveys.

1. Upstream of the EDZ. These two reaches were affected by both river scour and minor dredging (a single pass of the WID). Thalweg scour was the predominant mechanism of change, where a maximum of about 0.5m of deepening occurred (Figures 32 and 33). Average erosion over the period along these reaches was ~0.2m (Figure 34).

2. EDZ. These two reaches were impacted primarily by dredging but also underwent river-flow erosion. Thalweg scour was the predominant mechanism of change, where a maximum of about 1m of deepening occurred. Average erosion over the period along these reaches increased northwards, from ~0.35m to 0.55m.
3. Dredging Extension Zone (most of the original downstream monitoring zone). Van Ord surveys undertaken before this zone was dredged showed that no local accumulation of

Upstream kp	Downstream kp	Reach length m	Reach area m^2	Mean width m	Mean change m	% null (QC)	Volume change (m^3)	Erosion pattern	Dredge history
30275	29575	700	8,131	12	-0.2129	3.5	-1731	th	minor dredge
29575	29125	450	5,237	12	-0.1870	5.7	-979	th	minor dredge
29125	28675	450	4,937	11	-0.3580	5.5	-1767	th	EDZ full dredge
28675	28350	325	4,010	12	-0.5622	3.2	-2254	th	EDZ full dredge
28350	27925	425	5,948	14	-0.5208	3.2	-3098	th	Extension full dredge
27925	27525	400	5,505	14	-0.5421	4.3	-2984	th	Extension full dredge
27525	27125	400	6,990	17	-0.5037	1.9	-3520	th	Extension full dredge
27125	26625	500	9,903	20	-0.1928	2.6	-1909	th	No dredge (wide)
26625	26076	549	10,391	19	-0.2596	3.2	-2697	th	No dredge (wide)
26076	25626	450	7,486	17	-0.3235	6.6	-2422	th	No dredge (wide)
25626	25174	452	5,205	12	-0.1342	9.0	-698	bm	No dredge (narrow)
25174	24828	346	4,205	12	-0.1612	9.2	-677	bm	No dredge (narrow)
24828	24325	503	6,341	13	-0.1951	6.8	-1236	bm	No dredge (narrow)
24325	23927	398	5,418	14	-0.2264	5.1	-1226	bm	No dredge (narrow)
23927	23530	397	5,897	15	-0.2436	4.7	-1437	bm	No dredge (narrow)
23530	23081	449	6,312	14	-0.2441	4.0	-1540	bm	No dredge (narrow)
23081	22580	501	7,434	15	-0.2303	3.9	-1712	bm	No dredge (narrow)

Total erosion from all reaches **-31887**
Erosion from dredged reaches **-16333**

Table 5. Variability in bed-level change along the channel reaches. Mean level change is plotted in Figure 34 (top), th=thalweg scour predominated bm=berm erosion predominated.

dredged mud occurred through these three reaches prior to the second (extension) dredge activity. Thalweg scour was the predominant mechanism of change, where a maximum of about 1m of deepening occurred. Average erosion over the period along these reaches was the greatest seen in all areas and exceeded 0.5m.

4. No dredge zone (wide, pioneer dredged). The channel in these three pioneer dredged reaches is wide (Table 5, Figure 33) therefore having a larger cross-sectional area. Thalweg scour predominated and although undredged, up to 0.5m of thalweg deepening was seen with average erosion of 0.2-0.3m over the period

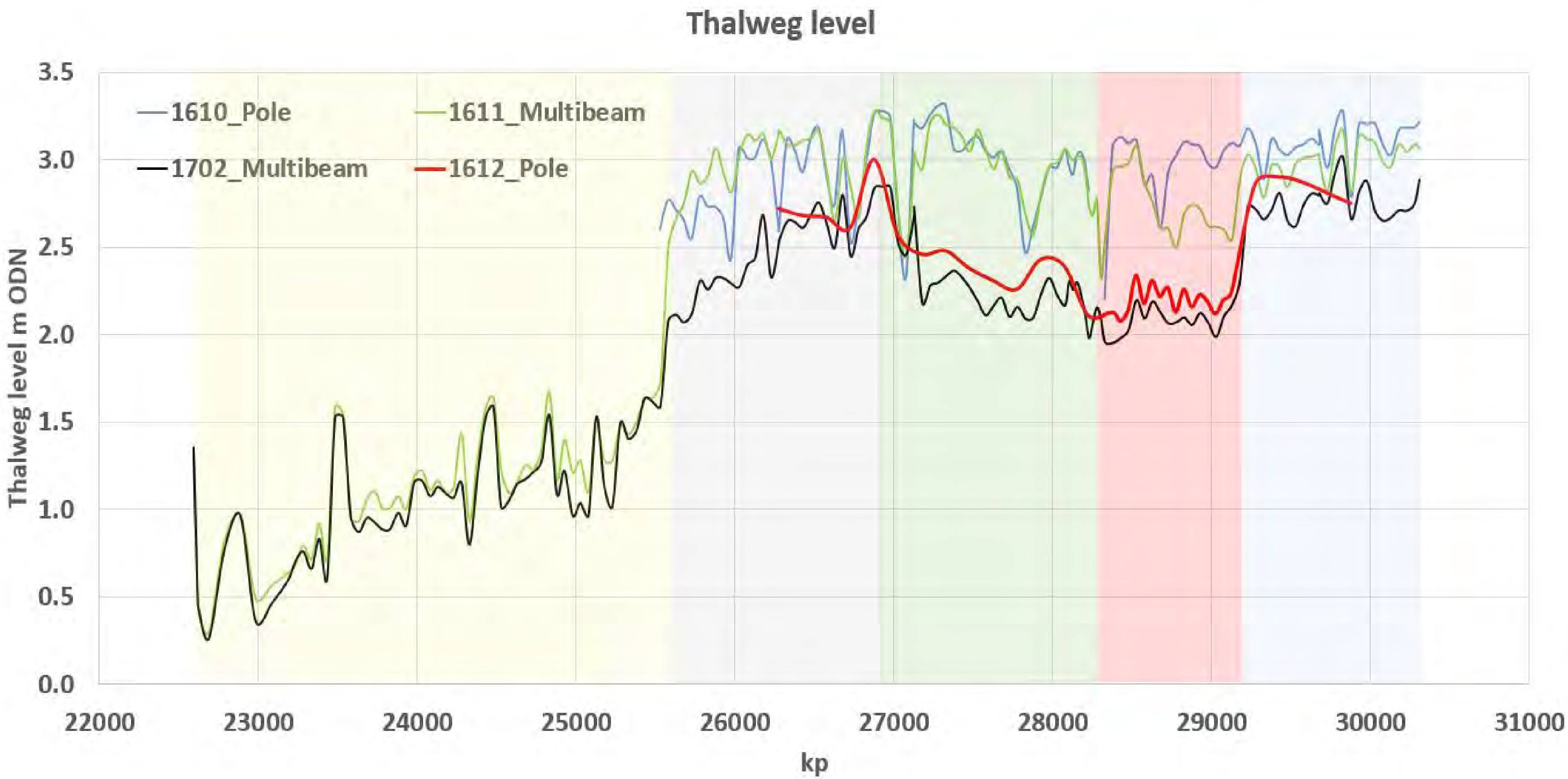


Figure 32. Comparison of pre- and post-dredge thalweg levels. See Table 5 for explanation of colour shading.

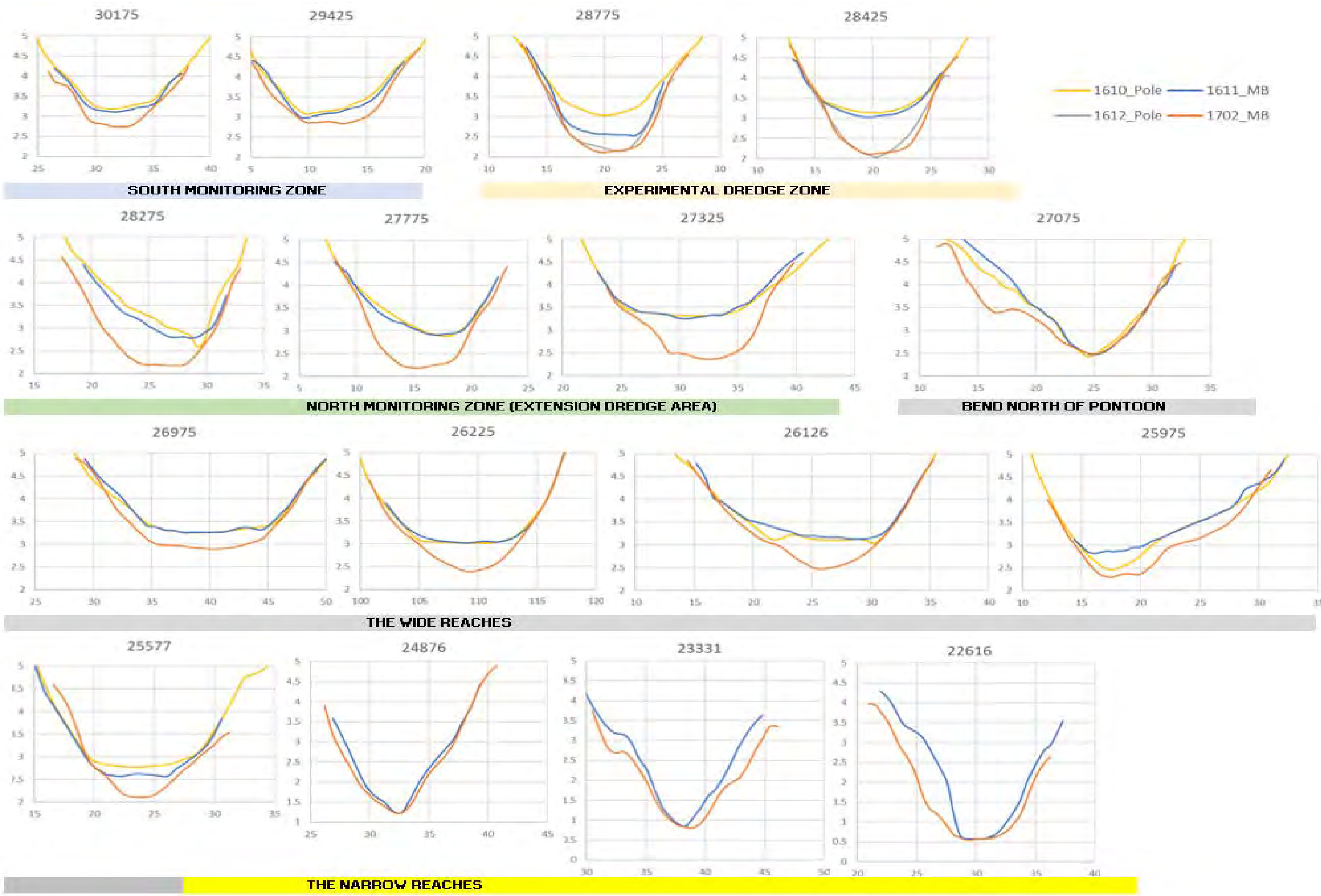


Figure 33. Illustrative cross-sections showing type and degree of change in bed levels between surveys. See Table 5 for explanation of colour shading.

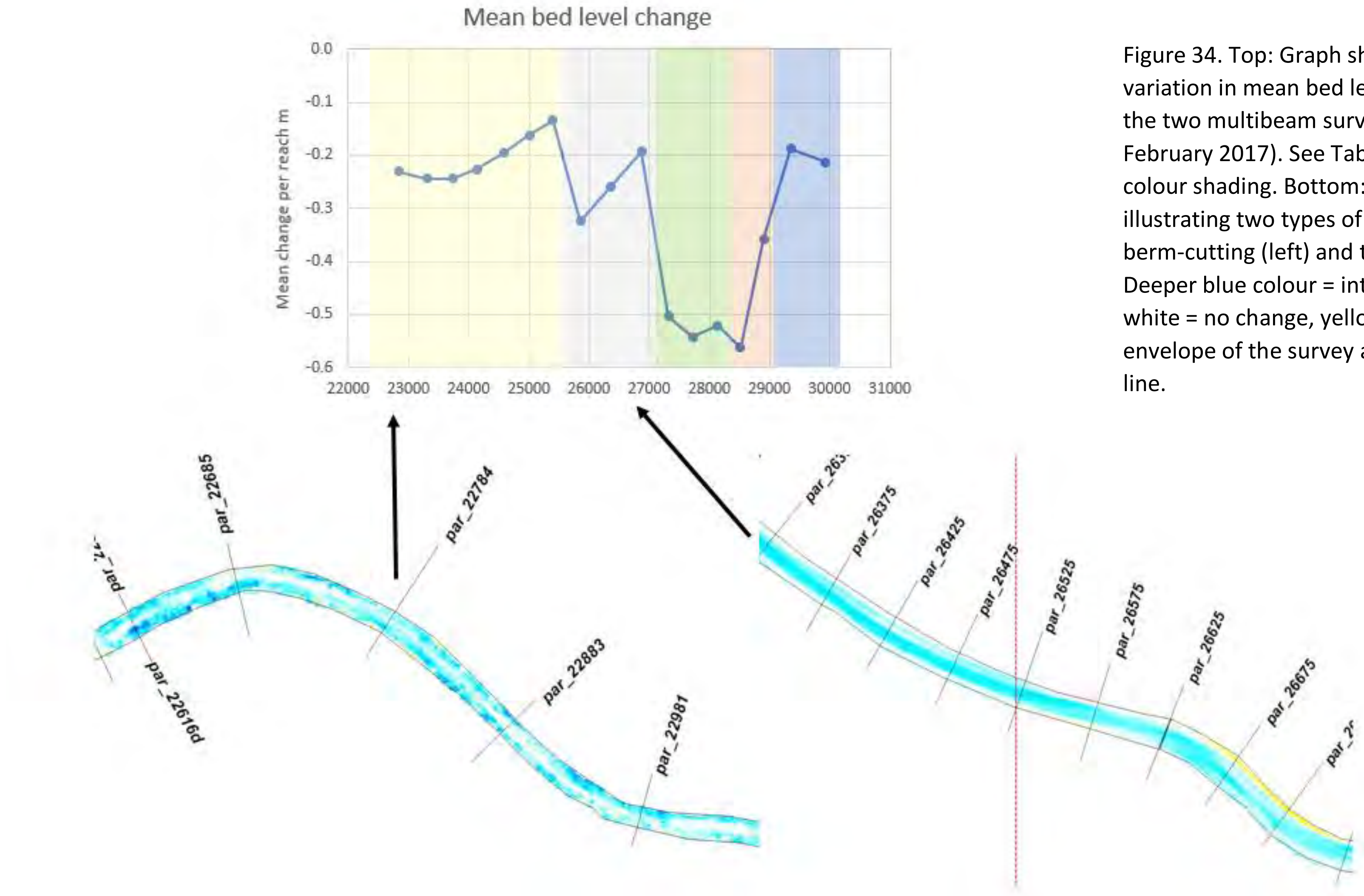


Figure 34. Top: Graph showing along-channel variation in mean bed level changes between the two multibeam surveys (November 2016-February 2017). See Table 5 for explanation of colour shading. Bottom: Channel plans illustrating two types of channel erosion, berm-cutting (left) and thalweg scour (right). Deeper blue colour = intensity of erosion, white = no change, yellow = deposition. The envelope of the survey area is shown as a grey line.

5. No dredge zone (narrow, not pioneer dredged). At about kp25500 the channel becomes narrow again (12-15m) and little erosion occurred here over the period (this local reach saw only 0.13m of mean bed lowering, Table 5, Figure 33). This pinch point appears to result from being the downstream limit of the 2014-16 pioneer dredge. Through the seven 'natural' reaches at and downstream of the 'pinch', berm erosion replaces thalweg scour as the principle pattern of erosion (Table 5, Figure 33 & 34). Thalweg levels erode only very slightly if at all (Figure 32) but mean bed lowered through the period was 0.2 to 0.3m (Figure 34), similar to the 'minor dredge' zone above the EDZ. The profiles through this undredged part of the channel are far more V-shaped than the pioneer-dredged trapezoidal sections to the south, and the profiles and erosion amount plans show erosion to be focused on the slope toes either side of the thalweg.

5.1. River Scour Compared to Dredging

As significant erosion has occurred between November 2016 and February 2017 in all of the channels monitored, it is clear that both river erosion and dredging have been responsible for scour. As will be addressed in the following section, there are several lines of evidence that clearly point to the persistence of alternating seasonal cycles of erosion and deposition in these reaches of the estuary, the erosion being driven by fluvial high discharge events.

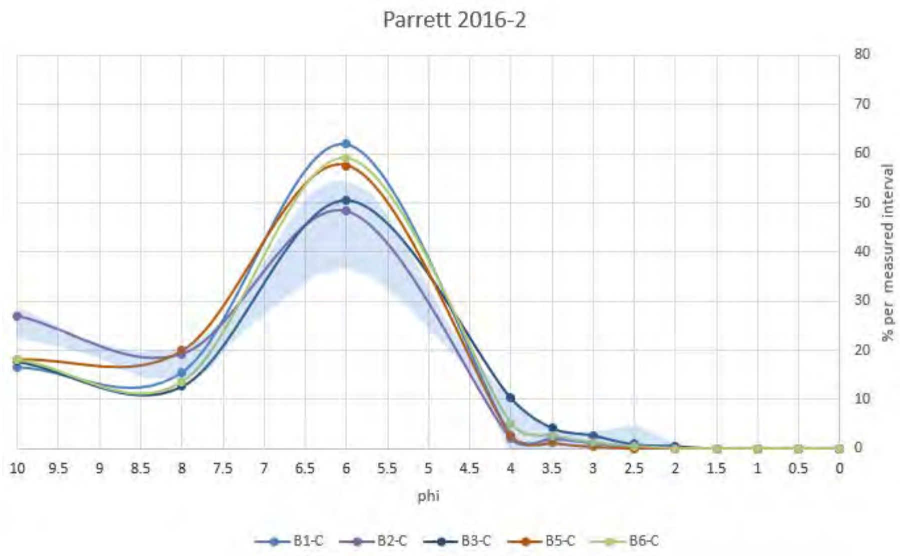
On the assumptions that a) the single pass dredge south of the EDZ had minimal impact and b) had no dredging taken place erosion inside the dredged zones would have been similar to that seen outside those zones, it can be calculated (on an area basis) that with river erosion alone these reaches would have yielded ~24,000m^3 of erosion between November 2016 and February 2017 (=average bed lowering in non-dredged areas x area of all reaches). Reality is that these reaches yielded ~32,000m^3 (Table 5), so the dredging effort (the difference) yielded 8,000m^3. The VO surveys undertaken immediately following dredging indicated dredging production to be 11,000m^3, consistent with this analysis (river scour would have naturally eroded the dredged reaches between November and January had no dredging been undertaken). Hence the dredging effort this winter increased 'natural' erosion by one third. This winter of 2016-17 actually saw quite low river discharge events compared with previous years (Figure 17) so it is quite possible that during years of really high fluvial input, river scouring might have naturally exceeded the 32,000m^3 achieved this year.

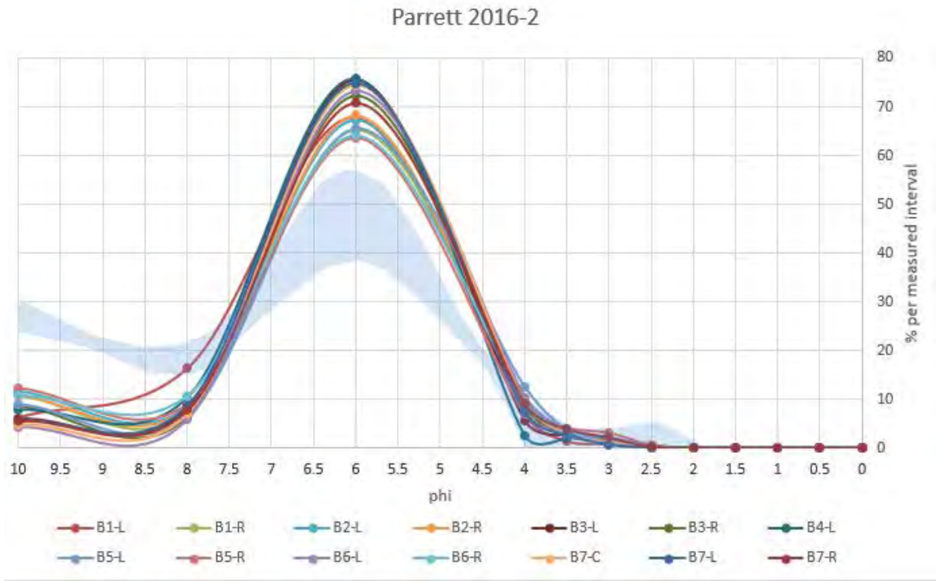
In evaluating the potential role that dredging might play in maintaining a high flow capacity channel, it would seem that an important objective is to quantify the scaling between the scouring that can be achieved by natural river erosion (taking into account the inter-annual variability) and the cleaning that can be pragmatically added by the use of dredging.

A final point to be made in this section is to highlight the potential different effectiveness of the two different profile shapes found, both for channelling flow and for promoting natural scour under river flood events. The deeper V-shaped (undredged) sections seem to encourage river flood erosion higher up on the side slopes (Figure 33).

5.2. Bed Sediment Characteristics

The estuary bed sampling survey undertaken on the 10th November (section 3.2) was repeated on the 8th December. Site locations are shown in Figure 2. Sites and methods were replicated as exactly as possible: water levels were slightly higher on the final survey so channel margin samples were taken a little higher up the bank. Sample site B4-R was not revisited as the sediment is a relict





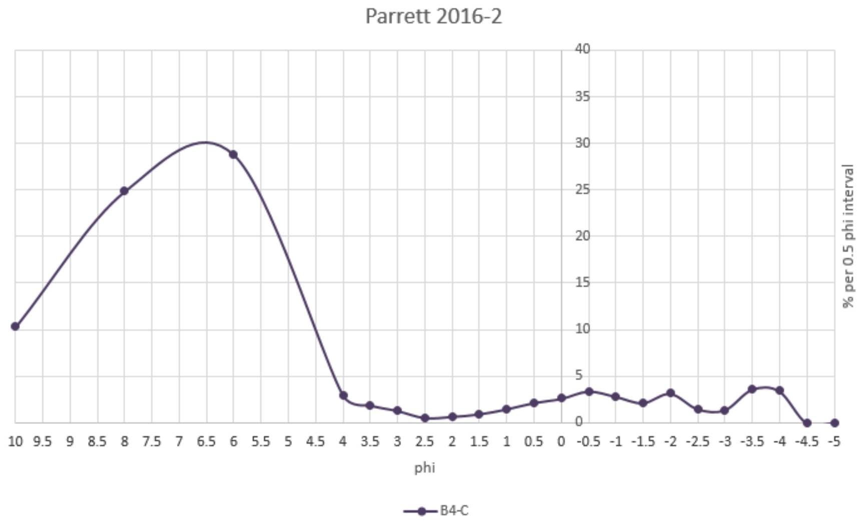


Figure 35. Discrete frequency distribution plots of the PSA data from the final monitoring bed survey. C=channel centre, L=left bank, R=right bank (looking seawards). See Figure 10 for a definition of phi.

	Field Sample ID	% Gravel (>2mm)	% sand (2mm-63um)	% silt & clay (<63um)	% of siltclay coarser than 16um	% of silt/clay finer than 4um	Dry Density t m^{3}	Bulk Density t m^{3}	Shear Strength kPa
BANK GROUP	B1-L	0	9.4	90.6	74.9	7.0	0.8	1.51	1.50
	B1-R	0	16.4	83.6	78.1	13.0	0.79	1.49	1.50
	B2-L	0	12.4	87.6	76.9	13.2	0.78	1.49	0.90
	B2-R	0	12.6	87.4	78.1	12.3	0.89	1.56	1.50
	B3-L	0	10.2	89.8	84.1	6.7	0.75	1.47	1.50
	B3-R	0	13.0	87.0	83.0	9.7	0.85	1.53	1.50
	B4-L	0	6.0	94.0	80.7	8.3	0.78	1.49	1.50
	B5-L	0	18.7	81.3	80.7	11.1	0.77	1.48	0.73
	B5-R	0	15.0	85.0	74.8	14.5	0.78	1.49	1.04
	B6-L	0	16.8	83.2	87.9	5.1	0.75	1.47	0.89
	B6-R	0	14.4	85.6	74.8	12.6	0.78	1.49	1.19
	B7-C	0	13.7	86.3	86.2	5.6	0.74	1.46	
	B7-L	0	11.0	89.0	84.0	6.2	0.77	1.48	1.50
	B7-R	0	15.8	84.2	84.1	6.6	0.81	1.50	0.95
	Average	*0*	*13.2*	*86.8*	*80.6*	*9.4*	*0.79*	*1.49*	*1.25*
	St Dev	*0*	*3.4*	*3.4*	*4.4*	*3.3*	*0.04*	*0.03*	*0.30*
CHANNEL GROUP 1	B1-C	0	6.0	94.0	65.9	17.6	0.61	1.38	
	B2-C	0	5.3	94.7	51.1	28.5	0.52	1.33	
	B3-C	0	18.9	81.1	62.4	21.9	0.77	1.48	
	B5-C	0	4.4	95.6	60.2	18.9	0.54	1.34	
	B6-C	0	9.4	90.6	65.2	19.9	0.70	1.43	
	Average	*0*	*8.8*	*91.2*	*61.0*	*21.4*	*0.63*	*1.39*	
	St Dev	*0*	*5.9*	*5.9*	*6.0*	*4.3*	*0.10*	*0.06*	
CHANNEL 2	B4-C	18	18.0	63.9	45.0	16.1			

Table 6. Summary PSA, density and shear strength data for the two sediment groups on the final survey. Note the shear vane could only read to 1.3 kPa so 1.5 kPa values shown here indicate 'failure not reached'.

		% sand (2mm-63um)	% silt & clay (<63um)	% of siltclay coarser than 16um	% of silt/clay finer than 4um	Dry Density t m-3	Bulk Density t m-3	Shear Strength kPa
BANK	**B1-L**	2.8	-2.8	7.1	-10.2	0.15	0.09	0.00
GROUP	**B1-R**	2.6	-2.6	1.2	-1.3	0.02	0.01	0.00
	B2-L	5.6	-5.6	0.2	0.8	0.06	0.03	0.00
	B2-R	0.9	-0.9	-0.5	0.1	0.11	0.07	0.00
	B3-L	0.5	-0.5	12.1	-8.6	0.06	0.04	0.42
	B3-R	9.9	-9.9	8.8	-1.7	0.14	0.09	0.00
	B4-L	-7.1	7.1	2.4	-5.6	0.06	0.04	0.00
	B5-L	5.6	-5.6	-0.6	0.2	0.00	0.00	-0.77
	B5-R	7.6	-7.6	3.0	-2.3	0.13	0.08	-0.16
	B6-L	10.7	-10.7	12.0	-6.9	-0.02	-0.01	-0.61
	B6-R	6.0	-6.0	-1.4	1.2	0.11	0.07	-0.01
	B7-C	7.1	-7.1	19.6	-13.8	0.12	0.07	0.00
	B7-L	-5.5	5.5	2.1	-6.8	0.01	0.01	0.40
	B7-R	9.5	-9.5	7.9	-5.8	0.10	0.06	-0.10
CHANNEL	**B1-C**	-10.7	10.7	17.1	-15.7	0.09	0.06	
GROUP	**B2-C**	-13.4	13.4	5.1	-6.7	0.04	0.02	
	B3-C	10.5	-10.5	8.3	-5.8	0.27	0.17	
	B4-C	16.8	-34.9	-10.8	-9.4			
	B5-C	-2.7	2.7	10.8	-9.1	0.00	0.00	
	B6-C	-1.6	1.6	0.1	-1.2	0.01	0.01	
BANK	**Average**	3.9	-3.9	5.9	-4.8	0.08	0.05	-0.06
GROUP	**St Dev**	-0.4	-0.4	-0.7	0.2	-0.01	-0.01	0.08
CHANNEL	**Average**	-0.6	0.6	9.4	-7.6	0.08	0.05	
GROUP	**St Dev**	-1.0	-1.0	1.9	-0.1	0.02	0.01	

Figure 36. Comparison of bed sediment characteristics between surveys (values Table 6 minus values Table 2). Increasing greenness reflects an increase in values between surveys, increasing redness decreasing values.

Figure 37. Sample B4-C showing presence of mud-clasts and fine gravel. Top: sediment surface seen in grab. Bottom: Gravel fraction from sample, post particle-size analysis (mud clasts dispersed).

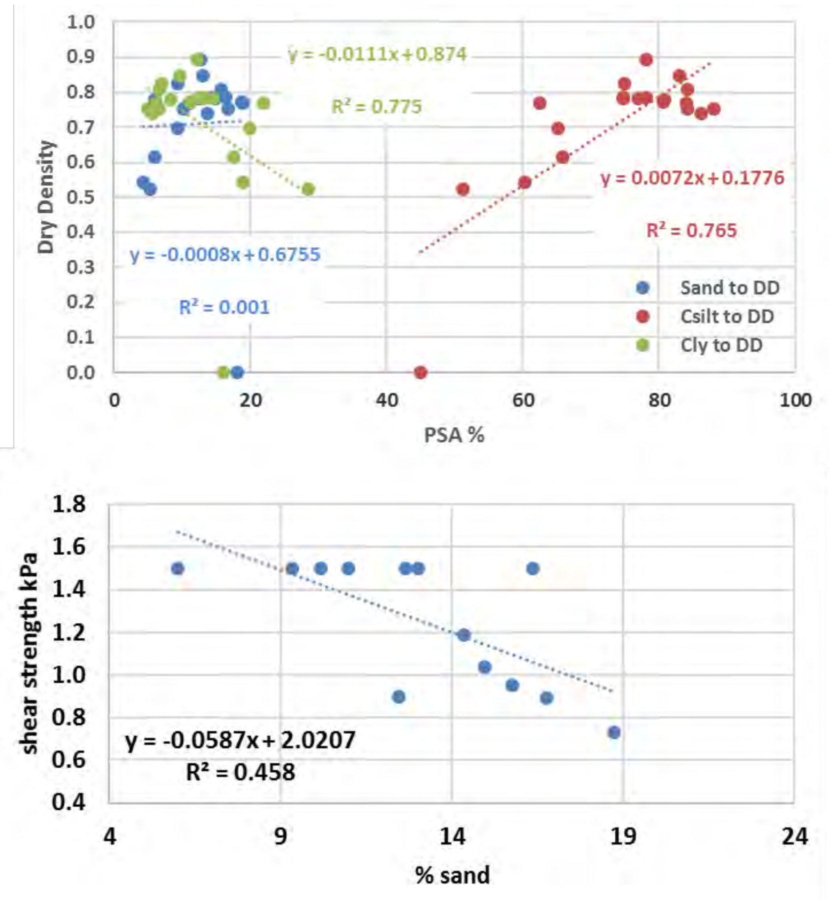


Figure 38. Sediment density to particle-size (top) and shear strength to sand content (bottom) interdependencies, final bed survey

eroding clay exposure between rock armour, and unrelated to modern channel conditions. The sampling was completed BEFORE the second (extended) dredging work took place.

The frequency distributions for the 20 samples collected in December are plotted in Figure 35. The grouping seen in the November survey remains the same, except that the channel floor sample at site 6, classed as bank group but almost between groups in November, showed characteristics of the channel floor group in December. In the figure the blue shaded area is the envelope of the plots of the channel group in November, for comparison purposes. Summary data for the two groups are given in Table 6. There seems no consistent longitudinal gradient in the bed sediment characteristics through the surveyed zone. There are modest changes in the sediment particle-size characteristics between the surveys but the basic characteristics of and differences between the bank and channel groups remain the same (former has higher coarse silt and lower clay).

The differences in the bed condition between the two surveys are shown in Table 6 (survey 1 values minus survey 2 values) where increasing colour density identifies greater degree of change. The differences seen can be summarised as follows.

- On the floor of the low water channel at Site 4 a completely new sediment type was seen. This contained 18% gravel, 18% sand and 64% mud. At the time of sample collection some of the mud was present as mud-clasts (Figure 37 top), showing recent break-up of a strongly cohesive mud bed. These clasts collapsed into mud particles on wet sieving. The actual gravel consisted of unencrusted, dull, angular to sub-rounded fine to medium gravel composed of shale and sandstone with some shell, wood and reed fragments (Figure 37 bottom).

- The sand % of the total sediment mostly increased (~4% on average) in the bank group and both increased and decreased in the channel group. The difference between sites in the channel group is interesting however because all the decrease-in-sand zones are upstream or downstream of the dredge zone. The dredge zone itself (Site 3) and the immediate lower end of the dredge zone (site 4) both showed large (10-20%, Figure 36) increase in sand content. This could be evidence that WID/Farrell dredging preferentially removes the silt/clay fraction of the bed, but sand tends to resettle to the bed locally.
- The coarse silt fraction of the sediment increased significantly at most sites in both groups (up 5-10%), although some sites saw a slight decrease. There was a corresponding decrease in the fine-silt/clay fractions.
- There was little change in sediment density (very small average increase). As in the initial survey, sediment density appears to be primarily controlled by the relative proportions of coarse silt to fine-silt/clay (Figure 38, top graph), the channel floor sediments therefore showing the lower density range compared to the banks. The general slight increase in density is consistent with the overall increase in the coarse silt fraction within the sediments.
- Seen altogether, the bank samples' bed shear strength reduced slightly, however most sites stayed at the same value as previously, and a few sites saw either quite a large reduction or increase in strength. This is interpreted as most sites having a strongly cohesive value, with local areas (in both surveys) having thin veneers of recently deposited mud accumulation. The sand content of the sediment appeared to play a stronger role in determining sediment shear strength in this final survey (Figure 38, bottom graph).

Visual observations of the intertidal sediment surfaces made during the final survey strongly indicate that the banks had been subject to strong erosion between the two bed surveys. A full description of observations made is given in Appendix 3. Images of the mud surfaces made during the survey and later during December are shown in Figure 39. Key features seen are as follows.

- In the upstream reaches of the monitoring zone, most of the intertidal mud surfaces were similar to the pre-dredge condition, being featureless or showing erosion sculpting, quite strong in places (Figure 39 A, Site B02)
- At site 3, within the dredged zone, erosion features became stronger, with micro-cliffs often separating an upper-bank featureless zone from a lower highly eroded zone (Figure 39 B, Site B03). The cliff is probably the result of water-margin erosion during (recent) higher river stage. It can be seen that the erosion of the bed reveals that the exposed sediment is strongly layered (evidence of deposition in incremental layers separated by time and/or an erosion period).
- For long sections of the bank downstream of Site B03, the cut marks of the Farrell dredger (made at time of highest river flow) were evident (Figure 39 C).
- At site B04 (lower end of dredge reach) the banks were often eroded and stepped, with crack-development leading to the release of large blocks of mud (Figure 39 D, siteB04).
- Most erosion was seen on inner-bend slip-off slopes, where large slump features had developed (Figure 39 E, between Sites B04 & B05). The slump faces again show that the exposed sediment has highly layered properties.
- On straight reaches there were wide scoured sediment surfaces, again exhibiting the stepped appearance due to sediment layering, but less prone to slumping (Figure 39 F, Site B06).

Figure 39. Photographs of sedimentary features on the intertidal. December 2016. … continues.

Figure 39. Photographs of sedimentary features on the intertidal. December 2016….. continues.


E.


F.


G.

Figure 39. Photographs of sedimentary features on the intertidal. December 2016.

- Only at Site B07, downstream of the sharp bend below the pontoon site, were the transverse bedforms (ripple marks widely seen during the initial survey) well preserved (Figure 39 E). At this point the channel has widened considerable, and the sediments on both banks and on the channel floor have some of the highest sand contents seen (11-16%, Table 6). The ripple marks are asymmetrical and clearly orientated to the formative seaward-going high river discharge.
- The inner sharp bend above Site 7 saw extreme erosion. Figure 39 F & G compare the situation in November (F) and on the 7th December (G). Very strong slumping and cliffing has occurred.

Through the dredge zone, some very large bank slumps developed through the weeks following dredging. The image seen in Figure 39 H was taken on 21st December.

From the bathymetric data (Sections 4.1 and 4.2) and from the above visual observations it is clear that most if the channel through the monitoring zone was subject to some level of erosion between November 2016 and January 2017. The (often modest) changes between the bed characteristics between the before and after surveys, therefore largely reflect the exposure of underlying deposits, the nature of which may not be related to processes active in the estuary through the monitoring period. It is therefore instructive to view the final survey as a starting point (cleanly-scoured bed left by the winter floods) and the initial survey as the end point (deposits that have built up during a spring/summer/autumn absence of river flows, dominance of marine flows and no dredging).

This approach recognises other evidence suggesting that there is a seasonal alternation of deposition and scour in the estuary, with mud building up during the summer months and being eroded in the winter. Evidence supporting this model can be listed as follows:

- Bathymetric data showing summer deposition and winter scour, with likely net deposition only over several years (Section 3.1, Figure 9)
- Turbidity data that shows both the delivery of mud from the sea on the highest spring tides and the cessation of this delivery once higher river flow sets in in the winter (Section 3.6).
- Layered properties of the estuary mud, indicating a history of alternating conditions of deposition and erosion (this Section)

On the basis of this model it is therefore useful to turn Figure 36 on its head, allowing the following observations to be made about the particle-size of the material that builds up through the (summer) low river discharge periods, compared to the residual mud deposits left behind after scouring by river floods and/or dredging.

1) The sand content of the summer accumulating material is lower than in the residual mud.
2) The summer accumulating material has more clay and fine silt than in the residual mud.

That is to say that the material that accumulates in the upper estuary through the 'summer' has particle-size characteristics more like the sediment flooring the estuary at its mouth (Figure 9), consistent with a marine source for most of the sediment in the estuary. The changing particle-size of the bed sediments in an up-estuary direction (Figure 9) may result from the effects of periodic river scour, preferentially removing the finer components (more easy to suspend a transport under modest flow conditions) from the marine-sourced material.

Finally for this section, visual evidence of post-flood/dredge bank deposit features indicates that lateral motion of sediment (slumping and sliding down the bank) may be an important aspect of cross-section scouring processes, providing a feed of material to the low-water-channel constant ebb flow. This process will tend to naturally create a V-channel section rather than a trapezoidal section. Bank deposits may be weakened while submerged at high water levels, but slumping probably continues whilst in a dry state. Dredging the toe of the bank must enhance this process.

5. Sediment Dispersion During Dredging

5.1. Trial 1 WID

The survey was undertaken on the 16th November, with low river flow, tidal range 12.49m (very high spring), HW at Hinkley 7:38 GMT (6.85m OD) and HW at Northmoor 08:45 GMT (6.42m).

Monitoring began at 9:15 and ran through until 13:15. The survey commenced upstream of the dredger which was located at the southern extremity of the southern EDZ reach, the tide was still very slowly flooding. One profile was taken. The second profile was taken just downstream of the dredger before WID activity commenced. The third profile was taken at 9.54 just after dredging commenced. Two drogue tack runs were then made during the remaining survey time. By the time the second drogue run started, the WID activity had already ceased (only 1.25 hours dredging that day). The WID dredge bar was maintained quite high above the bed, and not a large amount of sediment was dredged during this episode. All profiles and observations at a fixed height in the water column (~0.8m below the water surface) are plotted in Figure 40.

The first profile was theoretically taken from upstream of the dredger before dredging began, but with the last of the flood running from the dredger towards the survey boat. The presence of a

~1.5m thick layer of fluid mud on the bed is unlikely to be natural, and it is suspected that the WID side-ports, and energetic use of the propellers, in getting the vessel to her start location, had already initiated a lot of bed disturbance. The second profile, once the ebb had started to flow, and before dredging proper began, may better reflect the natural condition (~2 g/l surface, 10 g/l bed, cf Figure 23.).

During RUN 1 the plug of water running down the estuary comprised a well-mixed upper layer of around 15-20 g/l overlying a very dense suspension, 0.5-1.0m deep, with concentrations >20 g/l. This bed-supported fluid mud layer persisted to beyond the downstream monitoring limit. No absolute concentrations of sediment in this layer were established due to a malfunction of the Owen tube, preventing deep sampling. During RUN 2, after dredging had ceased, TSS levels reduced to ~2-3 g/l at the surface and 10-15 g/l near the bed. There were some higher levels immediately above the bed, but the fluid mud layer seen during RUN 1 has dispersed downstream from the monitoring reaches.

During both runs the TSS content of the surface water layer increased seawards as far as Kp 27.5 (the pontoon), indicating that sediment was not settling out onto the bed through these reaches but was being fed from the bed/fluid mud layer (Figure 40 lower graph). Downstream of this point however surface layer concentrations began to fall, indicating that settling was beginning to occur

5.2. Trial 2 WID

The survey was undertaken on the 18th November, with low river flow, tidal range 10.9m (high spring), HW at Hinkley 8:53 GMT (6.09m OD) and HW at Northmoor 10:55 GMT (5.86m).

Monitoring began at 11:07 and ran through until 14:30. The survey commenced immediately downstream of the dredger which was located at the northern end of the southern EDZ reach; the dredger was not operating. One was profile taken. The second profile was taken just downstream of the dredger after WID activity commenced. Two drogue track runs were then made during the remaining survey time. Dredging ceased at the time the second run ended. The WID dredge bar was maintained closer to the bed and more sediment was dredged during this episode. A stationary (on pontoon) set of observations was made from about 13:30 to 14:30. All profiles and observations at a fixed height in the water column (~0.8m below the water surface) are plotted in Figure 41.

The first profile, taken before dredging commenced, was as expected, showing apparently natural concentrations for a high spring tide (see Figure 23). As soon at the WID commenced turbidity rose and a flowing, dense near-bed suspension formed again (Profile 2 onwards), though thinner and less persistent along the reaches than during the previous trial. Owen tube samples were taken from within the fluid mud layer (points identified in Figure 41). Sample 7 at profile 10 gave a concentration value of 25 g l^{-1}, normal for a mobile dense suspension. Samples 8 (profile 2) and 4 (Profile 14) gave very high values (329 and 478 g l^{-1} respectively) more typical of a stationary (settled) fluid mud condition. A settling test conducted on sample 4 showed hindered settling conditions. It is possible that these very dense suspensions were not moving along the estuary bed.

In the water layer above the bed-supported fluid mud layer, TSS values were consistently in the range 5-10 g/l near the surface and 10-20g/l at the bed. The set-depth drogue tracking runs along the reaches below the dredging showed that on RUN1 the TSS content of the water plug dropped during the journey, indicating that sediment was settling out on to the bed. During RUN 2 TSS values stayed more constant, suggesting the suspension was stable. Once dredging stopped, TSS conditions towards the lower end of the monitoring zone dropped to ambient levels (~4 g/l) within an hour (Figure 41, bottom right graph).

5.3. Trial 3 Farrell

The survey was undertaken on the 25th November, with high river flow, tidal range 7.2m (high neap), HW at Hinkley 15:53 GMT (3.97m OD) and HW at Northmoor 17:15 GMT (6.18m).

Monitoring began at 11:44 and ran through until 15:20. The survey commenced alongside the dredger which was moored to the pontoon. A profile was taken. The survey launch then followed the dredger as it sailed to its start position at the northern edge of the EDZ. A profile was taken mid-trip (RUN 0). Observations were made astern of the dredger while it was setting up. At 13:00 dredging with the Farrell commenced, with a profile being taken immediately downstream. Two drogue tack runs were then made during the remaining survey time. Dredging ceased at the time the second run ended. All profiles and observations at a fixed height in the water column (~0.8m below the water surface) are plotted in Figure 42.

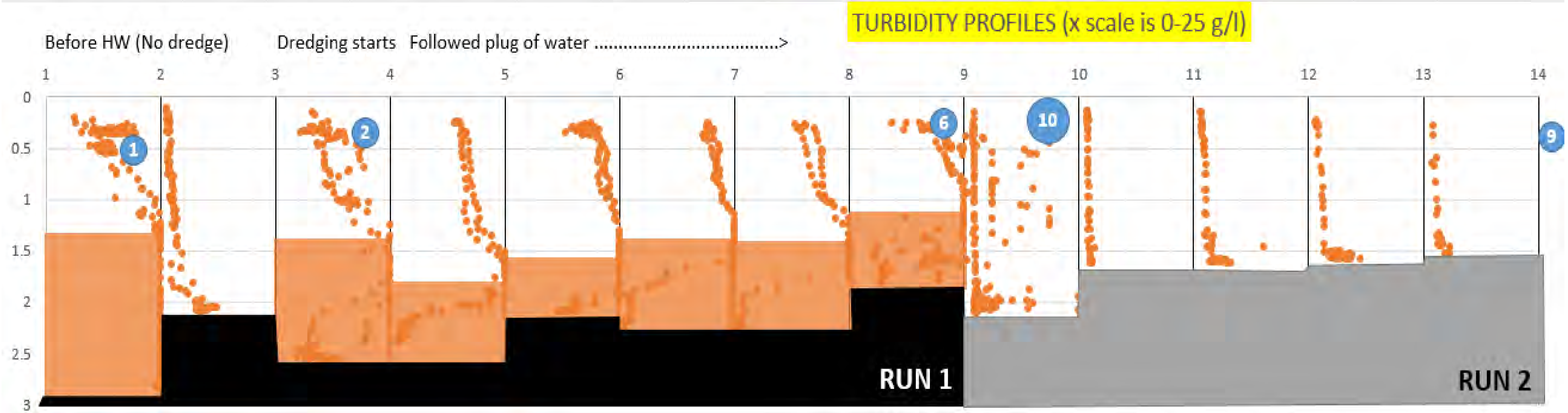
The first profiles taken showed that, due to the high river discharge, suspended sediment levels were much lower than previously seen, with ambient values being below 150 mg/l (bottom right graph Figure 42, first profile Figure 42. NOTE that the x-scale on this figure is x10 lower than in previous figures). During the initial period of getting on station and spudding in, the background TSS levels rose to 2500 mg/l, the highest concentrations to be seen that day. During the drogue tracking runs while the dredger was working downstream TSS concentration varied between 200 and 600 mg/l, with little drop in concentration with distance travelled, indicating that sediment was not falling out of suspension. The suspension was well mixed through the water column, the step of slightly higher concentrations measured at the bed possibly indicating exchange of particles between the bed and the overlying suspension, or a fine sand/coarse silt carpet flowing along the bed. TSS determinations from the various

5.4. Trial 4 Farrell

The survey was undertaken on the 28th November, with moderately high river flow, tidal range 9.2m (low spring), HW at Hinkley 5:53 GMT (4.91m OD) and HW at Northmoor 06:30 GMT (5.67m).

Monitoring began at 8:05 and ran through until 12:15. The survey commenced alongside the pontoon. A profile was taken (1). The survey launch then sailed to the dredger located at its start position within the north reach of the EDZ. The dredger had just started working with the Farrell on arrival. A profile was taken downstream of the dredger. Three drogue tack runs were then made during the remaining survey time. Dredging ceased after the time the last run. All profiles and observations at a fixed height in the water column (~0.8m below the water surface) are plotted in Figure 43.

The initial measurement made on the pontoon showed similar ambient TSS concentrations to the previous survey (Figure 43 bottom right graph, ~200-300 mg/land stable). During RUN 1, although the dredger was supposed to be pumping, TSS levels remained at the ambient concentration or lower. During RUNS 2 & 3 TSS levels increased as a result of the dredging, but not by a large amount,



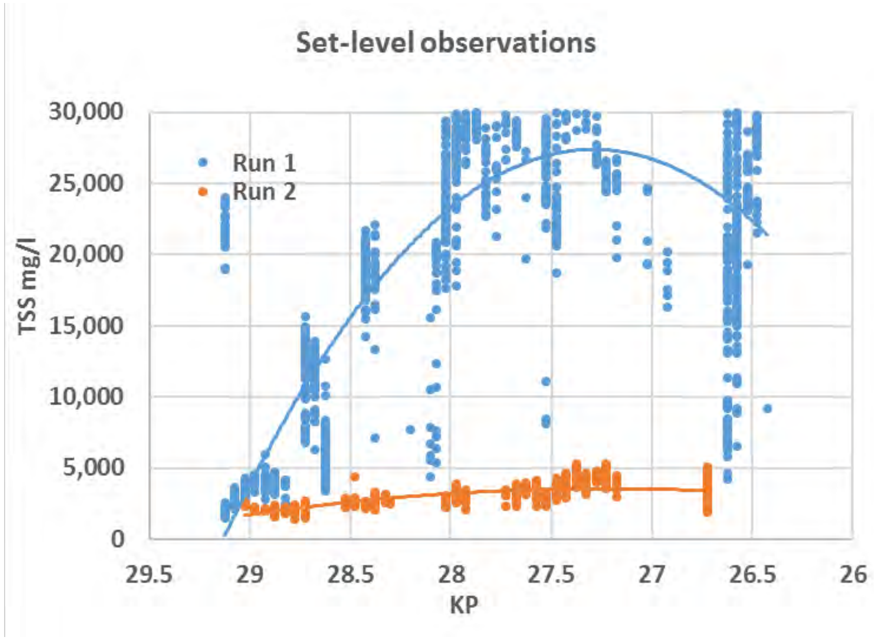


Figure 40. Total suspended solids (TSS) data collected during the first trial monitoring day (WID).

Top diagram shows successive vertical profiles (y-axis is depth below water surface in m, x-axis is TSS concentration scaled to a maximum value shown in the yellow title). Numbered blue circles are points where water samples were taken for calibration and (sometimes) sediment settling velocity measurement. Orange zones immediately above the bed indicate the presence of a layer of very dense mud suspension on the bed, as defined by the Partech transmissometer reading >20,000 NTU. YSI TSS readings seen behind this layer are spurious.

The left graph shows the constant depth monitoring undertaken between the profiles (a depth profile is given if this wasn't constant at about 0.8m). TSS value is plotted against kilometres along the estuary (Figure 1). Polynomial regression curves are fitted to these data to pick out the trends.

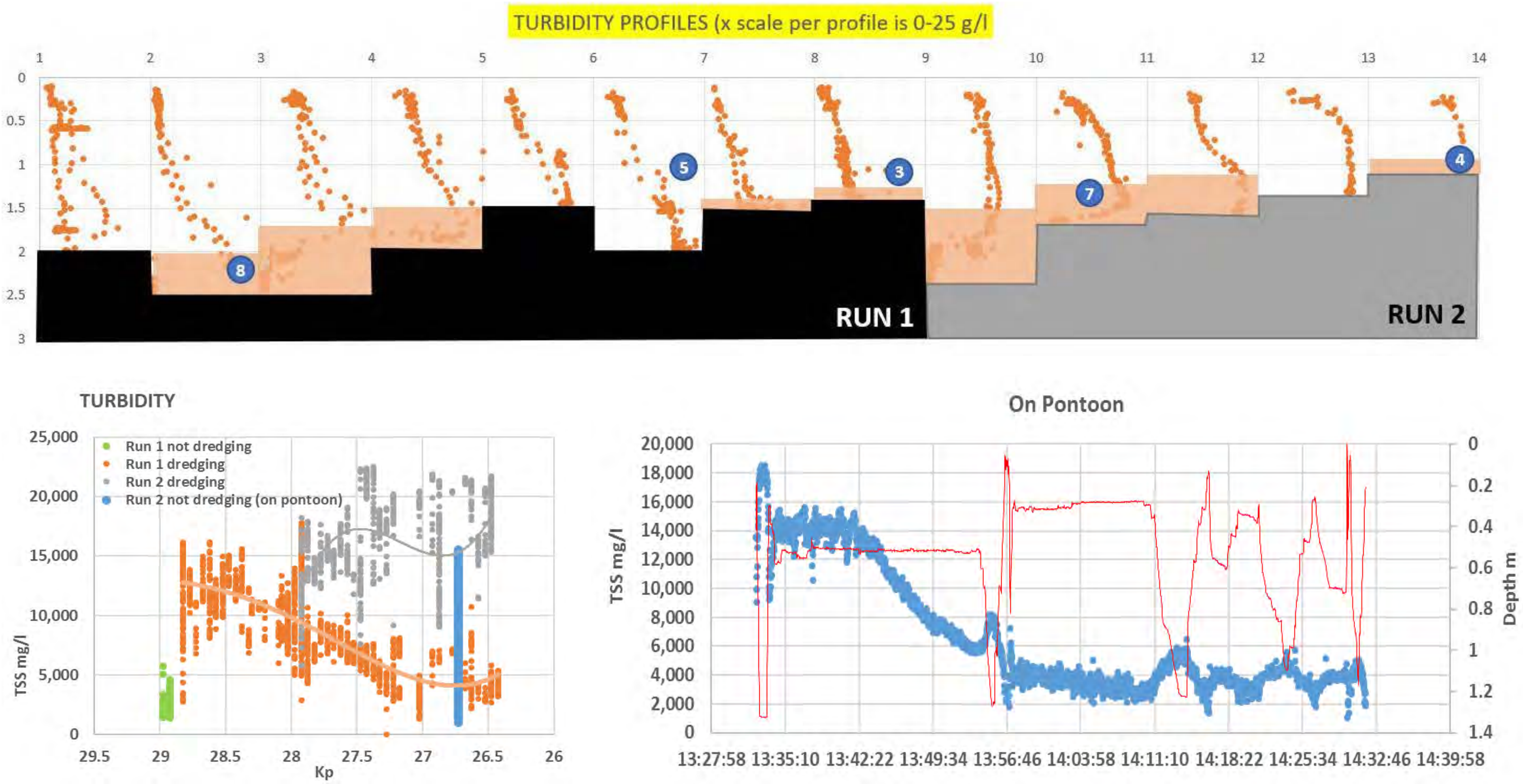


Figure 41. Total suspended solids (TSS) data collected during the second trial monitoring day (WID). For explanation see Figure 40.

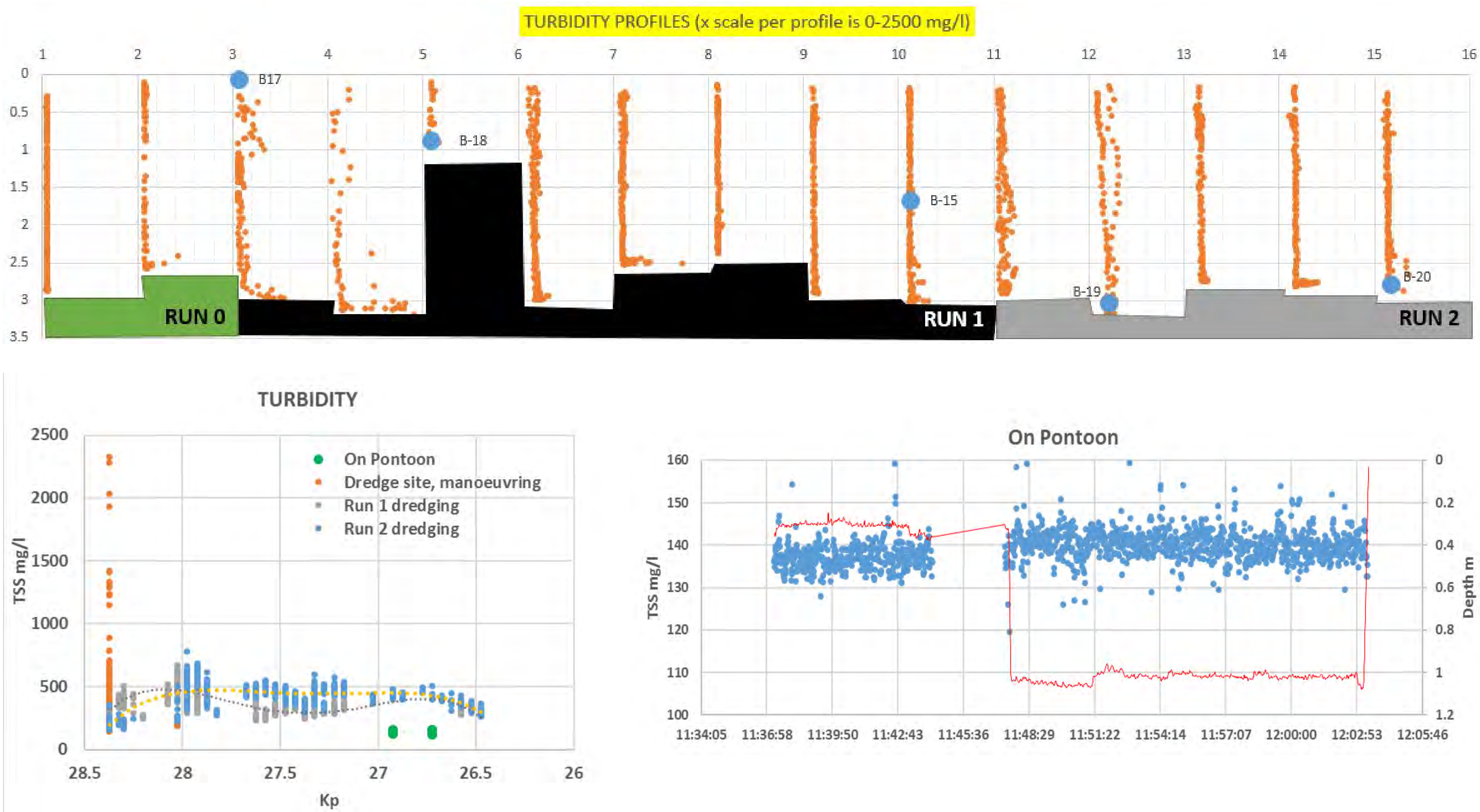
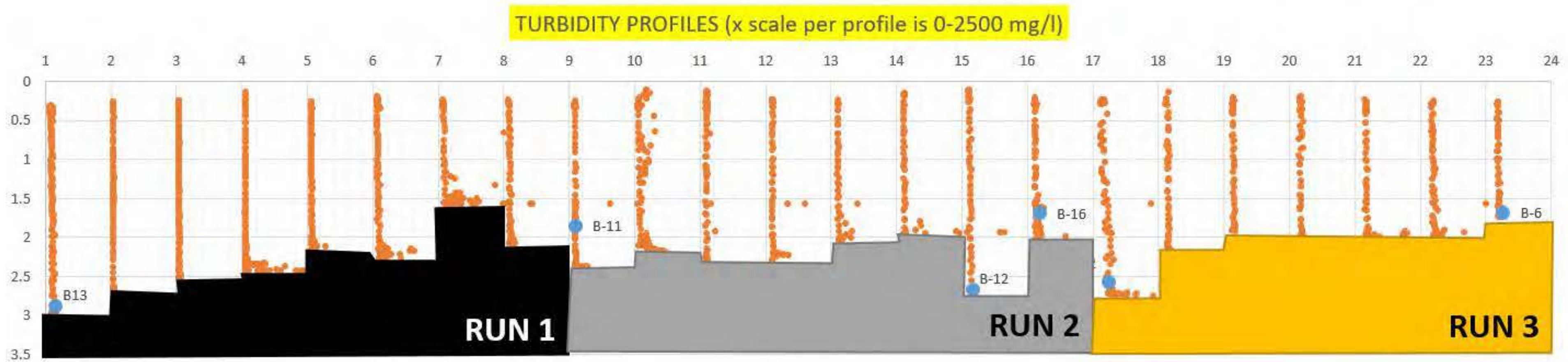
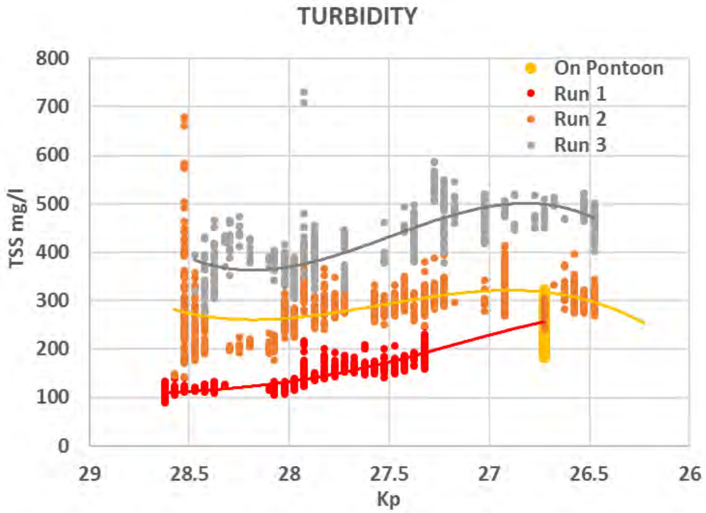


Figure 42. Total suspended solids (TSS) data collected during the third trial monitoring day (Farrell). For explanation see Figure 40.





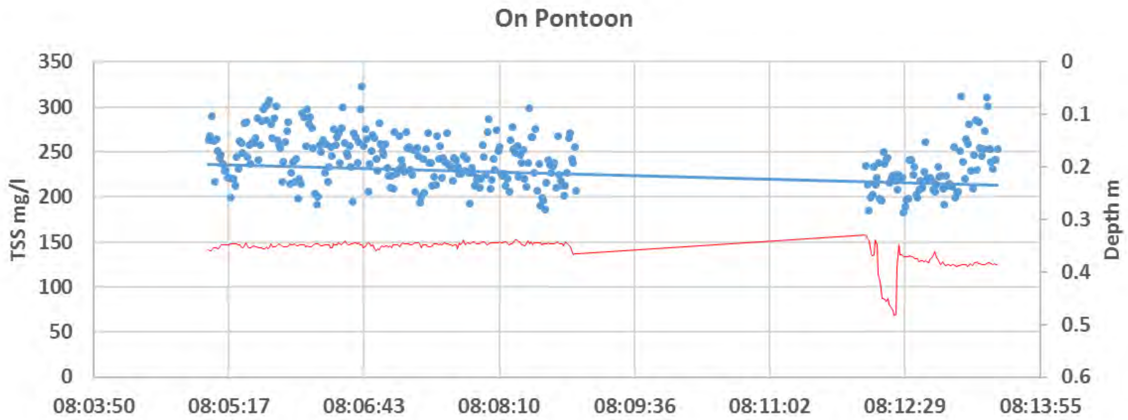


Figure 43. Total suspended solids (TSS) data collected during the fourth trial monitoring day (Farrell). For explanation see Figure 40.

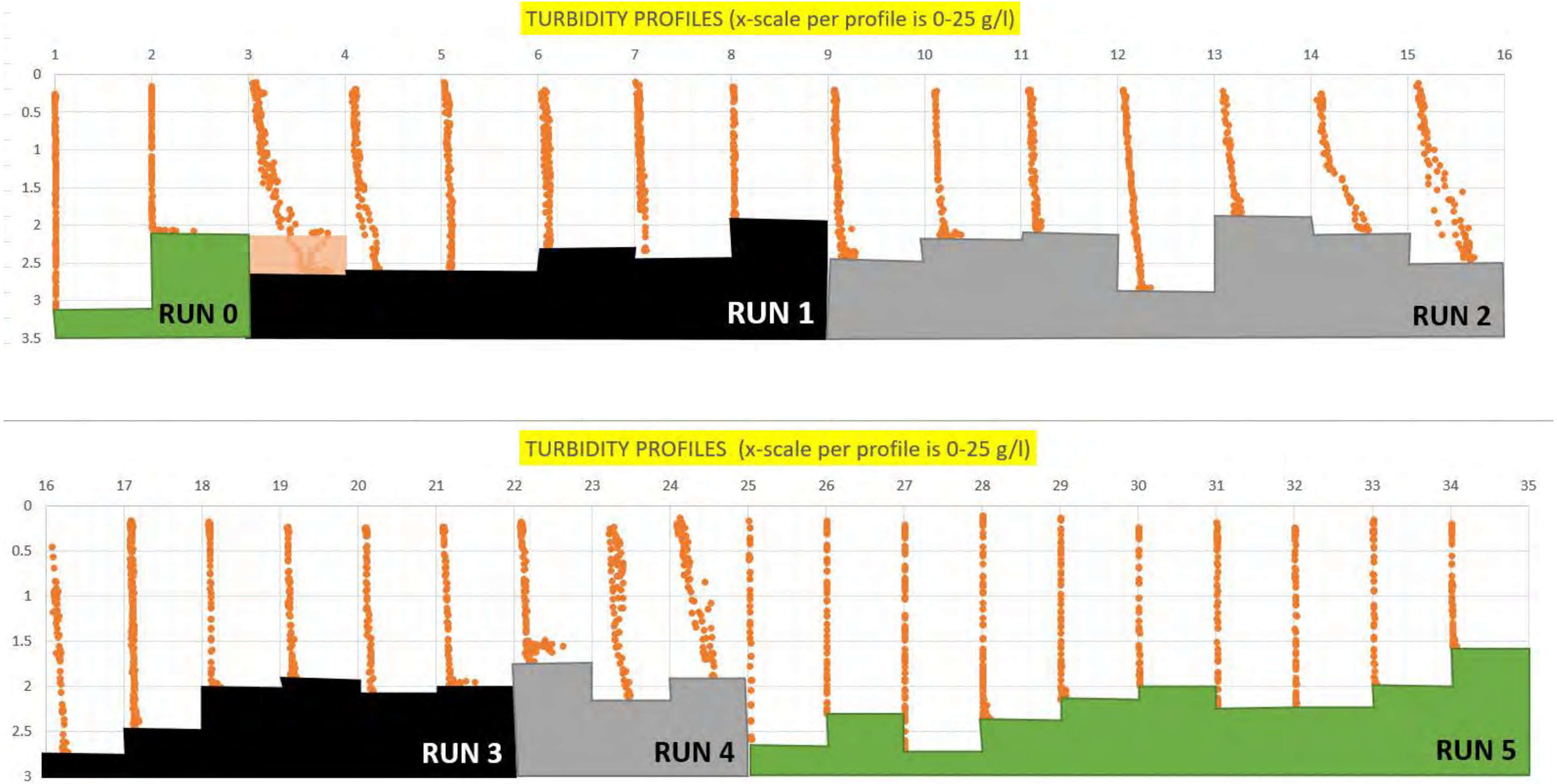


Figure 44 A. Total suspended solids (TSS) data collected during the fifth trial monitoring day (WID). For explanation see Figure 40.

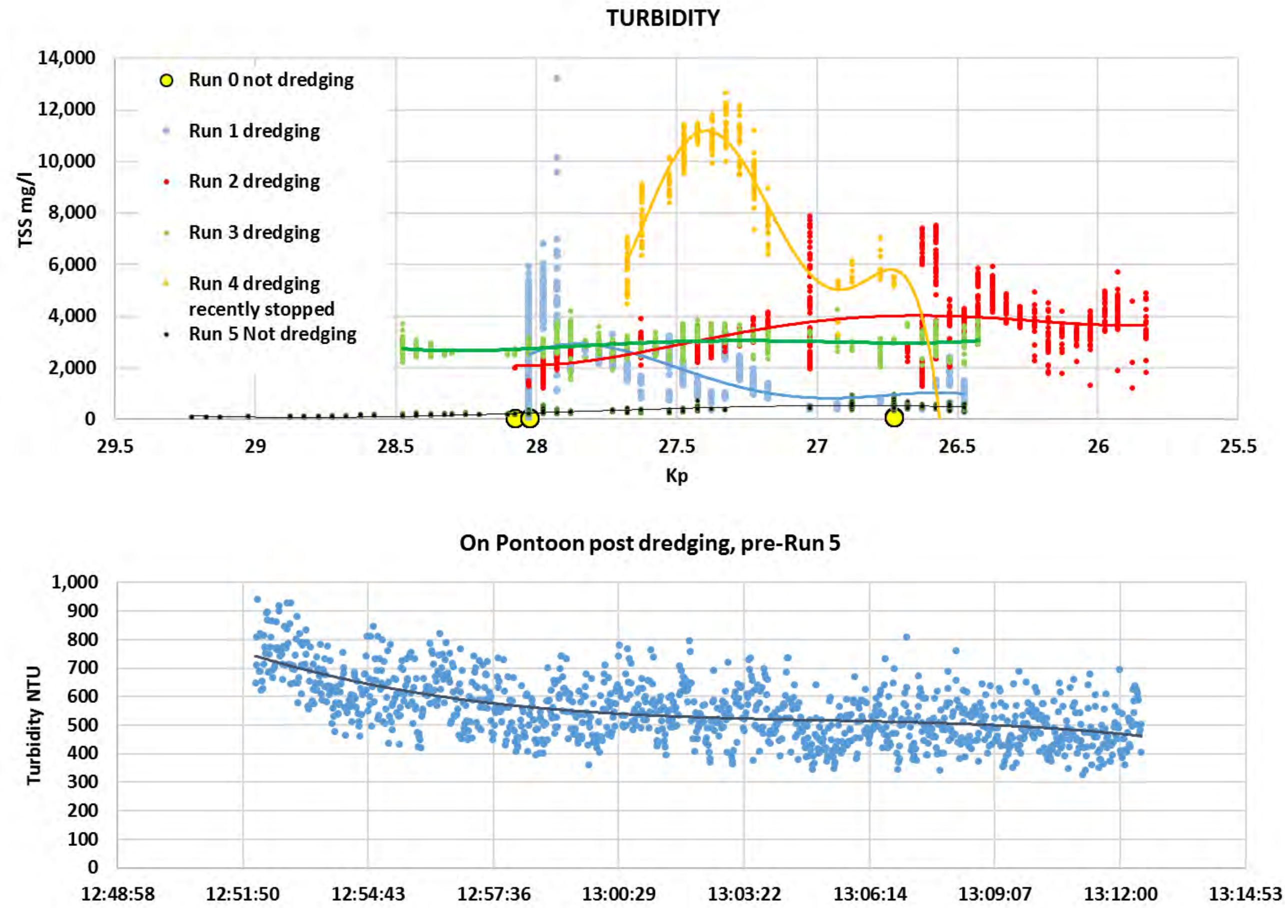


Figure 44 B. Total suspended solids (TSS) data collected during the fifth trial monitoring day (WID). For explanation see Figure 40.

reaching only about 600 mg/l maximum (Figure 43 bottom left graph). Regression lines fitted to the latter data sets show clear TSS level increases downstream of the dredger, indicating bed erosion under the natural flow rather than deposition from the dredger plume. This situation altered downstream of 27.5 Kp (pontoon site) and it would seem that particle settling began to happen below that point. Profiles (Figure 43 top) showed well-mixed conditions, but often a step increase in TSS levels close to the bed, indicating bed erosion or deposition, and/or a mobile carpet of particles with a higher settling velocity.

5.5. Trial 5 WID

The survey was undertaken on the 30th November, with moderate river flow, tidal range 9.9m (low spring), HW at Hinkley 6:53 GMT (5.30m OD) and HW at Northmoor 07:45 GMT (5.84m).

Monitoring began at 8:30 and ran through until 14:30. The survey commenced alongside the pontoon. A profile was taken. The survey launch took up position downstream of the dredger at the northern edge of the EDZ. Profile 2 was taken (no dredging). WID dredging commenced at 8:45. A profile 100m astern of the dredger was taken (3), then drogue runs commenced. Four drogue track runs were then made with the WID working continuously. Tracking stopped during RUN 4 when the WID ceased operation at 12:30. At 12:50 a short period of stationary mid-depth observations were made at the pontoon. At 13:40, a drogue track run (5) was made through the whole of the monitoring zone, the WID not having ben dredging for over an hour. All profiles and observations at a fixed height in the water column (~0.8m below the water surface) are plotted in Figure 44A&B. NOTE the x-scale on the graphs of Figure 44A are now back to a range of 0-25 g/l).

Initial profiling (RUN 0) showed ambient TSS levels to be very low (<300 mg/l). On commencement of dredging the whole water column TSS concentration rose quickly to 2-10 g/l and immediately astern of the dredger a ~0.5m thick dense mud layer (>20 g l^{-1}) was formed. This bed layer dispersed very quickly down the estuary, and the phenomenon was not seen at all during the remainder of the day's monitoring. During RUN 1 there was a strong decrease of TSS values in the water body tracked downstream (3 to 1 g/l, Figure Z11B), suggesting strong settling out to the bed. During RUN 2 this situation reversed and the form of the curve fitted to the data suggested slight erosion of the bed throughout the surveyed reaches, possibly being a mobilisation of the material that had fallen out during RUN 1. During RUN 3 conditions seemed stable in the plume throughout the monitoring zone, and during RUN 4 (when TSS values reached ~12 g/l) there was indication of strong erosion in the reaches between the dredger and the pontoon, possibly as a result of scour under the increasing velocities of the later, more confined ebb current. RUN 5 was undertaken about one hour after dredging had finished, and showed that water column TSS concentration had returned completely to ambient levels. The trendline fitted to these data along the reaches increased slightly seawards (~100 to 400 mg/l), indicating slight bed erosion. However there were no marked step increases in TSS levels close to the bed during this run, suggesting a clean bed, not clogged by unconsolidated sediment fallen out from the day's dredging, i.e. the WID process had successfully allowed all dredged material to be dispersed from the monitoring zone.

5.6 The Settling Characteristics of the Plume Suspended Sediment

The Owen tube was used on 15 occasions during the manned monitoring to determine the settling velocity of the plume suspension. The results are summarised in Table 7 and Figure 45.

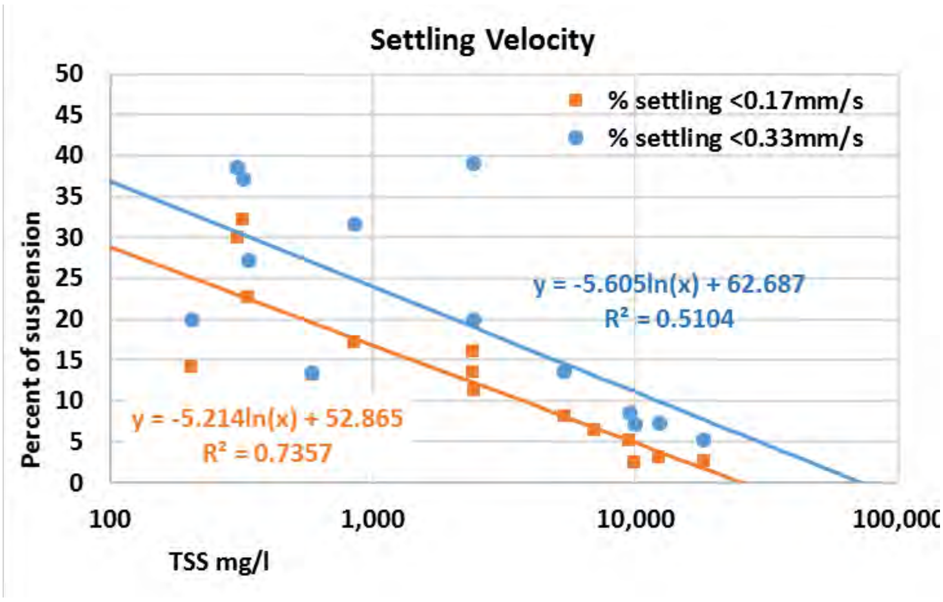


Figure 45. Relationships between sediment settling velocities and total suspended solids (TSS).

	Sample	YSI NTU	TSS mg l^{-1}	% sand	% settling<0.33mm/s	% settling <0.17mm/s
14/11/2016	1	1254	6,971	3.8		6.4
	2	786	2,428	2.0		11.3
16/11/2016	1	638	2,405	2.9	19.9	13.5
	2	1558	8,240	4.6		
	6	932	1,928	0.3		
	9	1100	5,350	6.5	13.6	8.1
	10	638	2,405	2.9	39.1	16.1
18/11/2016	3	1257	9,907	6.6	7.1	2.4
	4		478,376	4.5	0.2	0.1
	5	1705	6,838	1.2		
	7	1897	24,626	5.1		
	8		329,921	10.6		
25/11/2016	15	95	321	0.0	37.1	32.2
	17	55	161	0.0		
	18	68	336	0.0	27.2	22.7
	19	155	350	0.0		
	20	128	305	0.0	38.5	30.0
28/11/2016	2	174	473	0.0		
	6	198	700	0.0		
	11	66	204	0.0	19.9	14.1
	12	119	200	0.0		
	16	136	589	0.0	13.5	13.2
30/11/2016	1	747	1,530	0.0		
	3	308	849	0.0	31.6	17.1
	5	1164	9,488	10.1	8.5	5.1
	10	1649	18,216	6.9	5.2	2.6
	15	22	40	0.0		
	16	154	314	0.0		
	17	743	1,973	1.9		
	18	1229	3,354	0.0		
	19	1741	12,281	1.5	7.3	3.1

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The results show (the expected) strong relationship between mud settling rates and suspension concentration, the denser the suspension the higher the floc collision rates and the larger the flocs that form, with consequent higher settling rates. This model only applies at low current speeds, the shear associated with turbulence at high speeds acts to reverse this process and break up flocs. Still water does not occur during the ebb dispersion periods that have been monitored, but knowledge of settling rates is instructive as a) at modest flows with associated low vertical diffusion, particles can settle from a flow (either through the whole flow or just through the near-laminar near-bed layer) and b) it allows insight into the wider model of fine sediment dynamics in the Parrett estuary. Two standard settling velocities were measured on each experiment, and the percentage of the suspension settling slower than these velocities reported. These settling velocities were chosen as they are typical velocities for particles in the mid-silt range at normal temperatures, and therefore should relate to the Parrett sediments. The velocities (Table 7) are:

- 0.17 mm s^{-1}, which relates to a settling depth of 0.3m over a 30 minute period (the typical 'still stand' at HW on the Parrett)
- 0.33 mm s^{-1}, which relates to a settling depth of 0.6m over a 30 minute period.

At suspension concentrations of around 10g l^{-1}, in still water, about 90% of the sediment held in the near-bed 0.6m could sediment onto the bed (Figure 45). At 100mg l^{-1} only 60-70% would settle.

5.7 Autonomous Data Records from the Dredging Period

Data logged for the surface water layer at Westonzoyland (WZ) and Burrowbridge (BB) during the dredging period are plotted in Figure 46. Note this plot fits between the timeseries plots of Figure 24 and 29 (pre-dredge and post-dredge respectively). Dredge days are indicated by green blocks of shading.

At the water surface, the WID dredging of the 15th-18th November is lost in the high TSS peak naturally associated with the peak spring tide flows under low river discharge. The plot of Figure 46 is magnified in Figure 47 for this period, and shows clearly the dominance of the flood turbidity spike over the ebb turbidity levels. Only on the last tide of the sequence at WZ does the ebb dominate over the flood TSS level. The WID dredge of the 30th November, under a lower spring tide and much higher river discharge, is evident as an isolated peak at the WZ site only. The maximum value recorded (~3 g/l) agrees with the manual monitoring values (Figure Z11B). The time series data shows that ambient TSS levels were restored within about 12 hours of dredging finishing. On the Farrell dredging days (25th, 28th, 29th November and 1st December) minor peaks are evident in the TSS record at WZ. Peaks seen do not exceed ~500mg/l, consistent with the manual observations (Figures 42 and 43). Again, the timeseries data show restoration of ambient values within 12 hours of dredging ceasing.

From the start of dredging to the 11th December the only other turbidity peaks evident are between 19th and 22nd November, and coincide with the rising limb of the river flood passing through the system. Maximum TSS values reached about 1500 mg/l at Burrowbridge on the rising flood limb. By the time this water reached Westonzoyland the peak TSS concentration was in excess of 2 g/l, clearly some bed erosion occurred between the two sites. It is impossible to speculate how much of this erosion would have occurred under normal circumstances, and how much enhancement occurred as a result of the release of sediments disturbed during the dredging. Some effect of the dredging might be expected. Outside of the period of this flood limb, turbidity was very low at both BB and WZ sites, suggesting that any residual effects of the dredging on the turbidity regime must have been minor. After the 11th December a period of strong spring tides generated natural high turbidity associated with the upstream penetration of the tide. The level of turbidity generated under these processes was less that on previous spring tides (pre-dredge, Figure 24) presumably due both to the higher river condition, and sediment exhaustion due to the combined effects of dredging and the scour associated with the late November flood event. Any turbidity associated with the dredge extension period (12-16th December) was lost in the natural peak spring tide high TSS peaks.

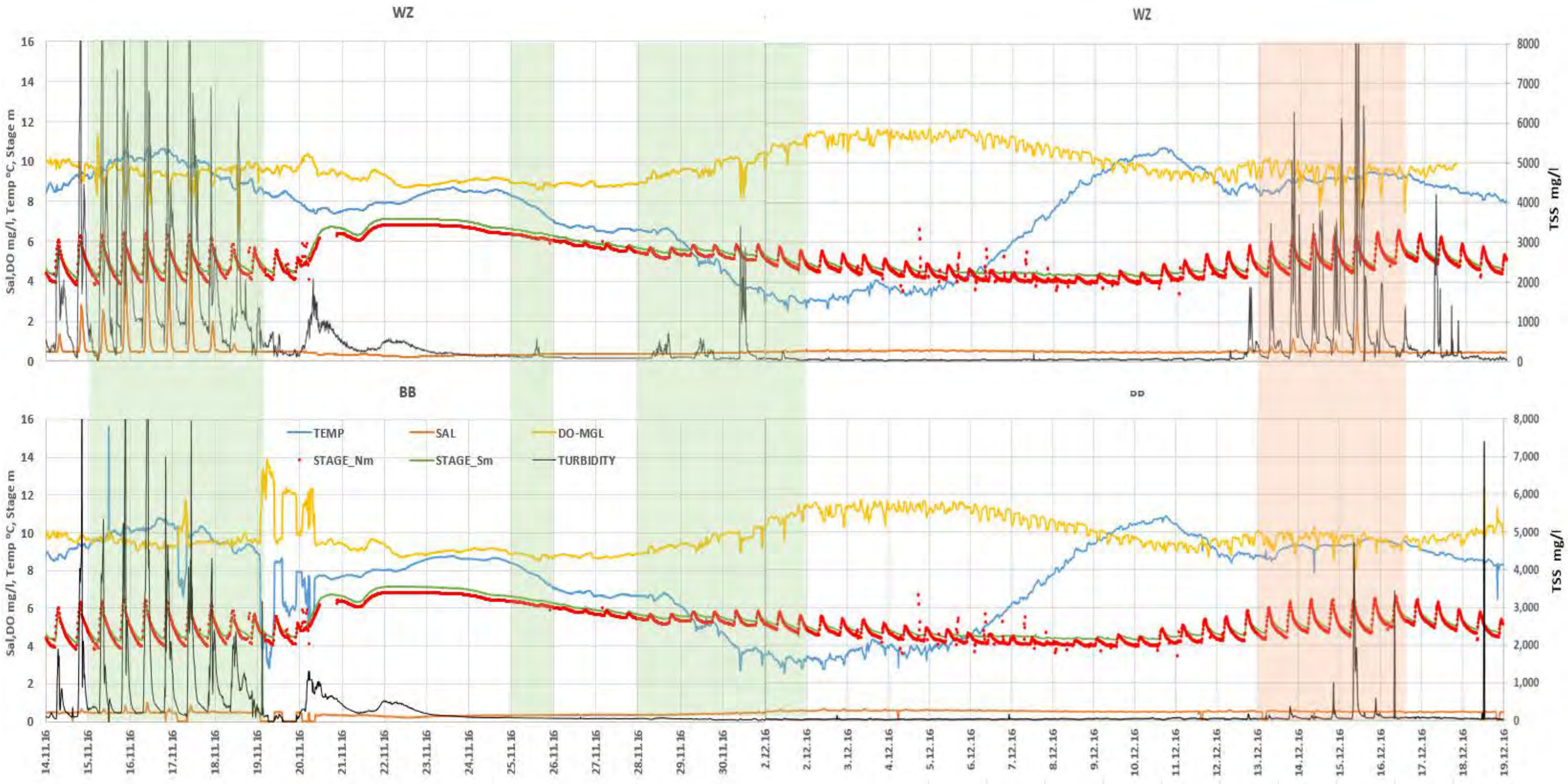


Figure 46. Autonomous monitoring data through the dredging period. Green boxes show original (fully monitored) dredge periods, pink box shows partially monitored extra-dredging period. YSI data for the 19th/early 20th November at BB are suspect (sensor became only partially submerged).

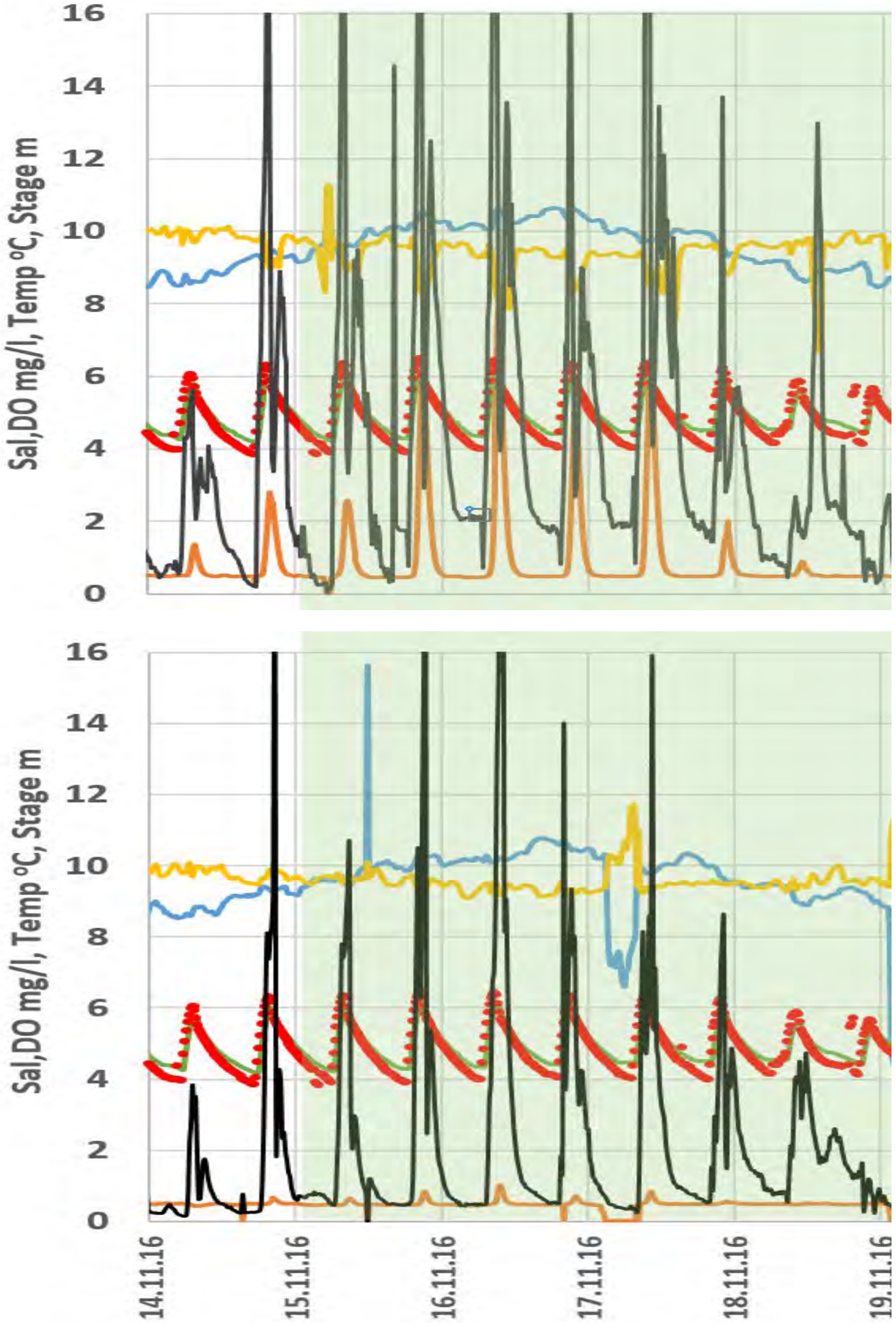
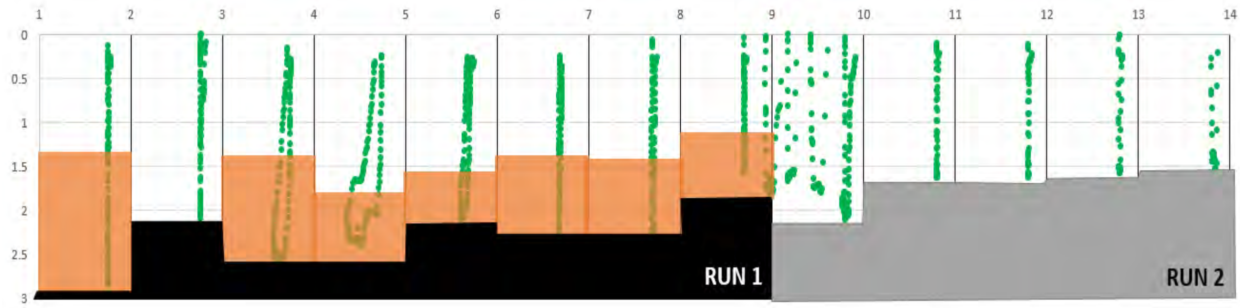
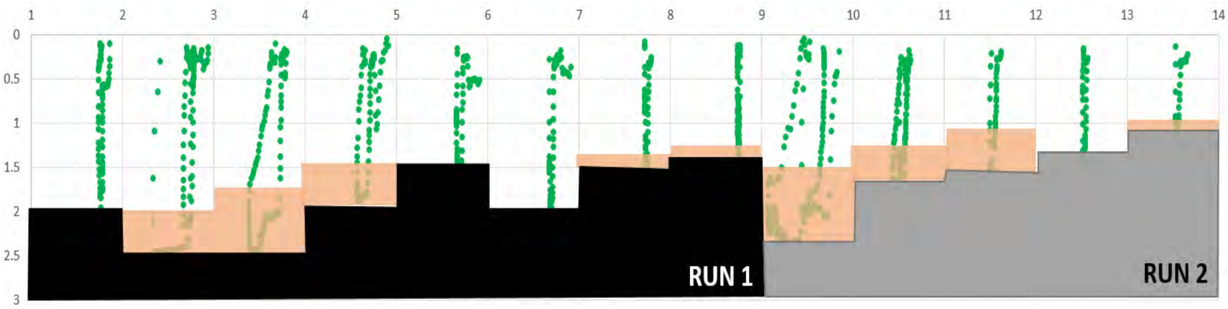


Figure 47. Zoom of part of Figure 46, covering the initial dredge period. See Figure 46 for the secondary y-axis labels (TSS mg/l). Top WZ, bottom BB.



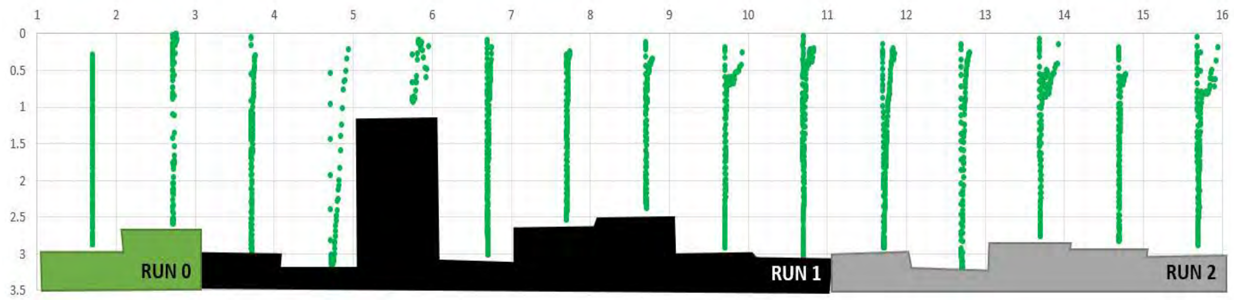
16/11/2016



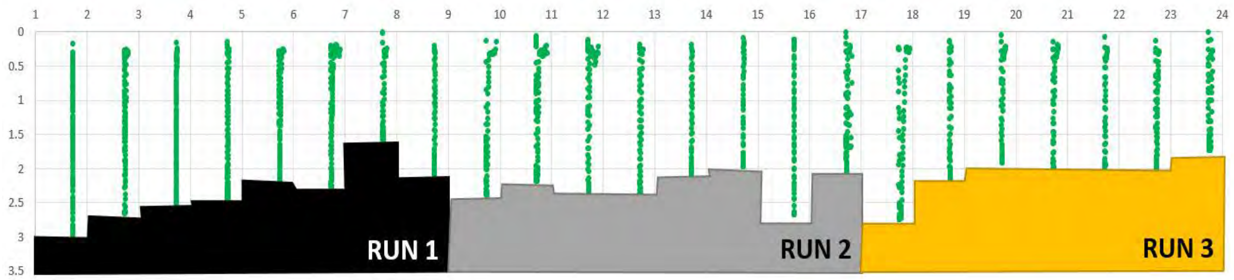
18/11/2016

30/11/2016

Figure 48. Dissolved oxygen profiles during the WID trials. Figure 48. Dissolved oxygen profiles during the Farrell trials. X-axis is scaled to 100% per profile, y-axis is depth below water surface.



25/11/2016



28/11/2016

Figure 49. Dissolved oxygen profiles during the Farrell trials. X-axis is scaled to 100% per profile, y-axis is depth below water surface.

6. Water Quality Impacts

6.1. Dissolved Oxygen

WATER INJECTION DREDGING. All the dissolved oxygen profiles observed during the WID dredging trials are plotted in Figure 48. Most of the profiles are simple, vertical and with values at around 75%, showing a normal, well-mixed and oxygenated water column. However some of the profiles that pass into fluid mud at the bed show a strong drop in dissolved oxygen on entering the layer, which takes a while to recover during the return limb of the cast. The latter is simply due to the time taken for the dense suspension to wash clean of the sensor, and the (slow) response time of the sensor. In one worst case (profile 9 on the 18th November) the DO % reached zero. The fluid mud clearly can have a high oxygen demand, as might be expected. If pools of this mud were to accumulate in trap zones along the channel thalweg, fish/eels/infauna trapped in the pre-existing bed layer could become deprived of oxygen.

FARRELL CUTTER DREDGING. All the dissolved oxygen profiles observed during the Farrell dredging trials are plotted in Figure 49. On all occasions the DO % was above 75%.

6.2. Ammonia

No discernible effects on ammonia concentrations were recorded from either WID or Farrell dredging systems.

7. Ecological Impacts

Prior to the start of the trials, the potential for the experimental dredging systems to have ecological effects was assessed in an Environmental Impact Assessment and an Environmental Action Plan was prepared, which helped establish the monitoring and mitigation requirements for the trials. Significant ecological impacts were avoided by undertaking the trials at the least ecologically sensitive time of year and by selecting dredging methods that had minimal impact on bankside vegetation and geomorphology. The potential for minor effects on water voles, fish and upper bank habitat (vegetation)[17] are discussed below.

7.1. Water Vole

River banks between Burrowbridge and Westonzoyland were surveyed for water vole signs on three occasions (Sept, Oct and Nov 2016) prior to the start of the dredging trials. These land-based surveys found no evidence water voles (burrows, feeding signs or latrines) in the monitoring zone. This is not unexpected, since the high sedimentation rates and large fluctuations in water levels, due to the tide, make these sections of the channel generally sub-optimal for water vole. Predation pressure on the banks is also relatively high and vegetation cover can be patchy, especially in the inter-tidal zone. Water vole signs are more commonly recorded in the upstream sections of the Parrett and Tone, above Burrowbridge, but rarely downstream of Burrowbridge. However, safe access to the banks for ecological surveys is also an issue and the negative survey results cannot be taken as confirmation of the absence of water vole in the monitoring zone. The post-dredge boat survey provided good opportunities to examine the lower inter-tidal zone for water vole signs, and water vole footprints were found at several locations, especially in the upstream section of the monitoring zone. During the trials, the survey boat disturbed a heron that had just caught a water vole. The heron was filmed taking off carrying the water vole, thus there is confirmation the sighting. The heron almost certainly caught the water vole on the Parrett. The boat surveys confirmed that water vole are present on the Parrett banks between Burrowbridge and Westonzoyland, albeit in very low densities. In contrast to bucket excavation dredging, which removes sediment and vegetation from the banks, it is unlikely that the experimental systems impacted on water vole, as dredging activity was focused on submerged non-vegetated areas within the channel and the inter-tidal zone. However, the use of the Farrell system for precision dredging could potentially disturb water voles, or disrupt marginal habitats, which may require further evaluation.

7.2. Fish

The channel was monitored downstream of the experimental dredging for signs of fish in distress and fish mortality. No impacts could be unambiguously linked to the dredging activity and silt plume, even when the WID generated very low oxygen levels within the liquid mud layer, during periods of low fluvial flow. The absence of any low DO impacts on fish is likely to reflect the strong stratification in oxygen concentrations, which always remained high (above 80%) in the near surface (autonomous sensor) measurements, and would allow fish to escape low oxygen water. The potential for WID to create an oxygen deficient liquid mud layer under low fluvial flows, and the time taken for the plume to disperse and DO concentrations to recover, will require further evaluation and measures may be required to minimise the potential for impacts on fish.

Only on one occasion were dead fish seen in the monitoring zone. This occurred during a WID trial on 30th Nov and included one yellow eel (approx. 30cm in length) and two small freshwater fish

[17] These sections provided by Phil Brewin, SDBC

(probably roach). The eel was recovered and examined. It had been dead a few days and had no obvious signs of external damage or disease, although the gills were extruded out though the mouth, suggesting a pressure effect as the cause of death. The eel is unlikely to have been entrained in the WID pump, since it had been dead for a few days and this was the first time the WID system had been used for more than 10 days. It is possibly that the eel had been caught by the cutter head of the Farrell, which had was used on the two days prior to the eel being found. However, the cutter head rotation speed is low and it would be much more likely to cause external damage to the eel, rather than a pressure injury, which is more typical of passage through a pump. It is quite likely that the eel and two small fish died some distance upstream of the dredging trials and floated into the monitoring zone. They were found following a period of heavy rainfall (between 19-21st Nov) and spillway flows onto the moors, when all of the principal land drainage Pumping Stations had been operating for several days.

7.3. Trees and Scrub

No trees or scrub growth were removed from the banks by the experimental dredging systems. It is worth noting that riparian vegetation surveys identified several areas where the lower vegetated sections of the banks have recently been colonised by young willow trees. This new growth of woody vegetation was most apparent on the inside of bends, where large volumes of the silt had been dredged from the banks in 2014, suggesting 'pioneer' dredging may have provided excellent conditions for entraining floating willow branches in the rapidly reaccreting sediment. The experimental dredging systems are unsuitable for controlling tree and scrub growth on the banks, and complementary maintenance methods will be needed for managing bankside vegetation, if the experimental dredging methods are adopted.

8. Conclusions and Recommendations.

A trial dredging project and associated programme of environmental monitoring was successfully undertaken over the period November 2016 to February 2017. The project addressed a series of issues.

UNDERSTANDING THE NATURAL REGIME OF SEDIMENTATION

A primary objective of the project was to improve our understanding of the natural sedimentary regime of the upper Parrett estuary, in order that any sediment management strategy that may be developed is optimally designed to work with nature. This report brings together rather patchy and inconclusive data from previous studies of the Parrett, providing a fuller and clearer conceptual model of the natural sedimentary system and explaining some anomalies that were previously apparent. Data generated in this study are fully compatible with data previously generated.

From the information gathered during this project several strong and independent lines of evidence have emerged demonstrating that a seasonal alternation of sedimentary processes is found in the estuary. Sediment influx from marine sources at times of high spring tides and low river discharge is replaced by effective seaward scouring of this material at times of higher river discharge. These two regimes can be summarised as follows.

Fluvial dominance. Sedimentary processes under the control of river flow prevail for most of the time. At times of low river flow, and when the Severn Estuary tidal range is less than about 8m (neap tides) these is no or little tidal effect the monitored area of the upper Parrett estuary. The water currents flow seaward all the time, possibly slowing with a modest rise in water level on the late flood, and no saline water is seen. At higher river discharge levels the tide is even more excluded, and during the highest river floods even peak spring tides only minorly affect local river-flow conditions. Under this fluvial regime, the suspended sediment concentration in the water is normally low, with TSS values around 500 mg/l, and in the reaches between Burrowbridge and Westonzoyland bed scour normally dominates (deduced from the observation that water turbidity generally steadily rises in concentration as the flow moves between these two sites). During river flood events scour is even more pronounced, and observed TSS values peak around 2 g/l (higher values are likely to be seen during the rising limb of the highest flood events). As a result there is little potential for sediments of (primary) fluvial origin to accumulate in these reaches, and during the winter both the channel floor and the lower side slopes of the channel are eroded, with 10-20 cm of scour being typically seen. During these periods of erosion the bed sediments tend to become sorted, with the finest particles (clays and fine silts) becoming dispersed seawards and coarse silt and sand remaining.

Marine dominance. Much higher suspended sediment concentrations are seen in the upper Parrett estuary monitoring zone during the spring/summer/autumn months (when periods of low river flow prevail) at the times of highest spring tides. These effects are seen when the Severn estuary tidal range exceeds about 11m (seen for up to about ten tides in most lunar cycles). The phenomenon results from the combination of two factors: firstly the ability of the tide to penetrate upstream as a function of the high-tide water level and secondly the massive mobilisation of settled fluid mud deposits that occurs in the upper Severn Estuary over these periods of high tidal energy, increasing the feed of highly concentrated mud suspensions into the Parrett. Mean TSS values reach about 1 g/l and maximum (near bed) values exceed 25 g/l. The distortion of the rising limb of the tide (due to the high tidal range and the long, narrow sinuous estuary morphology) creates a short (~2 hour) powerful flood (landward-going) current. In contrast the ebb is a much longer period of less energetic seaward going currents. A very strong peak of suspended solids concentrations is associated with the flood (up to ~10 g/l), and the protracted ebb also sees high turbidity, but generally lower than on the flood. Fine sediment deposits from the flood-source suspended sediment body over the short (~30 minute) high water stand, and although some of this deposit may be reworked during the ebb there is a net accumulation of mud over the tide. This process provides the primary supply of sediment to the upper estuary. The sediment is of (recent) marine origin and is dominated by clay and fine silt particles.

The seasonal balance between the (scouring) fluvial/ebb influence and the less frequent spring flood tide supply of marine sediment (accumulation) dictates the net sedimentation situation. There may be significant inter-annual variability due principally to different peak river discharge conditions between the years. A natural equilibrium between these conflicting processes will prevail, with associated channel profile dimensions and shapes. Where dredging is used, these equilibria will be disrupted and net accretion will become the norm. Under natural conditions, accumulation may be expected to dominate on the estuary lower side slopes (inundated by the sediment-rich flood tides, dry for much of the ebb and low river discharge periods) and an equilibrium maintained on the channel floor (thalweg) where prolonged ebb currents can scour away accumulations. The deposits on the side slopes are periodically scoured by the severest winter river floods, to create a natural system where the cross-sectional area of the conduit changes seasonally. This is the nub of the problem from the flood prevention stance, as the natural clearance of the channel section only takes place during and after the occurrence of overbank flooding. Vegetation may play an important role in trapping sediments on the higher bank slopes, affecting longer-term equilibria. This mechanism has not been addressed in the current study.

The sediment bed of the upper estuary that forms as the net result of the temporal interfingering of these two very different (fluvial and marine) processes is a coarse silt, with a lesser fine silt and clay content, and typically <15% very fine sand. This material moves as suspended load once set in motion, although mass-failure of cohesive mud deposits can produce large clasts of mud that may temporarily roll as bedload until disintegrated. The cycle of bed sediment formation sees (marine) fine silt and clay and lesser amounts of coarse silt and very fine sand washed into the area from the lower estuary on infrequent spring floods, and (the more easily eroded) fine-silt and clay preferentially scoured seawards again during strong fluvial flow, leaving a residual coarse silt dominance. The frequent episodes of erosion and long intertidal drying times enhance mud consolidation, and the deposits are remarkably dense and strong compared to more typical estuarine muds. The cyclic nature of the deposition and erosion created a very layered sediment, which impacts on its geotechnical properties.

Many aspects of this model remain poorly understood, or data are not available to allow robust modelling of the phenomena. An example of the former is the apparent exhaustion of mud supply over the peak spring tide periods, with flood tide turbidity peaks dying out while high energy is still available for transport. This observation suggests that at any one time the source body of available mud for transport in the upper estuary has a limited volume. An example of the latter is the absence of good data on river flow entering the system on the Parrett and Tone, making it difficult to model with any detail the progressive interchange between fluvial and marine conditions.

DETERMINING THE EFFECTIVENESS OF THE EXPERIMENTAL DREDGING SYSTEMS

Two systems were trialled, a WID (high productivity) and a Farrell (high precision).

An important objective of the study has been to Identify and quantify the processes of sediment dispersion downstream from the dredger, to ensure that the dispersing flows did not simply redeposit the dredged sediments further downstream.. The processes of sediment dispersion varied between the method, and also according to whether marine (tidal) or fluvial processes were dominant at the time (river discharge).

In the upper Parrett estuary under low river flow conditions, the WID can only work during the ~2 hour period after HW on spring tides, due to the poor water depth at other times (and landward flow on the flood). Under these conditions the high productivity of the WID system tended to swamp the low volume of water passing the dredger, suspended sediment concentrations were very high and a mobile dense suspension (>20g l^{-1}, 0.5-1m thick) formed along the bed downstream of the dredger, often persisting all the way through the monitored reaches. At times the density of this layer at the most downstream monitored site reached 0.5t m^3, the density of a settled mud deposit, so it is likely that the movement of this layer was close to stopping or had stopped, resulting in local accumulation of the dredged sediment rather than dispersion into the lower estuary. For this reason and also for the very low dissolved oxygen conditions sometimes seen in the bed layer, the use of the WID at times of low river flow is unlikely to be the most practical option.

Using the WID under higher river flow conditions, and also with the lower productivity of the Farrell system, less dense plume conditions were generated. The method used of following a body of water down the estuary clearly showed that at times there was no increase or decrease in TSS values in the water body as it passed through the reaches (suspension stable), sometimes an increase in TSS (bed eroding) or sometimes a decrease in TSS (sedimentation onto the bed was occurring(). Which model dominated at any particular time must be largely controlled by the ambient current speed. It was observed that sometimes a 'depositional' plume was followed by an 'erosional' plume, so good dispersion downstream was achieved in the longer term. Post-dredge bathymetric surveys showed that natural river scour prevented the long-term accumulation of any of the dredged mud as far north as the M5 motorway. Selecting optimum river flow conditions, to ensure both good dispersion at the time of dredging a prolonged period of subsequent downstream dispersion, would be an important aim of dredge programme planning.

Given that the lower reaches of the estuary contain a large reservoir of mud that feeds the process of (spring tide) pumping of mud into the upper reaches, it is probably not important to be concerned about the ultimate sink sites of the dredged material. Just so long as the dredged material became mixed back into the source reservoir of mud in the middle/lower reaches of the estuary, the situation cannot really be improved. Further information on the sediment regime in the mid/lower estuary would give further confidence to this statement. Much survey work in these zones was undertaken by HRWallingford in the 1970s, and although unpublished may still be available for study.

The process of lateral slumping of the side slope berms through the dredged reaches was very marked at some locations, and occurred during the weeks following the primary dredge activity. This second phase of 'natural' lateral translation of the side berm sediments down into the main channel (where the persistent seaward flow would wash the material downstream) could be an advantageous phenomenon, allowing just WID dredging of the channel floor, and a natural reaccommodation of the side slopes. The presence of high river levels and strong fluvial discharge through this readjustment period will make the cleansing process more effective.

On the wider issue of effectiveness, the dredging is being undertaken in order to take the estuary cross-section area out of 'regime' (where it is in equilibrium with average energy conditions) so that it is ideally prepared to effectively conduct the highest floods occurring. By definition, destroying this energy equilibrium will encourage deposition to occur, both by reducing the effectiveness of fluvial/ebb scour, and by encouraging inland penetration of the sediment rich marine water under tidal action. Optimising dredging effectiveness maximises the cost benefit of this activity. To minimise the cost of dredging three analyses have to be made.

- Hydraulic modelling that can identify the downstream point beyond which dredging has little effect on floodwater transmission: definition of the dredge reaches
- Identification of dredge method that operates most cost effectively (known to be systems that have high productivity and rely on natural dispersion of dredged material).
- Establish the optimum timing (inter-annual frequency, seasonal optimisation of impact) for the dredging operations

The first analysis lies outside the scope of this study, but it is flagged here as a critical piece of work to be undertaken. The most productive dredging method (second analysis) is clearly the WID system (the Farrell is precise but much slower). This study has shown that the WID can be carefully used at high productivity and with a sufficient degree of precision for maintenance of engineering safety (no undercutting of the banks). The third analysis depends totally on the continued development of a good understanding of the natural system, which will require further investigations/monitoring, ideally establishing a practical monitoring system that will advise proactively on the timing of intervention decisions rather than relying on a reactive approach.

Through all the channel reaches from Burrowbridge to the M5 motorway, between November 2016 and February 2017, it can be estimated (GIS analysis) that some 32,000m^3 of mud was dispersed seaward, into the mid/lower estuary or sea. Only some of these reaches were dredged and logically applying non-dredged area losses to all the reaches it can be calculated that river action alone would have removed some 24,000m^3, thus attributing 8,000m^3 to the dredge activity. The winter of 2016-2017 did not see particularly high river flows, and significant inter-annual variability in the capacity of the river to scour itself should be expected. Critically, using a WID/Farrell system for dredging must be seen as a method of supplementing the natural processes of scour, and should always take place a) as early as possible in the winter (to maximise post-dredge river scour) and b) always at times of high river flow (to ensure optimum initial dispersion). A better understanding of the annual inter-annual variability in natural scour processes, and similarly the spring/summer/autumn rates of sediment supply, ought to be an important input into any assessment of the effectiveness of dredging operations, allowing a scaling of the relative contributions of natural processes and pragmatic dredging intervention. A long-term programme of sediment flux monitoring in the upper Parrett estuary would be the simplest approach to provide answers to this question, and would also provide guidance on the required timing of dredging interventions.

ENVIRONMENTAL IMPACT

Geomorphologically, the pioneer dredging of recent years has put much of the upper estuary channel zone out of its natural equilibrium, and rates and patterns of sediment movement are likely to be adjusting to this impact. Future maintenance dredging impacts need to be assessed on this basis. Positively, the proposed enhancement of winter scour in order to maintain larger estuary cross-sections is enhancing a natural process rather than imposing a completely new situation. In this respect the impact on local geomorphological processes may be minimal. Two issues arise from this study:

- Keeping the upper estuary freer of marine derived sediments by enhancing scour (dredging) may modify the size and behaviour of the pool of mobile sediment in the mid-lower estuary reaches. This should be examined in future EIAs.
- Dredging may selectively resuspend and disperse different sediment particle fraction. The study has shown that natural scour retains sand and coarse silt in the upper estuary, creating a fining gradient of sediment size into the lower estuary. Results from this survey showed that the sand content of the dredged channel floors was higher than before dredging. Selective retention of coarser sediment by frequent WID activity needs to be considered as a potential geomorphological impact.

The biological impact of the dredging would primarily affect water quality, benthic ecology and upper-bank habitat.

- No significant changes in the nature or frequency of occurrence of water quality conditions have been observed with the exception of a few instances of very low dissolved oxygen levels in the on-bed fluid mud layer during the initial WID trials. The operation of the WID during low river flows is therefore not ideal practice.
- As the submerged surfaces of the upper estuary channels undergo a natural, river-scour-driven erosion each year, of 10-20cm, the short-term, local exacerbation of this system to 0.5 to 1m of scour under dredging is unlikely to have untoward impact on the benthic ecology. However, fish/eels buried in the sediment can respond equitably to slow natural scour, but may face problems when confronted by dredging. One or two fish/eel kills were noted during the dredging experiments. This issue may require further evaluation.
- During this experimental dredging there was little impact on the upper (vegetated) bank slopes as a result of dredging. If a strategy can be developed where thalweg dredging is all that is necessary, and the banks adjust themselves naturally (by river scour and/or slumping)

then this habitat should remain secure. Achieving this objective will revolve around definition of optimum channel profile shapes, a theme which has only been touched upon lightly in this study.

ALTERNATIVE STRATEGIES

The channel cross-sections in the upper Parrett estuary are naturally created as a balance between fluvial/ebb scour processes and intermittent high spring flood tide delivery of high volumes of marine mud. The flood prevention strategy this study is directed at is to assess the feasibility of upsetting this natural balance by enhancing the scour processes (using dredging) to maintain over-sized cross-sections that are always prepared to more effectively transmit peak river flood events. Another approach to maintaining this imbalance might be to restrict the peak spring flood tide delivery of sediment. A tidal (storm-surge protection) barrier is being considered for the lower Parrett estuary[18]. If this project goes ahead, with the correct construction, this gated barrier could be used to manipulate flow over the late flood tide just on peak spring tides, to prevent the upper levels of these tides occurring inside the estuary. Doing this could markedly reduce the supply of marine sediment to the upper estuary, thus effecting the required imbalance between sedimentation and scour, and helping maintain 'naturally' larger channel sections. By controlling just the late flood tide levels (as opposed to stopping a whole tide entering the estuary) this critical management ploy could be conducted with minimal environmental impact.

Assessment of the flood prevention barrier options [17] only considered a tide surge barrier (closed at low tide on the rare occurrences that a very high tide is expected) or a tidal exclusion barrier (allowing river flow out on the ebb but permanently preventing any tidal inflow on the flood, thus creating an impounded estuary lake). The (simpler) tide surge barrier is the preferred option. The report states

"A Tidal Surge Barrier would not significantly alter the present dredging and channel maintenance needs. A Tidal Exclusion Sluice would reduce dredging needs upstream of the structure by preventing the passage of silt upstream from the estuary. However, this may lead to rapid siltation downstream of the structure, which would need to be dredged to maintain navigation, and unpredictable effects on sediment transport in the Parrett Estuary. Fluvial derived sediment would still deposit upstream. There is considerable uncertainty associated with the geomorphological impact of the Tidal Exclusion Sluice. An initial study is underway to inform this, but a full assessment will be required as part of the approvals process."

The results of our study suggest that a) fluvial-derived sediment volumes are tiny compared with marine inputs and b) it would be only necessary to shut the barrier at say half flood tide at times of very high spring tides to significantly reduce the rate of fine sediment accumulation in the upper reaches of the estuary. This minimal closure time would reduce the wider concerns about the geomorphological impacts of the barrier. To achieve this capability, the additional cost on top of the basic Tide Surge Barrier would be to have a gate that could be closed at any state of the tide (capable of operating against strong lateral pressure).

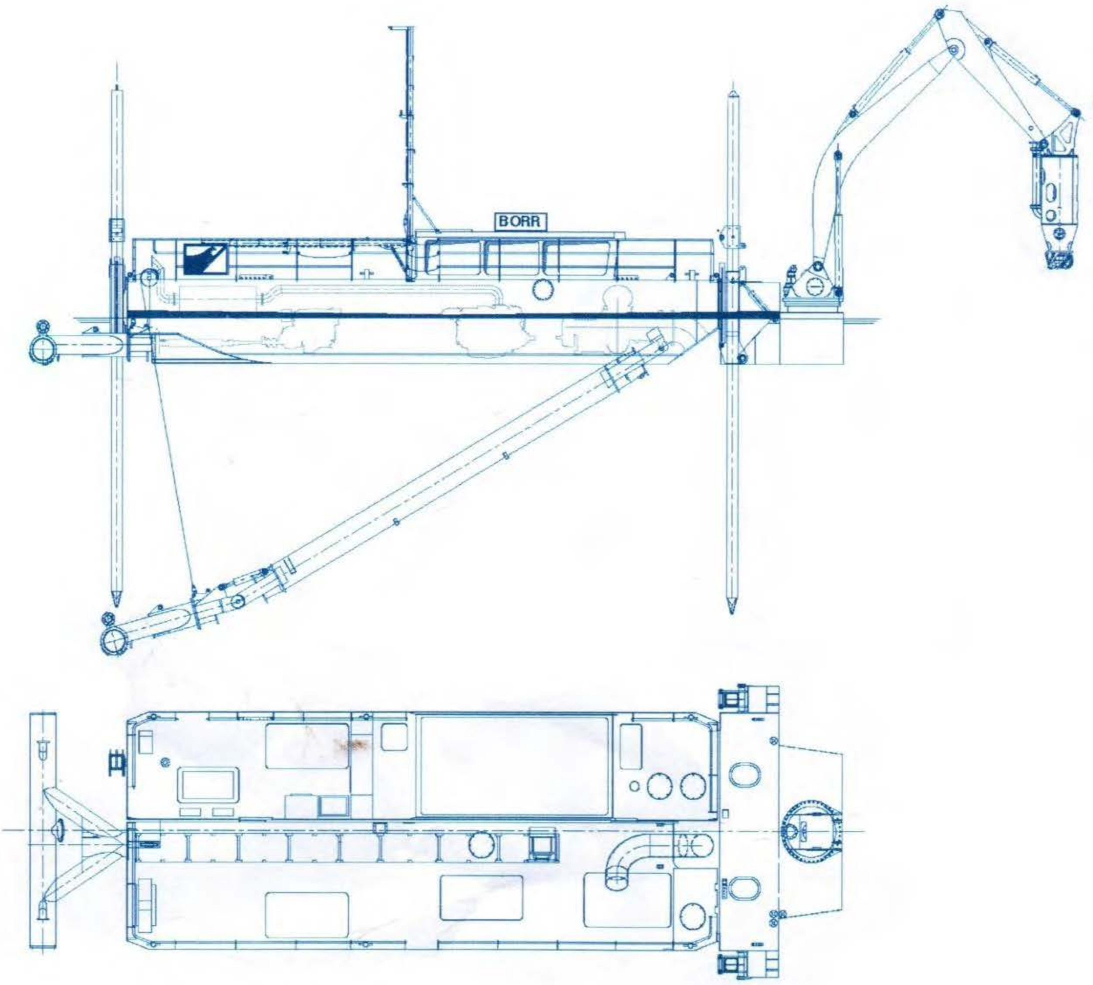
[18] Protecting Bridgwater and the Somerset Levels & Moors from Tidal Flooding Flood Risk Management Review November 2014 Black and Veatch. For EA and Sedgemoor DC

RECOMMENDATIONS

The following recommendations are made:

- Effort should be made to set-up a gauging system for real-time monitoring of fresh water discharge into the estuary through the upper tidal limits of the Parrett and Tone (Objective: allow a more detailed understanding and modelling of the interaction of fluvial and marine processes)
- Bathymetric surveys have proven a valuable tool for assessing sedimentation. There is probably no need in the long term for more than one survey per year. This should be taken at the same time each year, with the objective of identifying net inter-annual volume changes in the bed. There appears to be no difference in the accuracy between pole or multibeam surveys. The multibeam surveys provide full longitudinal coverage and allow accurate bed sediment volume changes to be made. However they provide no coverage of the upper banks, and the trialled laser method is confounded by the bank vegetation. It is therefore recommended that a multibeam survey is conducted annually in say January, when river levels are normally high and the greatest part of the channel is inundated. Pole surveys should be undertaken at the same time, on selected profiles and only by walking (upper banks) to provide full cross-section information at key points. These recommendations are made to optimise scientific and economic objectives in the medium to long term. In the short term, in the interests of continuing the twice yearly bathymetric survey pattern already established (October and April) may be the more sensible approach.
- Exploration should be made to see if the results of the extensive turbidity surveys of the estuary carried out by HRWallingford in the 1970s and 80s are archived and can be studied. (Objective: Allow further insight into natural processes of sediment transport in the mid-lower Parrett estuary)
- Detailed consideration needs to be given to optimal channel cross-section shape and area for future dredging activity. This needs to take into account the capabilities of the dredger-type, the flow-transmittance efficiency (related to flood prevention demands) and the minimisation of sedimentation. In relation to the latter, the significance of the currently seen differences in channel shape and erosion behaviour above and below kp 25,000 (pinch point generated at the seaward extent of the pioneer dredging)) needs further consideration.
- A simple monitoring system based on the continuous measurement of sediment flux (water flow and suspended sediment content) should be considered as a basic tool for predictive sediment management for the critical estuary reaches (for flood management) in the future. This would involve a monitoring site at the two tidal limits and in the vicinity of the M5 motorway. The lower monitoring system would have to be a profiling device, allowing vertical variability in turbidity (considerable at times) to be measured. The plan should be for very long-term monitoring, to evaluate thoroughly inter-annual variability in sediment flux, and to provide information for safely assessing how a minimum dredging regime can be operated (dredging to need rather than routinely).
- Discussions should be pursued with the EA to investigate the Surge Barrier Operation option for achieving reduced sedimentation in the upper reaches of the Parrett estuary.

Appendix 1. Dredger BORR Specification



Borr

Name	Borr		
Type	Water injection dredger		
Description	Borr:	Dismountable dredger, transportable on two trailers	
	Farrell:	Pontoon with spuds, hydraulic crane with clamshell or cutter unit	
Sailing and dredging area	Inland waters only		
Year of construction	2015		
Dimensions Borr	Length overall		18.73 m
	Breadth overall		5.32 m
	Moulded depth		1.80 m
Dimensions Borr & Farrell	Length overall		21.73 m
	Breadth overall		6.70 m
	Moulded depth		1.80 m
Maximum dredging depth	Borr:		14.00 m
	Farrell:		8.00 m
		with clamshell or cutter unit	

Width injection pipe	5.16 m
Propulsion	2 x 89 kW
Total power installed	460 kW
Jet pump	260 kW

Contact

Van Oord
PO Box 8574
3009 AN Rotterdam
The Netherlands
T +31 88 8260000

Appendix 2. Sensor calibrations

This Appendix is supplied as an accompanying Excel file << 2016-7 Parrett TurbiditySensorCals.xlsx>>

Appendix 3. Bed surveys Visual log.

This Appendix is supplied as an accompanying Excel file << 2016-7 Parrett BedSedLogs.xlsx>>

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

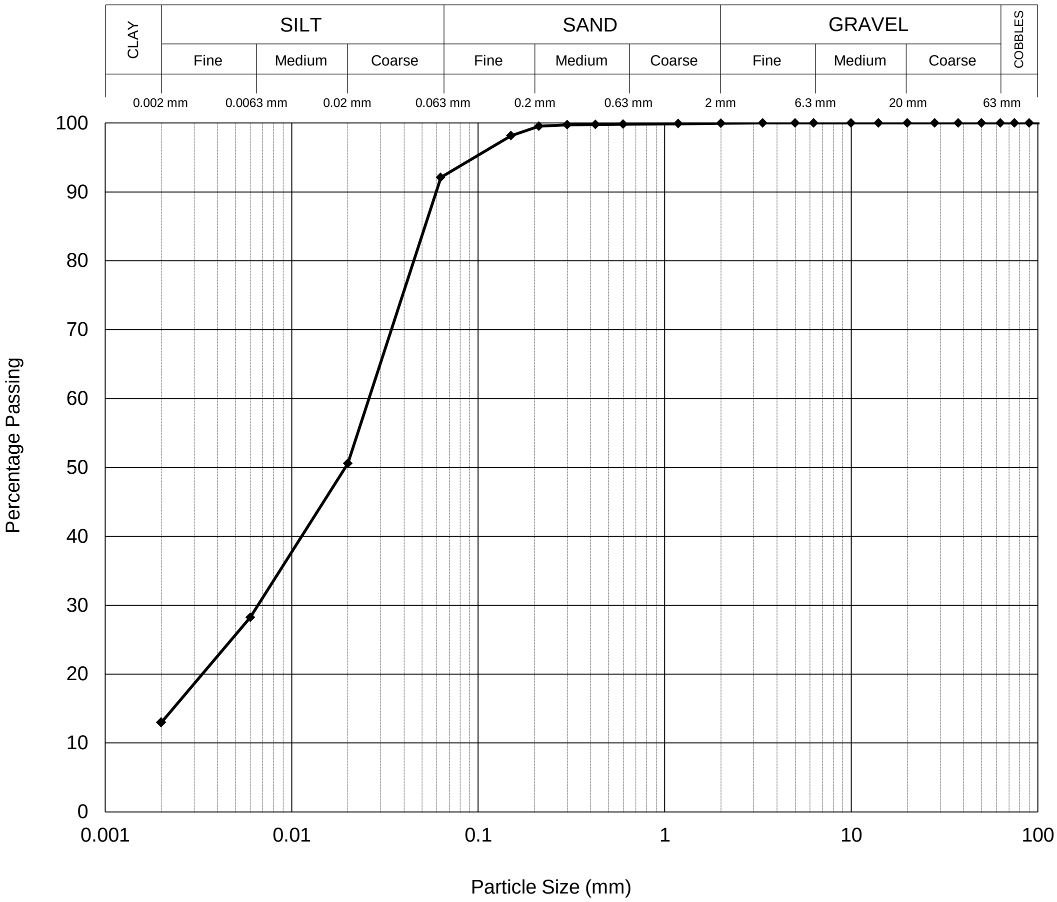
Sample Ref	10 PSD
Sample Type	B

Description

Greyish brown slightly sandy clayey SILT with rare rootlets. Sand is fine.

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve
BS EN ISO 17892-4 : 2016 : Clause 5.4 - Sedimentation by Pipette

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	100
5.00 mm	100
3.35 mm	100
2.00 mm	100
1.18 mm	100
600 µm	100
425 µm	100
300 µm	100
212 µm	100
150 µm	98
63 µm	92



Sedimentation	
No Pre-treatment used	
Temp (°C)	25
Size	% Pass
20 µm	51
6 µm	28
2 µm	13
Particle Density 2.70(A) Mg/m³	

Particle Proportions	
Cobbles	0
Gravel	0
Sand	8
Silt	79
Clay	13

Checked and Approved by

S Burke

S Burke - Senior Technician
03/07/2018

Project Number:

GEO / 27623

Project Name:

RIVER PARRETT DREDGING
HYG 477

GEOLABS

UKAS TESTING 1982

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

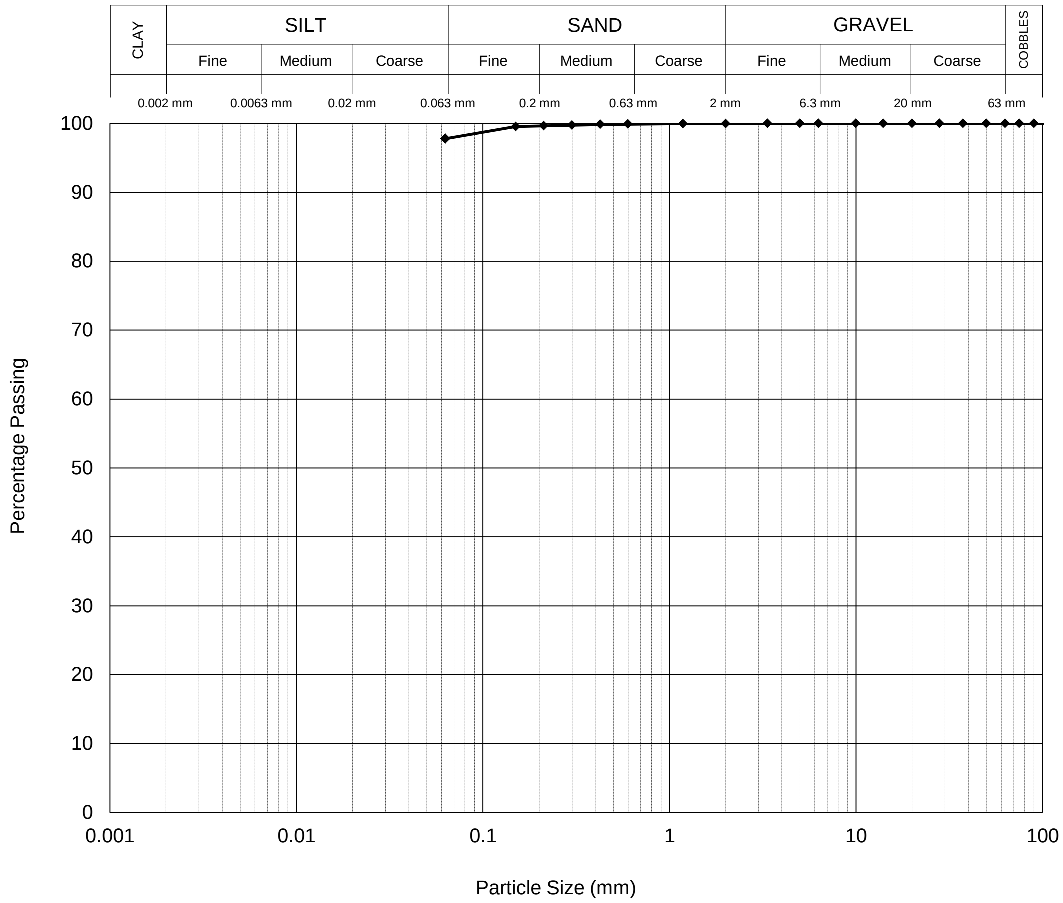
Sample Ref	1PSD
Sample Type	B

Description

Brown clayey SILT

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	100
5.00 mm	100
3.35 mm	100
2.00 mm	100
1.18 mm	100
600 µm	100
425 µm	100
300 µm	100
212 µm	100
150 µm	100
63 µm	98



Particle Proportions	
Cobbles	0
Gravel	0
Sand	2
Silt & Clay	98

Checked and Approved by

S Burke

S Burke - Senior Technician
03/07/2018

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RIVER PARRETT DREDGING
HYG 477

GEOLABS

UKAS TESTING 1982

1262 - PSD 11 PSD B - 27623-302413.XLSM

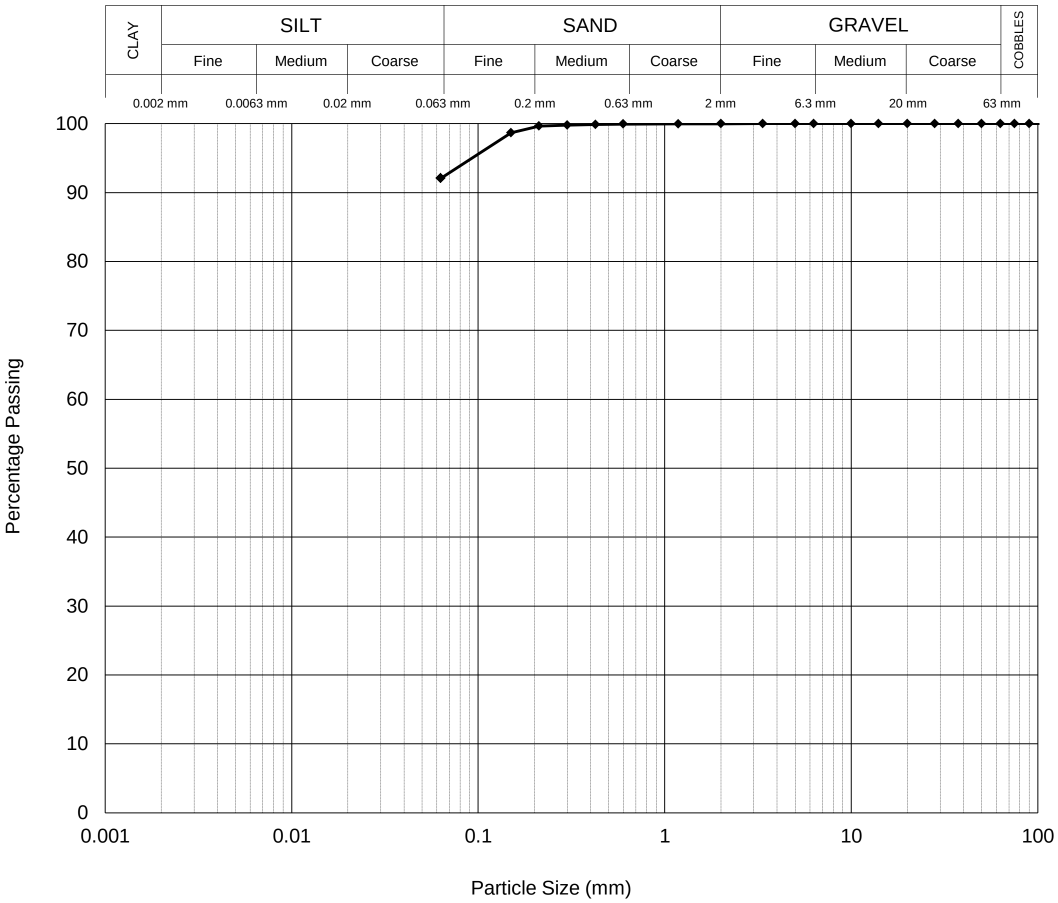
BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

		Description
Sample Ref	11 PSD	Brown slightly sandy clayey SILT. Sand is fine.
Sample Type	B	

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	100
5.00 mm	100
3.35 mm	100
2.00 mm	100
1.18 mm	100
600 µm	100
425 µm	100
300 µm	100
212 µm	100
150 µm	99
63 µm	92



Particle Proportions	
Cobbles	0
Gravel	0
Sand	8
Silt & Clay	92

GL:Version 1.90 - 04/05/2018

Checked and Approved by	Project Number:
S Burke	**GEO / 27623**
	Project Name:
S Burke - Senior Technician 03/07/2018	**RIVER PARRETT DREDGING** **HYG 477**

GEOLABS

UKAS TESTING 1982

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

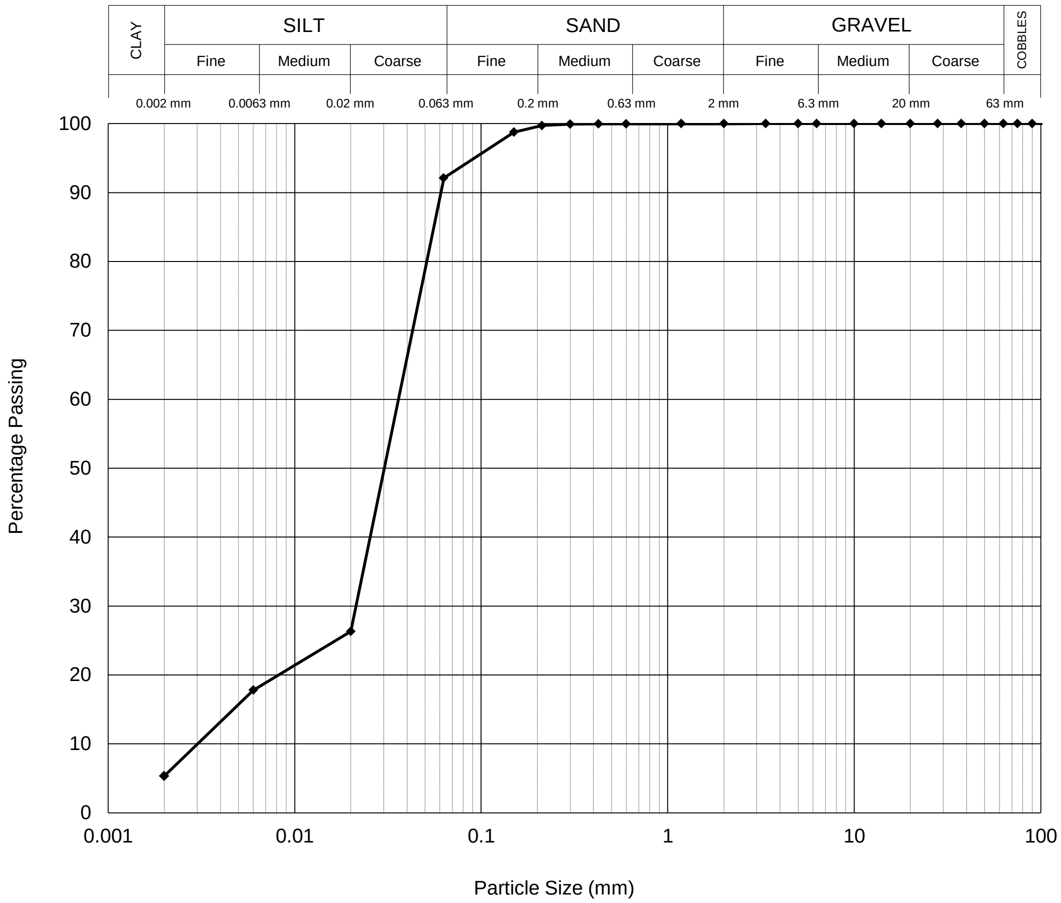
Sample Ref 12 PSD
Sample Type B

Description

Brown slightly sandy clayey SILT with rare rootlets. Sand is fine.

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve
BS EN ISO 17892-4 : 2016 : Clause 5.4 - Sedimentation by Pipette

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	100
5.00 mm	100
3.35 mm	100
2.00 mm	100
1.18 mm	100
600 µm	100
425 µm	100
300 µm	100
212 µm	100
150 µm	99
63 µm	92



Sedimentation	
No Pre-treatment used	
Temp (°C)	25
Size	% Pass
20 µm	26
6 µm	18
2 µm	5
Particle Density 2.70(A) Mg/m³	

Particle Proportions	
Cobbles	0
Gravel	0
Sand	8
Silt	87
Clay	5

Checked and Approved by

S Burke

S Burke - Senior Technician
03/07/2018

Project Number:

GEO / 27623

Project Name:

RIVER PARRETT DREDGING
HYG 477

GEOLABS
UKAS TESTING 1982

1262 - PSD 13 PSD B - 27623-302425.XLSM

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

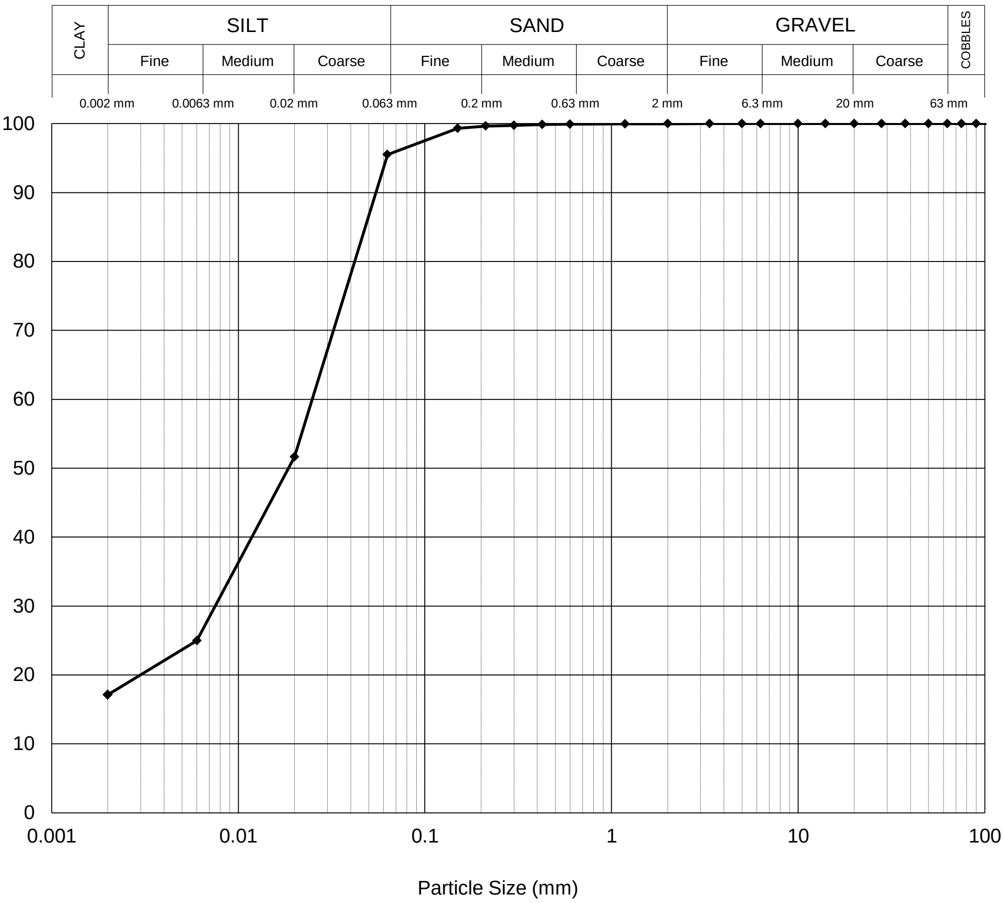
Sample Ref	13 PSD
Sample Type	B

Description

Greyish brown clayey SILT with rare rootlets.

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve
BS EN ISO 17892-4 : 2016 : Clause 5.4 - Sedimentation by Pipette

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	100
5.00 mm	100
3.35 mm	100
2.00 mm	100
1.18 mm	100
600 µm	100
425 µm	100
300 µm	100
212 µm	100
150 µm	99
63 µm	96



Sedimentation	
No Pre-treatment used	
Temp (°C)	25
Size	% Pass
20 µm	52
6 µm	25
2 µm	17
Particle Density 2.70(A) Mg/m³	

Particle Proportions	
Cobbles	0
Gravel	0
Sand	4
Silt	78
Clay	18

Checked and Approved by

S Burke

S Burke - Senior Technician
03/07/2018

Project Number:

GEO / 27623

Project Name:

RIVER PARRETT DREDGING
HYG 477

GL:Version 1.90 - 04/05/2018

1262 - PSD 14 PSD B - 27623-302428.XLSM

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

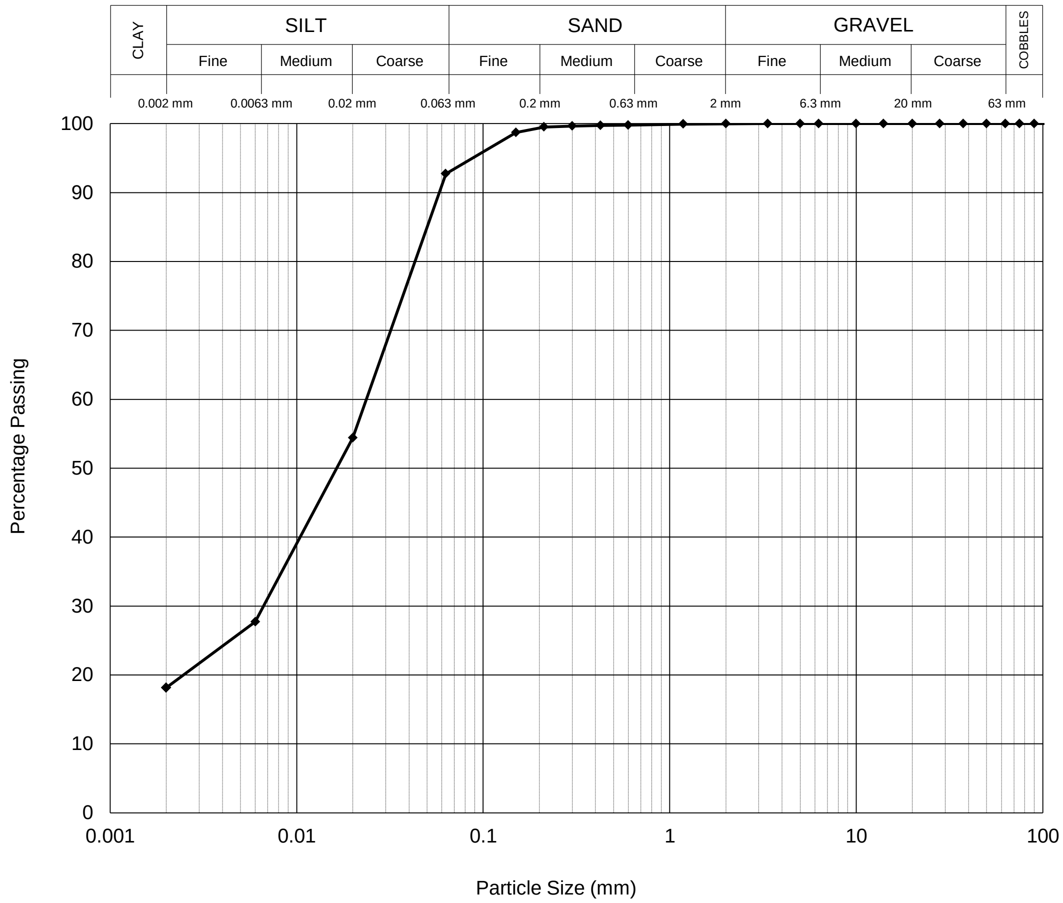
Sample Ref	14 PSD
Sample Type	B

Description

Greyish brown slightly sandy clayey SILT with rare rootlets. Sand is fine.

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve
BS EN ISO 17892-4 : 2016 : Clause 5.4 - Sedimentation by Pipette

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	100
5.00 mm	100
3.35 mm	100
2.00 mm	100
1.18 mm	100
600 µm	100
425 µm	100
300 µm	100
212 µm	100
150 µm	99
63 µm	93



Sedimentation	
No Pre-treatment used	
Temp (°C)	25
Size	% Pass
20 µm	54
6 µm	28
2 µm	18
Particle Density 2.70(A) Mg/m³	

Particle Proportions	
Cobbles	0
Gravel	0
Sand	7
Silt	75
Clay	18

GL:Version 1.90 - 04/05/2018

Checked and Approved by

S Burke

S Burke - Senior Technician
03/07/2018

Project Number:

GEO / 27623

Project Name:

RIVER PARRETT DREDGING
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1262 - PSD 15 PSD B - 27623-302427.XLSM

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

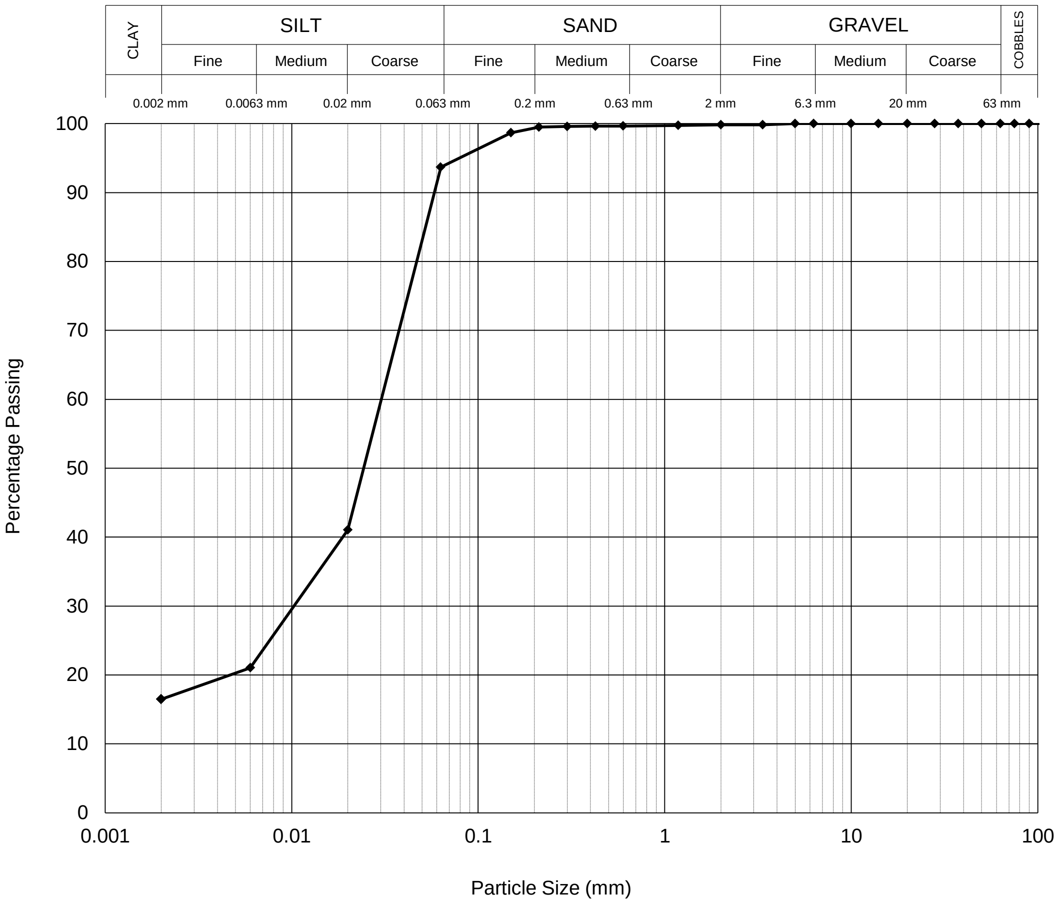
Sample Ref 15 PSD
Sample Type B

Description

Greyish brown clayey SILT with rare rootlets

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve
BS EN ISO 17892-4 : 2016 : Clause 5.4 - Sedimentation by Pipette

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	100
5.00 mm	100
3.35 mm	100
2.00 mm	100
1.18 mm	100
600 µm	100
425 µm	100
300 µm	100
212 µm	99
150 µm	99
63 µm	94



Sedimentation	
No Pre-treatment used	
Temp (°C)	25
Size	% Pass
20 µm	41
6 µm	21
2 µm	16
Particle Density 2.70(A) Mg/m³	

Particle Proportions	
Cobbles	0
Gravel	0
Sand	6
Silt	77
Clay	17

Checked and Approved by

S Burke

S Burke - Senior Technician
03/07/2018

Project Number:

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Project Name:

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BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

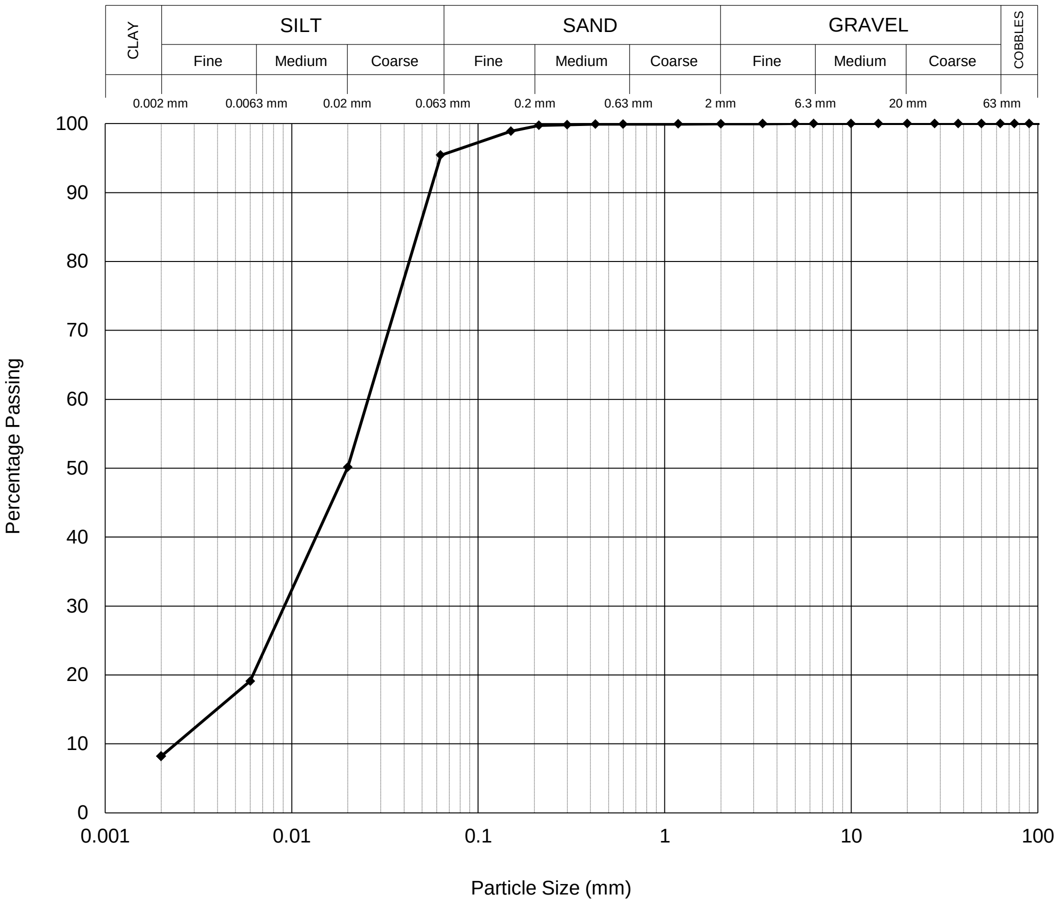
Sample Ref	16 PSD
Sample Type	B

Description

Brown clayey SILT with rare rootlets.

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve
BS EN ISO 17892-4 : 2016 : Clause 5.4 - Sedimentation by Pipette

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	100
5.00 mm	100
3.35 mm	100
2.00 mm	100
1.18 mm	100
600 µm	100
425 µm	100
300 µm	100
212 µm	100
150 µm	99
63 µm	95



Sedimentation	
No Pre-treatment used	
Temp (°C)	25
Size	% Pass
20 µm	50
6 µm	19
2 µm	8
Particle Density 2.70(A) Mg/m³	

Particle Proportions	
Cobbles	0
Gravel	0
Sand	5
Silt	87
Clay	8

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1262 - PSD 17 PSD B - 27623-302430.XLSM

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

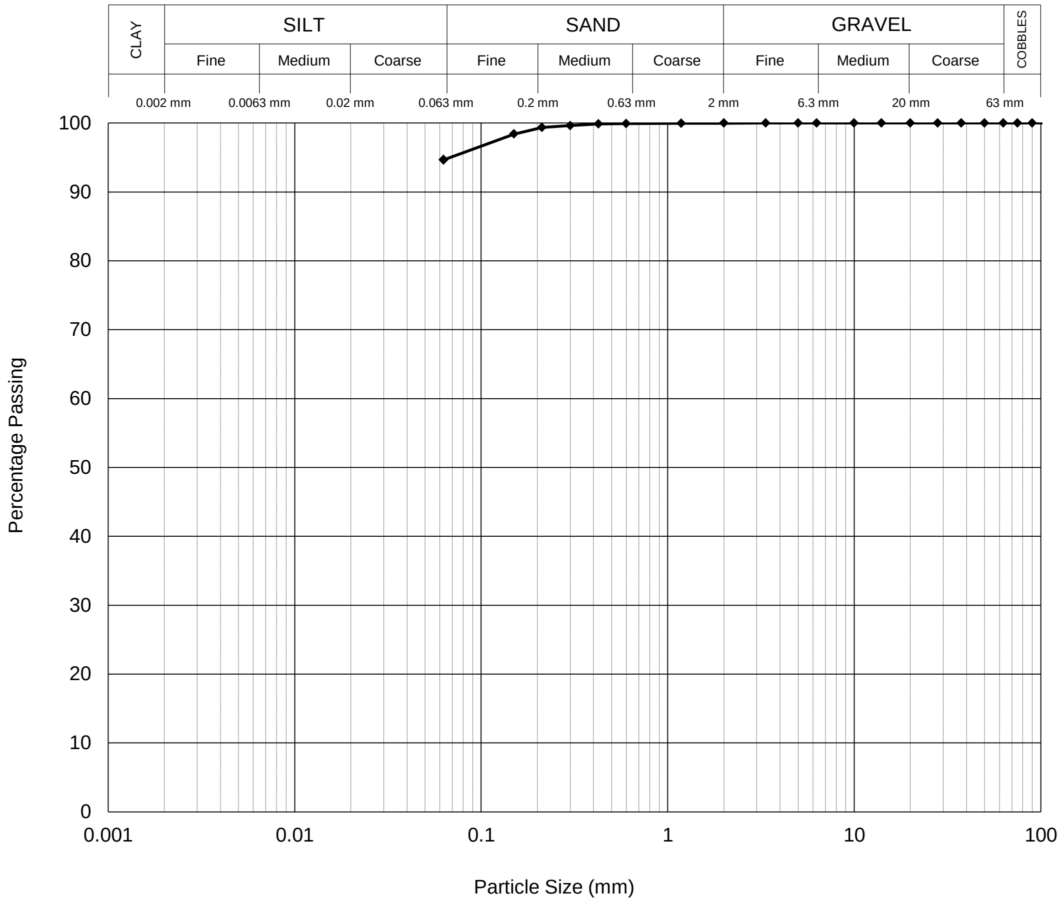
Sample Ref	17 PSD
Sample Type	B

Description

Brown clayey SILT with rare rootlets

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	100
5.00 mm	100
3.35 mm	100
2.00 mm	100
1.18 mm	100
600 µm	100
425 µm	100
300 µm	100
212 µm	99
150 µm	98
63 µm	95



Particle Proportions	
Cobbles	0
Gravel	0
Sand	5
Silt & Clay	95

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S Burke

S Burke - Senior Technician
03/07/2018

Project Number:

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Project Name:

RIVER PARRETT DREDGING
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GL:Version 1.90 - 04/05/2018

Test Report By GEOLABS Limited Bucknalls Lane, Garston, Watford, Hertfordshire, WD25 9XX

Client : Hydrogeo, 36 Lion Street, Abergavenny, NP7 5NT

(Ref 1530635587)

1262 - PSD 18 PSD B - 27623-302421.XLSM

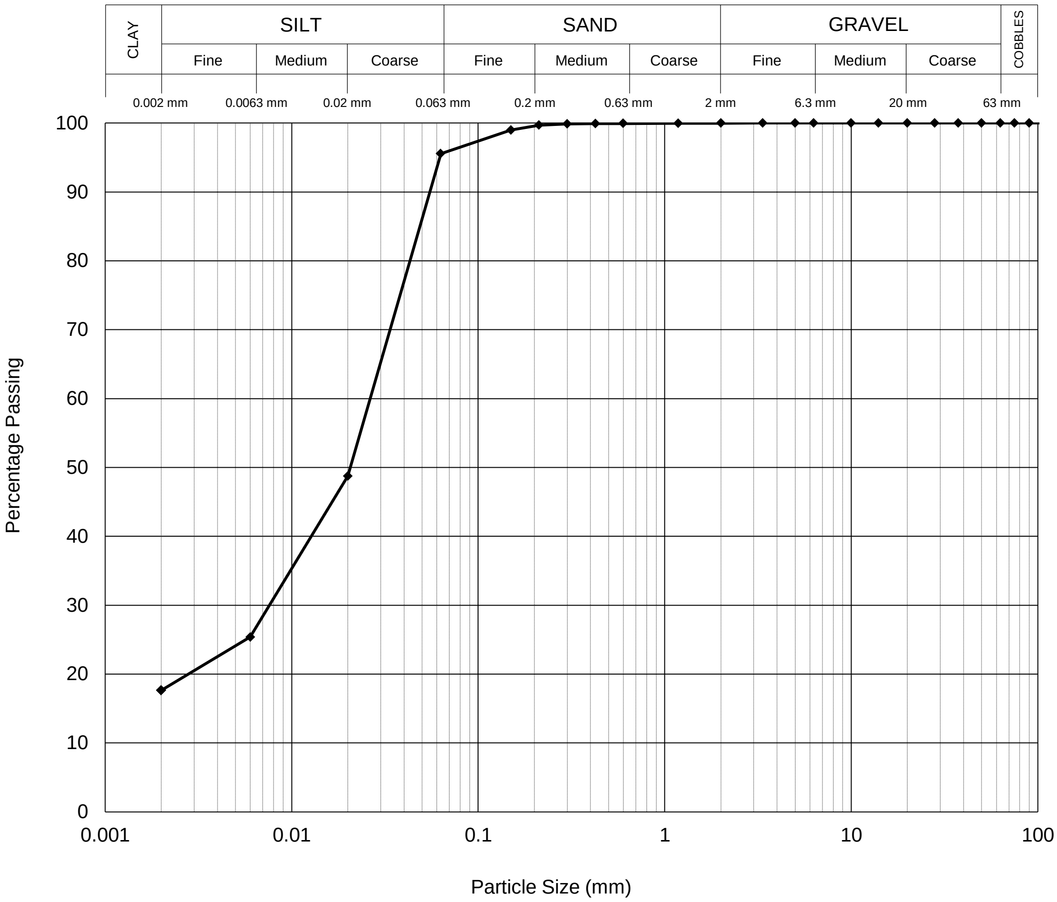
BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

		Description
Sample Ref	18 PSD	Greyish brown clayey SILT with rare rootlets.
Sample Type	B	

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve
BS EN ISO 17892-4 : 2016 : Clause 5.4 - Sedimentation by Pipette

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	100
5.00 mm	100
3.35 mm	100
2.00 mm	100
1.18 mm	100
600 µm	100
425 µm	100
300 µm	100
212 µm	100
150 µm	99
63 µm	96



Sedimentation	
No Pre-treatment used	
Temp (°C)	25
Size	% Pass
20 µm	49
6 µm	25
2 µm	18
Particle Density 2.70(A) Mg/m³	

Particle Proportions	
Cobbles	0
Gravel	0
Sand	4
Silt	78
Clay	18

GL:Version 1.90 - 04/05/2018

Checked and Approved by

S Burke

S Burke - Senior Technician
03/07/2018

Project Number:

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1262 - PSD 19 PSD B - 27623-302411.XLSM

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

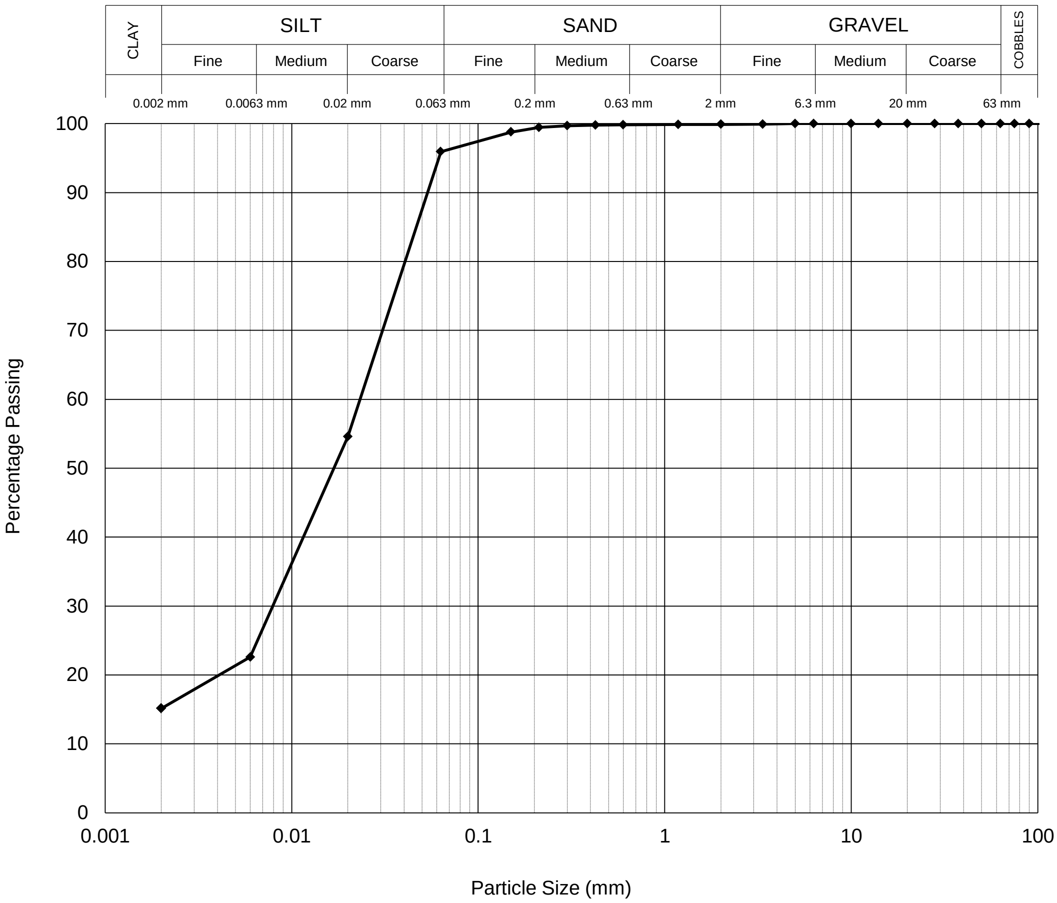
Sample Ref	19 PSD
Sample Type	B

Description

Greyish brown clayey SILT with rare rootlets

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve
BS EN ISO 17892-4 : 2016 : Clause 5.4 - Sedimentation by Pipette

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	100
5.00 mm	100
3.35 mm	100
2.00 mm	100
1.18 mm	100
600 µm	100
425 µm	100
300 µm	100
212 µm	99
150 µm	99
63 µm	96



Sedimentation	
No Pre-treatment used	
Temp (°C)	25
Size	% Pass
20 µm	55
6 µm	23
2 µm	15
Particle Density 2.70(A) Mg/m³	

Particle Proportions	
Cobbles	0
Gravel	0
Sand	4
Silt	81
Clay	15

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BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

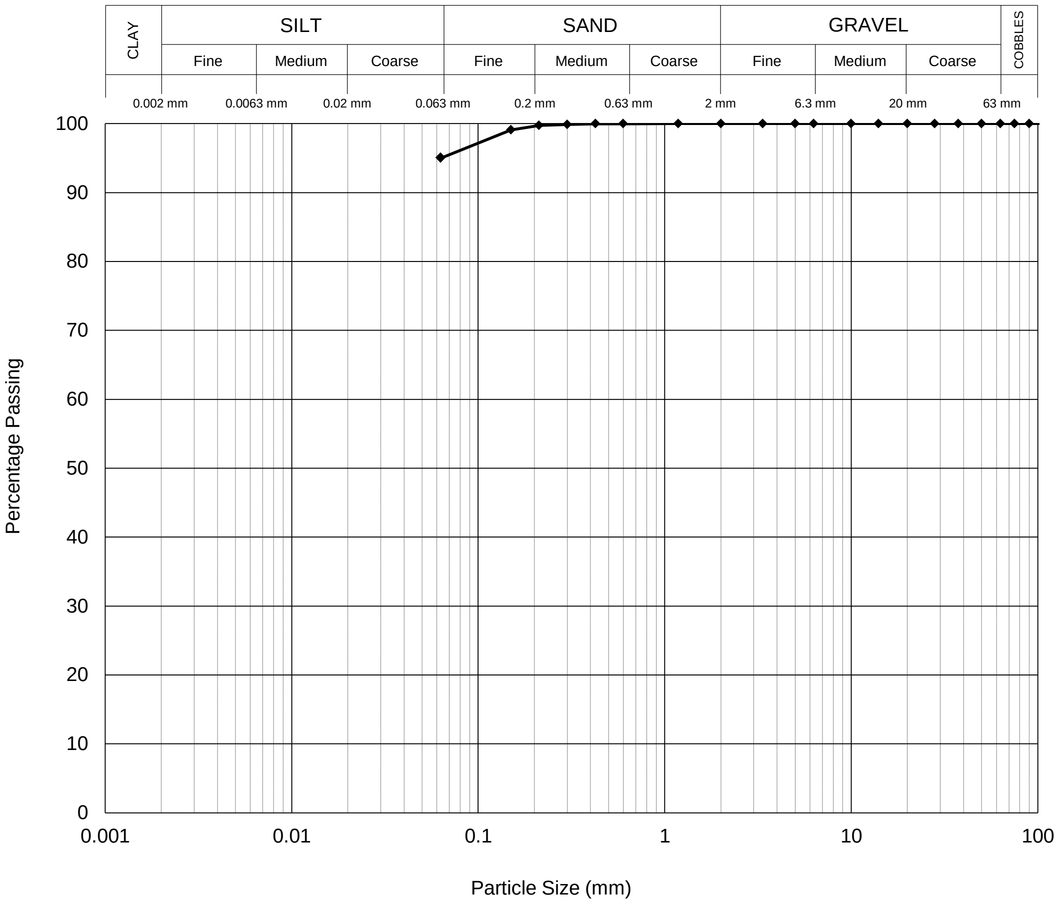
Sample Ref	20 PSD
Sample Type	B

Description

Brown clayey SILT with rare rootlets

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	100
5.00 mm	100
3.35 mm	100
2.00 mm	100
1.18 mm	100
600 µm	100
425 µm	100
300 µm	100
212 µm	100
150 µm	99
63 µm	95



Particle Proportions	
Cobbles	0
Gravel	0
Sand	5
Silt & Clay	95

Checked and Approved by

S Burke

S Burke - Senior Technician
03/07/2018

Project Number:

GEO / 27623

Project Name:

RIVER PARRETT DREDGING
HYG 477

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Test Report By GEOLABS Limited Bucknalls Lane, Garston, Watford, Hertfordshire, WD25 9XX

Client : Hydrogeo, 36 Lion Street, Abergavenny, NP7 5NT

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

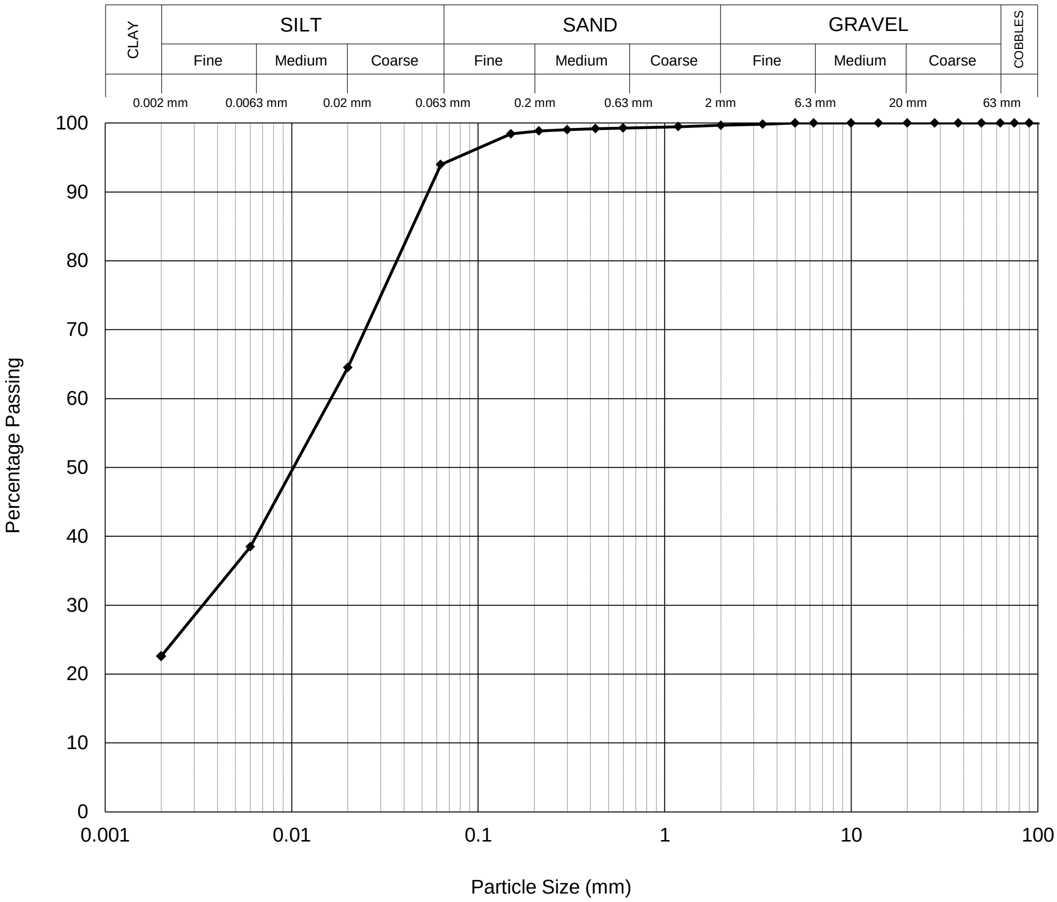
Sample Ref	2PSD
Sample Type	B

Description

Greyish brown slightly sandy silty CLAY with rare rootlets

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve
BS EN ISO 17892-4 : 2016 : Clause 5.4 - Sedimentation by Pipette

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	100
5.00 mm	100
3.35 mm	100
2.00 mm	100
1.18 mm	99
600 µm	99
425 µm	99
300 µm	99
212 µm	99
150 µm	98
63 µm	94



Sedimentation	
No Pre-treatment used	
Temp (°C)	25
Size	% Pass
20 µm	65
6 µm	38
2 µm	23
Particle Density 2.70(A) Mg/m³	

Particle Proportions	
Cobbles	0
Gravel	0
Sand	6
Silt	71
Clay	23

Checked and Approved by

S Burke

S Burke - Senior Technician
03/07/2018

Project Number:

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BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

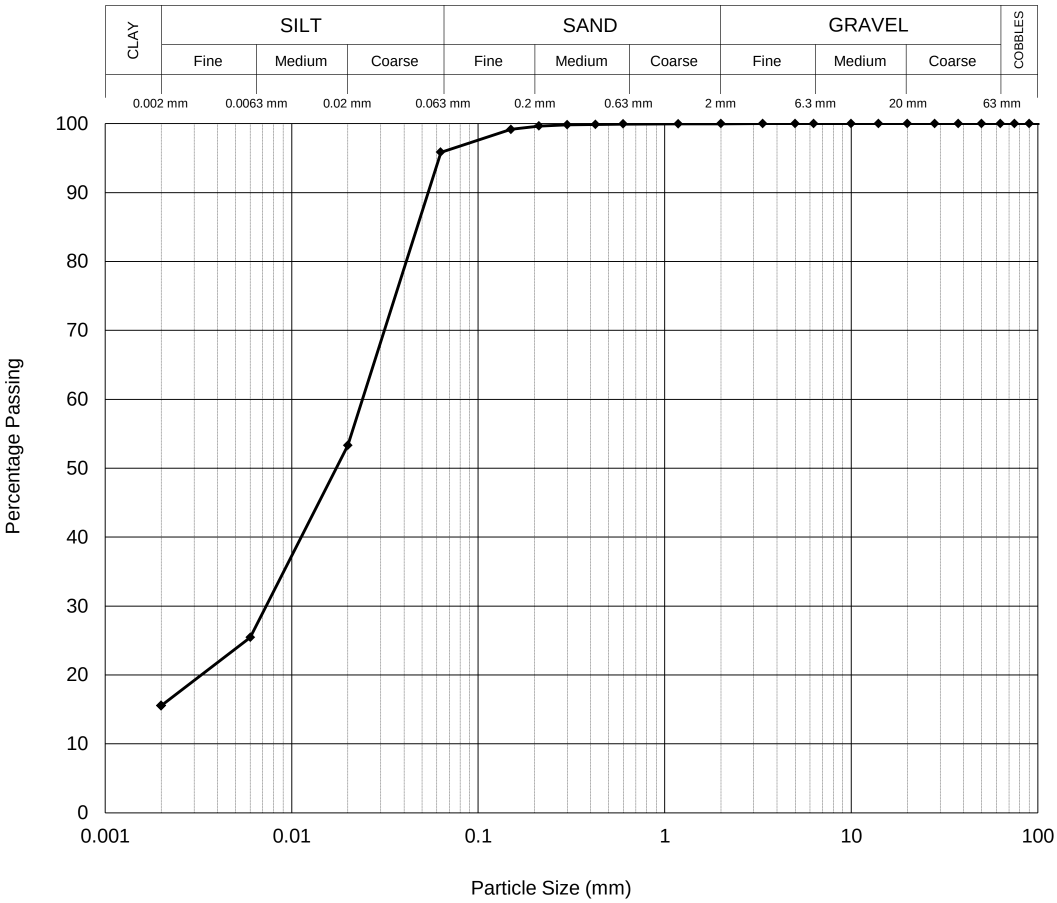
Sample Ref	21 PSD
Sample Type	B

Description

Greyish brown clayey SILT with rare rootlets

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve
BS EN ISO 17892-4 : 2016 : Clause 5.4 - Sedimentation by Pipette

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	100
5.00 mm	100
3.35 mm	100
2.00 mm	100
1.18 mm	100
600 µm	100
425 µm	100
300 µm	100
212 µm	100
150 µm	99
63 µm	96



Sedimentation	
No Pre-treatment used	
Temp (°C)	25
Size	% Pass
20 µm	53
6 µm	25
2 µm	16
Particle Density 2.70(A) Mg/m³	

Particle Proportions	
Cobbles	0
Gravel	0
Sand	4
Silt	80
Clay	16

Checked and Approved by

S Burke

S Burke - Senior Technician
03/07/2018

Project Number:

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Project Name:

RIVER PARRETT DREDGING
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1262 - PSD 30PSD B - 27623-302424.XLSM

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

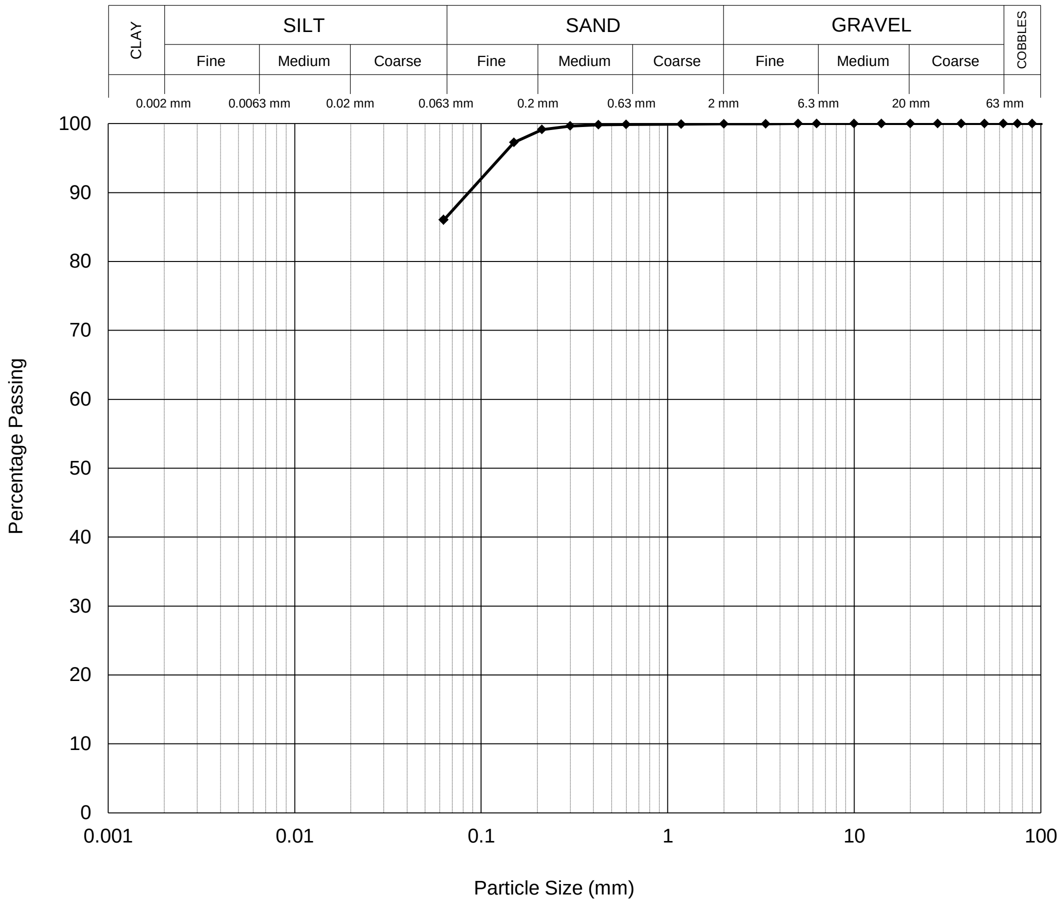
Sample Ref 3PSD
Sample Type B

Description

Brown clayey SILT with rare roots.

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	100
5.00 mm	100
3.35 mm	100
2.00 mm	100
1.18 mm	100
600 µm	100
425 µm	100
300 µm	100
212 µm	99
150 µm	97
63 µm	86



Particle Proportions	
Cobbles	0
Gravel	0
Sand	14
Silt & Clay	86

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S Burke

S Burke - Senior Technician
03/07/2018

Project Number:

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Project Name:

RIVER PARRETT DREDGING
HYG 477

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Test Report By GEOLABS Limited Bucknalls Lane, Garston, Watford, Hertfordshire, WD25 9XX

Client : Hydrogeo, 36 Lion Street, Abergavenny, NP7 5NT

(Ref 1530635608)

1262 - PSD 40PSD B - 27623-302416.XLSM

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

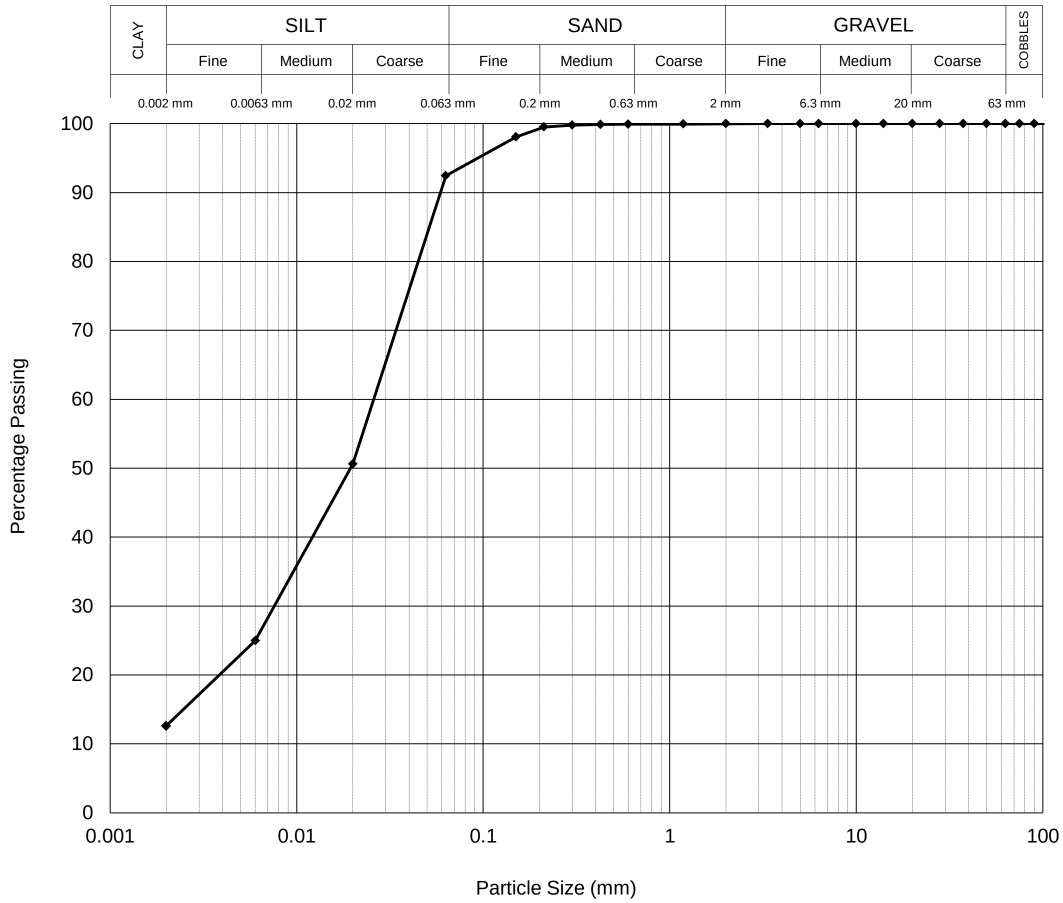
Sample Ref	4PSD
Sample Type	B

Description

Greyish brown slightly sandy clayey SILT with rare rootlets. Sand is fine.

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve
BS EN ISO 17892-4 : 2016 : Clause 5.4 - Sedimentation by Pipette

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	100
5.00 mm	100
3.35 mm	100
2.00 mm	100
1.18 mm	100
600 µm	100
425 µm	100
300 µm	100
212 µm	100
150 µm	98
63 µm	92



Sedimentation	
No Pre-treatment used	
Temp (°C)	25
Size	% Pass
20 µm	51
6 µm	25
2 µm	13

Particle Density 2.70(A) Mg/m³

Particle Proportions	
Cobbles	0
Gravel	0
Sand	8
Silt	80
Clay	12

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S Burke

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03/07/2018

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BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

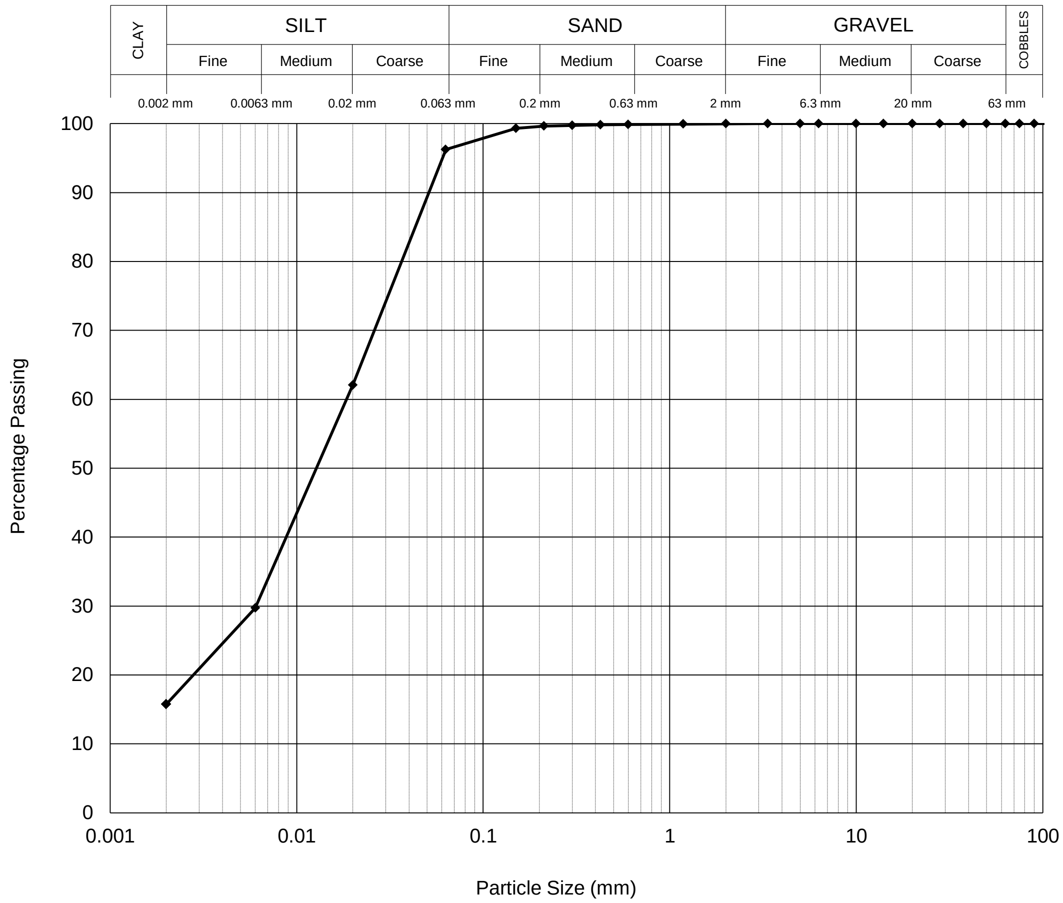
Sample Ref 5PSD
Sample Type B

Description

Greyish brown clayey SILT with rare rootlets.

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve
BS EN ISO 17892-4 : 2016 : Clause 5.4 - Sedimentation by Pipette

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	100
5.00 mm	100
3.35 mm	100
2.00 mm	100
1.18 mm	100
600 µm	100
425 µm	100
300 µm	100
212 µm	100
150 µm	99
63 µm	96



Sedimentation	
No Pre-treatment used	
Temp (°C)	25
Size	% Pass
20 µm	62
6 µm	30
2 µm	16
Particle Density 2.70(A) Mg/m³	

Particle Proportions	
Cobbles	0
Gravel	0
Sand	4
Silt	81
Clay	15

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S Burke

S Burke - Senior Technician
03/07/2018

Project Number:

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Project Name:

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1262 - PSD 60PSD B - 27623-302417.XLSM

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

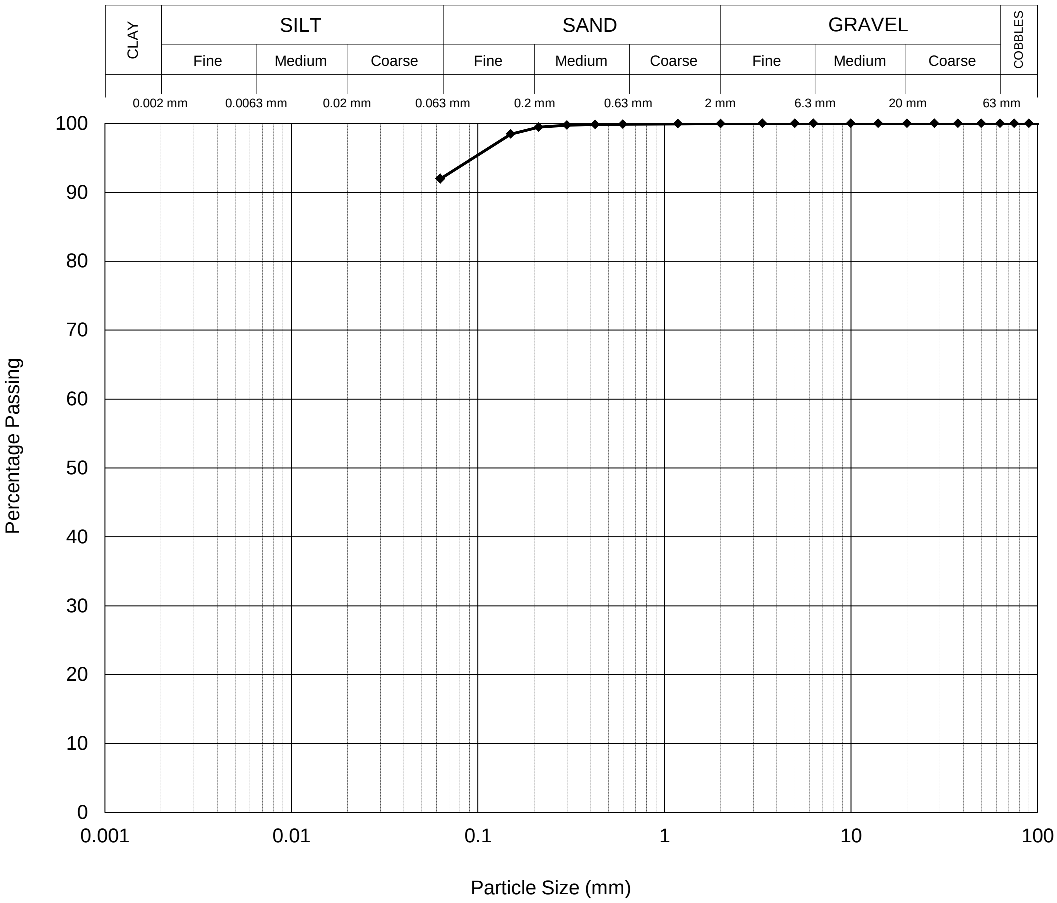
Sample Ref	6PSD
Sample Type	B

Description

Brown slightly sandy clayey SILT. Sand is fine.

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	100
5.00 mm	100
3.35 mm	100
2.00 mm	100
1.18 mm	100
600 µm	100
425 µm	100
300 µm	100
212 µm	99
150 µm	98
63 µm	92



Particle Proportions	
Cobbles	0
Gravel	0
Sand	8
Silt & Clay	92

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Checked and Approved by

S Burke

S Burke - Senior Technician
03/07/2018

Project Number:

GEO / 27623

Project Name:

RIVER PARRETT DREDGING
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Test Report By GEOLABS Limited Bucknalls Lane, Garston, Watford, Hertfordshire, WD25 9XX

Client : Hydrogeo, 36 Lion Street, Abergavenny, NP7 5NT

(Ref 1530635619)

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

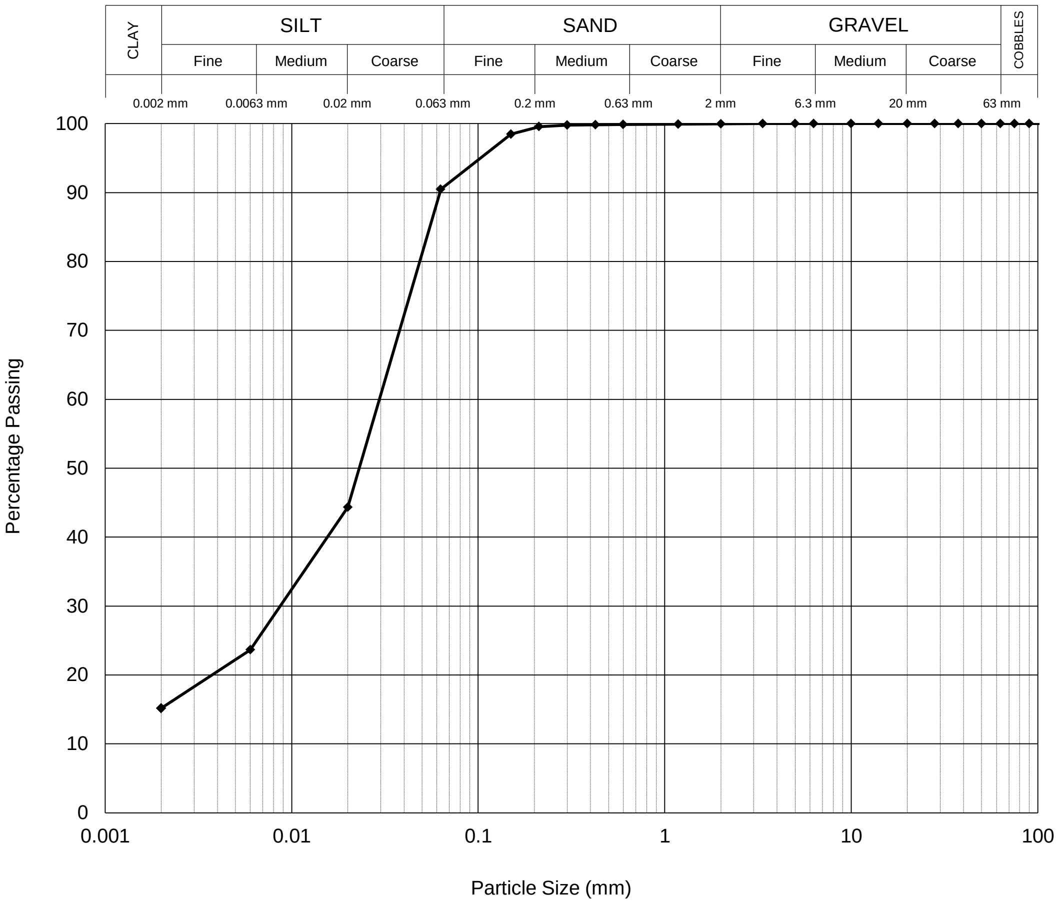
Sample Ref 7PSD
Sample Type B

Description

Greyish brown slightly sandy clayey SILT. Sand is fine.

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve
BS EN ISO 17892-4 : 2016 : Clause 5.4 - Sedimentation by Pipette

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	100
5.00 mm	100
3.35 mm	100
2.00 mm	100
1.18 mm	100
600 µm	100
425 µm	100
300 µm	100
212 µm	100
150 µm	98
63 µm	90



Sedimentation	
No Pre-treatment used	
Temp (°C)	25
Size	% Pass
20 µm	44
6 µm	24
2 µm	15
Particle Density 2.70(A) Mg/m³	

Particle Proportions	
Cobbles	0
Gravel	0
Sand	10
Silt	75
Clay	15

Checked and Approved by

S Burke

S Burke - Senior Technician
03/07/2018

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BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

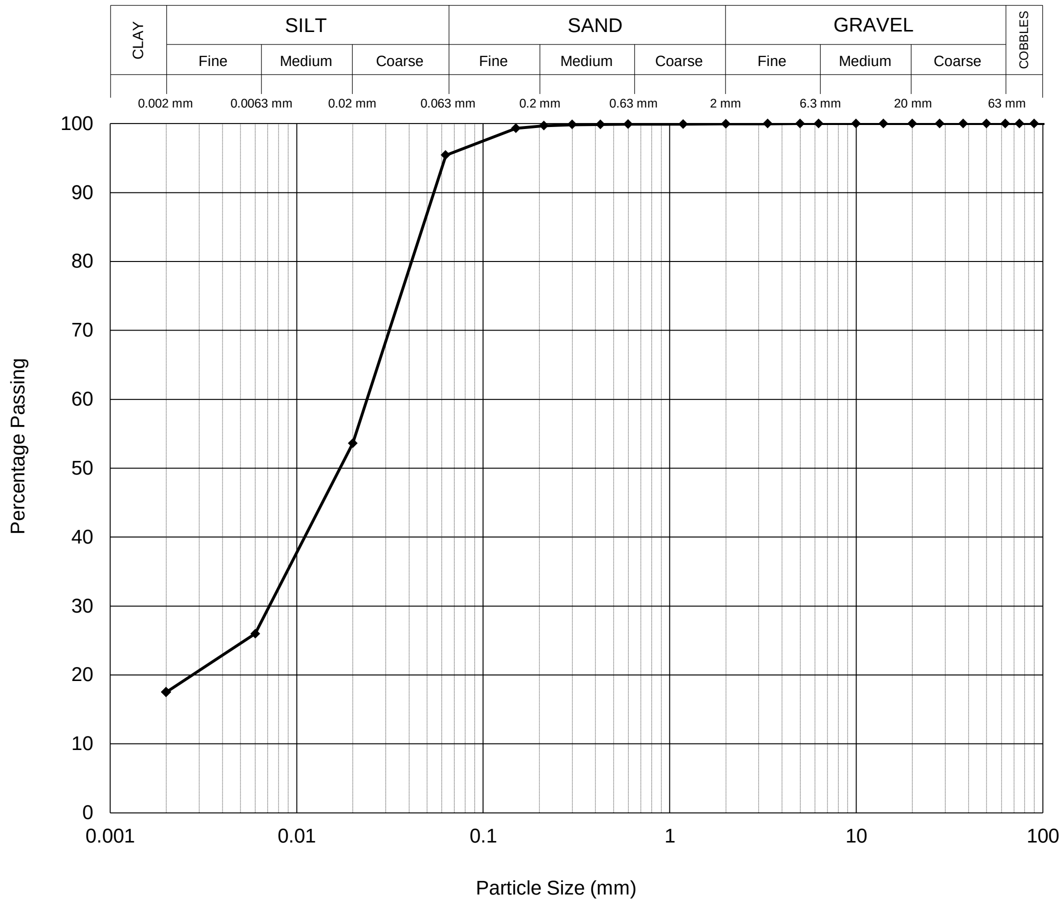
Sample Ref 8PSD
Sample Type B

Description

Greyish brown slightly sandy clayey SILT. Sand is fine.

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve
BS EN ISO 17892-4 : 2016 : Clause 5.4 - Sedimentation by Pipette

Sieve	
Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	100
5.00 mm	100
3.35 mm	100
2.00 mm	100
1.18 mm	100
600 µm	100
425 µm	100
300 µm	100
212 µm	100
150 µm	99
63 µm	95



Sedimentation	
No Pre-treatment used	
Temp (°C)	25
Size	% Pass
20 µm	54
6 µm	26
2 µm	18
Particle Density 2.70(A) Mg/m³	

Particle Proportions	
Cobbles	0
Gravel	0
Sand	5
Silt	78
Clay	17

Checked and Approved by

S Burke

S Burke - Senior Technician
03/07/2018

Project Number:

GEO / 27623

Project Name:

RIVER PARRETT DREDGING
HYG 477

GEOLABS

UKAS TESTING 1982

BS EN ISO 17892-4 : 2016

PARTICLE SIZE DISTRIBUTION

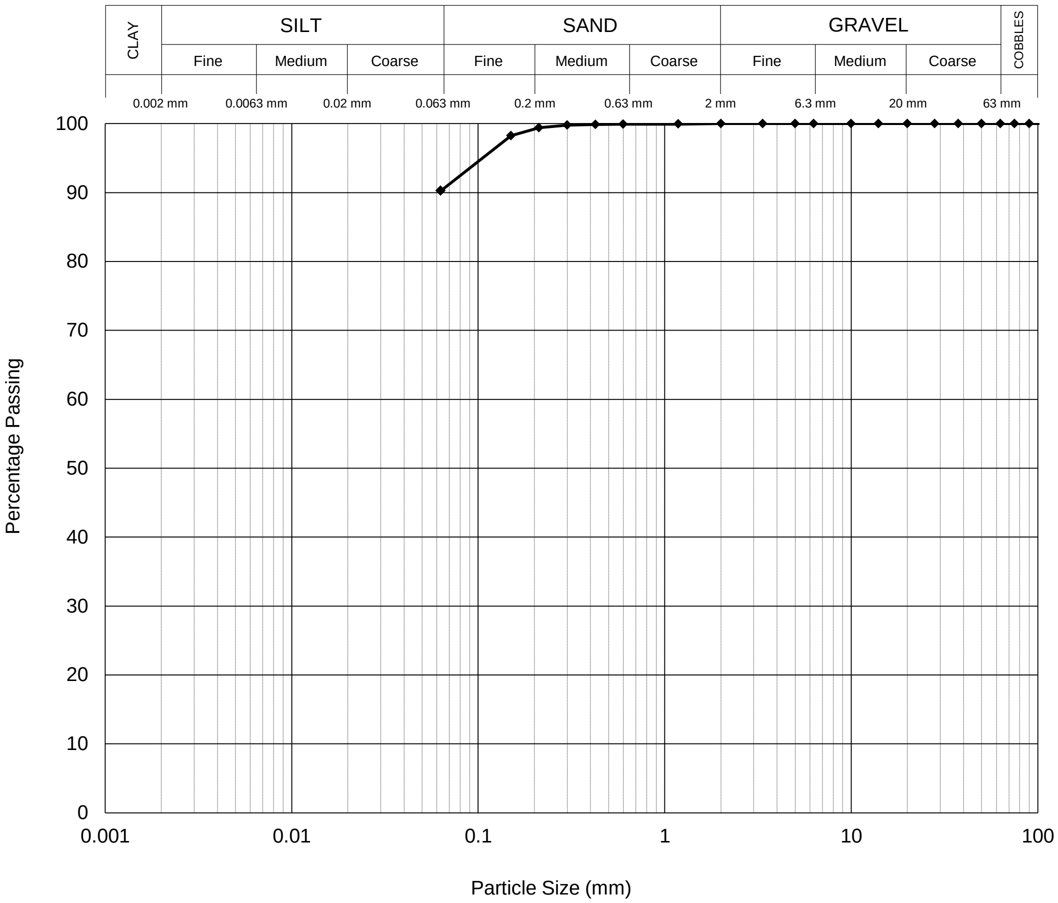
Sample Ref	9PSD
Sample Type	B

Description

Brown slightly sandy clayey SILT. Sand is fine.

BS EN ISO 17892-4 : 2016 : Clause 5.2 - Wet Sieve

Sieve Size	% Pass
200.0 mm	100
125.0 mm	100
90.0 mm	100
75.0 mm	100
63.0 mm	100
50.0 mm	100
37.5 mm	100
28.0 mm	100
20.0 mm	100
14.0 mm	100
10.0 mm	100
6.30 mm	100
5.00 mm	100
3.35 mm	100
2.00 mm	100
1.18 mm	100
600 µm	100
425 µm	100
300 µm	100
212 µm	99
150 µm	98
63 µm	90



Particle Proportions	
Cobbles	0
Gravel	0
Sand	10
Silt & Clay	90

Checked and Approved by

S Burke

S Burke - Senior Technician
03/07/2018

Project Number:

GEO / 27623

Project Name:

RIVER PARRETT DREDGING
HYG 477

GEOLABS® UKAS TESTING 1982

TraC-MImAS Technical report

(Development and Review of a TraC Hydromorphology Decision Support Tool for (a) screening proposed new or altered activities / structures for compliance with WFD water body status and (b) classifying TraC waters under the WFD)

Produced for UKTAG Phase 2 Environmental Standards stakeholder consultation

September 2012

Project Team

Dr Mark Williams, Marine Science, Scottish Environment Protection Agency, Clearwater House, Heriot Watt Research Park, Avenue North, Riccarton, Edinburgh EH14 4AP. mark.williams@SEPA.org.uk

Dr Nick Cooper (nick.cooper@rhdhv.com), Dr Julian Carolan and Phil Williamson (philipwilliamson@rhdhv.com), Royal Haskoning, 4 Deans Yard, Westminster, London, SW1P 3NL.

Project Technical Panel

Niall Phelan, Mike Best, Lucy Taylor, Greg Whitfield and Adam Waugh (EA)

Douglas Walker (Marine Scotland)

Shane O‟Boyle (EPA)

Chris Vivian (CEFAS)

Project Steering Group

Chris Vivian and Andrew Birchenough (CEFAS)

Niall Phelan, Mike Best, Lucy Taylor, Greg Whitfield, Adam Waugh, Helen Brailey and Rebecca Coales (EA)

Douglas Walker and Colin Megginson (Marine Scotland)

Shane O‟Boyle (EPA)

Francis O‟Beirn (Marine Institute, Galway)

Kelly Kasperczyk (Jacobs)

Mike Elliott (IECS, University of Hull)

Michael McAliskey (NIEA)

UKTAG contacts

Janet Forbes (SNIFFER)

Use of this report

The development of UK-wide classification methods and environmental standards that aim to meet the requirements of the Water Framework Directive (WFD) is being sponsored by UK Technical Advisory Group (UKTAG) for WFD on behalf its member and partners.

This technical document has been developed through a collaborative project, managed and facilitated by SEPA, Environment Agency, Environmental and Heritage Service and SNIFFER, and has involved the members and partners of UKTAG. It provides background information to support the ongoing development of the standards and classification methods.

Whilst this document is considered to represent the best available scientific information and expert opinion available at the stage of completion of the report, it does not necessarily represent the final or policy positions of UKTAG or any of its partner agencies.

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Preamble

Introduction and background information

Under the Water Framework Directive, the UK and Ireland are now required to manage morphological change to ensure that all surface water bodies aim to achieve “Good Ecological status” and that there is no deterioration in status.

UK regulators are experienced in regulating morphological alterations, particularly in transitional and coastal (TraC) waters. Where regulation occurs, decisions are typically made on a case by case basis, using a combination of field data and expert judgement.

The initial TraC-MImAS tool development project was tasked with developing a tool to help regulators determine whether proposals to alter morphological features could risk the ecological objectives of the WFD. Tool development was based on the methodology developed for rivers (Rivers-MImAS)[1]. Although the principles underpinning the Rivers and TraC-MImAS tools are largely analogous, TraC-MImAS incorporates a number of significant customisations to suit application to TraC waters. Specifically, the tool is intended to help regulators identify those proposals that could:

- Threaten the aim of achieving „good ecological status; or
- Result in a deterioration in ecological status

In developing a tool of this nature, it was important to recognise the current state of knowledge on the relationships between morphology and ecology. Generally, there is a lack of quantitative data describing the relationships between hydromorphological conditions and ecological health. It is clear however that many human induced hydromorphological pressures impact on aquatic ecology. Furthermore, it is recognised that different biological and morphological parameters may be more sensitive to certain hydrological or morphological processes than others, and that the relative sensitivities will differ between different TraC environments.

In response to the current lack of ecological data to support the development of „evidence-based‟ Environmental Standards for morphology, a tool has been developed that uses assessments of morphological features and pressures to determine risks to ecology.

The tool is not intended to be applied in isolation, and would be used to compliment existing regulatory procedures. Similarly, the tool is not intended to replace expert judgment or existing impact assessments. The tool will compliment these areas and provide risk-based guidance to inform regulatory decisions.

[1] Details of the Rivers-MImAS approach can be found on the UKTAG website:

UKTAG (2006). UK Environmental Standards and Conditions (Phase 1)
WFD49 (Rivers) (2006). A new impact assessment tool to support river engineering regulatory decisions
WFD49 (Rivers) (2006). Peer review short summary (Aug 06)
WFD49c CRESS (2006). Trialling of MImAS and proposed Morphological Condition Limits

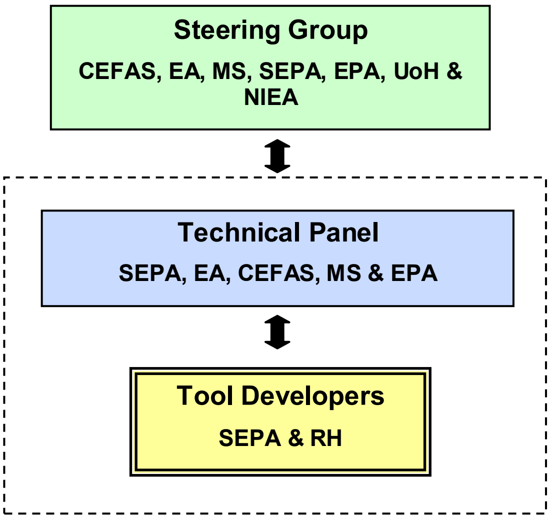
In addition to providing a method to screen risks to ecology from new morphological alterations, the tool also had to meet the following specifications:

- The tool should be capable of considering cumulative modifications
- The tool should be simple to apply by regulatory staff
- The tool should produce consistent and reproducible outputs
- The tool should not be data intensive.
- It should be possible to update and refine the tool over time as new data becomes available
- The tool should be capable of informing WFD classification decisions, particularly those decisions relating to the identification of high status sites.

The tool is not intended to:

- Provide an accurate representation of hydromorphological status
- Replace the need for detailed assessments or professional judgement
- Act as an engineering design tool
- Define remediation options
- Provide a quantitative assessment of the presence or quality of habitats
- Consider conservation requirements (protected habitats or species or special features).

The project is part of a wider UKTAG work programme tasked with developing new tools and environmental standards to support implementation of the Directive and associated UK legislation and regulations. SNIFFER commissioned Royal Haskoning to develop the existing TraC-MImAS tool in consultation with a core technical group (SEPA, CEFAS, EA and Marine Scotland) and wider steering group with experts from EA, CEFAS, Marine Scotland, EHS, EPA, Marine Institute (Galway), University of Hull and consultants from the Republic of Ireland (Figure 1).



EA - Environment Agency
CEFAS - Centre for Environment, Fisheries and Aquatic Sciences
SEPA - Scottish Environment Protection Agency
MS – Marine Scotland (formerly Fisheries
RH – Royal Haskoning
Research Services)
EPA - Environment Protection Agency (Republic of Ireland) (includes representation from Marine Institute, Galway and Jacobs)
UoH – University of Hull
NIEA – Northern Ireland Environment Agency

Figure 1 Project structure and links to steering groups.

The remainder of the report is divided into four main sections.

SECTION 1 - Provides a high level overview of the TraC-MImAS tool and the associated Morphological Condition Limits

SECTION 2 - Operational guide describing how the tool could be used to assist in regulatory decision-making.

SECTION 3 - Summarises outputs from the TraC-MImAS tool. This section provides figures, tables and case studies summarising real world limits on engineering works produced by the tool.

SECTION 4 - Conclusions and Bibliography

APPENDICES - Provide technical details of the TraC-MImAS tool and summaries of all data contained/used in each module.

Section 1

Summary of TraC-MImAS and Morphological Condition Limits

1.1 SUMMARY OF THE TRAC-MIMAS TOOL AND ITS DEVELOPMENT

Under the Water Framework Directive (WFD) the UK and Republic of Ireland are required to manage hydromorphological change as a result of human activity to prevent ecological deterioration transitional and coastal (TraC) waters. In response to the lack of ecological data to support the development of „evidence-based" Environmental Standards, a risk-based regulatory decision-support tool was developed to help regulators determine whether proposals to alter hydromorphological features could risk the ecological objectives of the WFD.

The tool, termed TraC-MImAS (Transitional and Coastal Waters Morphological Impact Assessment System) was developed by a core of experts from the UK environment agencies as part of a wider UKTAG programme in 2007. TraC-MImAS is based on a methodology developed for rivers (Rivers-MImAS) and incorporates a number of significant customisations to suit application to TraC waters. Specifically, the tool is intended to help regulators identify those proposals that could threaten the aim of achieving „good ecological status; or result in a deterioration in ecological status.

The TraC-MImAS tool uses the concept of „system capacity" which assumes that as system capacity is consumed by human activities it follows that there is an increased risk that morphological and ecological conditions will degrade. The tool comprises five modules that collectively provide an assessment of the amount of „system capacity" that has been used up in a water body. By considering impacts on system capacity, the tool can be used to allow the rapid determination of the level of risk posed by new development proposals. The outputs from TraC-MImAS provide a basis for identifying situations where extra information or more site specific assessment is required. To date the tool has been used to complement existing regulatory procedures by Marine Scotland and in the absence of other tools has been used by the environment agencies to guide the hydromorphological classification process during the first River Basin Management Planning (RBMP) cycle.

SNIFFER commissioned Royal Haskoning to develop the existing TraC-MImAS tool, set the outputs within a broader deterioration and regulatory framework and to provide a sufficient picture of likely outcomes to important habitats e.g. saltmarsh and seagrass.

The following principal changes have been made to the existing tool:-

- The pressure categories (originally without high and low change in impact categories) have been developed by expanding them to include low and high change in impact categories to take a better account of varying spatial and temporal factors i.e. magnitude and frequency of activity.

- The impact ratings have been categorised into 5 categories of sensitivity to enable impact rating comparisons to be made with ease. Originally, the sensitivity was based on 3 categories (0 – no impact, 0.5 - moderate impact and 1.0 – high impact).

- The tool has been adapted in the manner by which it assesses impounding structures and causeways, and other structures that have the potential to make a significant protuberance into the flow regime whilst having a small footprint; e.g. long breakwaters that extend across an estuary to narrow its width by 20% but occupy a small direct footprint area on the estuary bed. A simple rule has been developed any impoundment present either within or adjacent to a water body will indicate that that water body cannot be at a high status. Within the tool, any impoundment pressure will cause exceedence of the Morphological Condition Limits and therefore trigger expert assessment. Therefore, any impoundment, historic or new, should automatically trigger expert assessment.

- Impact ratings have been developed for important WFD habitats in each type by incorporating these under the „Morphological features and substrate" attribute in the ecogeomorphic attributes module using a similar approach to those already developed within the existing tool.

- Pressure categories have been incorporated for pipelines and high voltage cabling and tidal devices. Blasting and large scale shellfish farming have not been included.

- The sensitivity of the tool has been explored by running the tool with less sensitive impact ratings and more sensitive impact ratings for some pressure categories. In developing the existing version of the tool a significant amount of effort went into making minor adjustments to the values in the tool as part of an iterative process to ensure that the impact ratings were logical and sensible.

1.2 SUMMARY OF IMPORTANT CONCEPTS AND DEFINITIONS

TraC-MImAS comprises a series of interdependent modules. Collectively, the modules provide an assessment of the level of impact to morphological conditions[2] that are likely to result from individual morphological alterations, or combinations of morphological alterations.

Morphological conditions - *Refers to the list of attributes in Annex V of the Directive. For TraC waters these attributes include- depth variation, quantity, structure and substrate of the seabed, and structure of the intertidal and sub-tidal zones.*

Morphological alterations - *Any pressures acting on the water environment that could affect morphological conditions. Examples of morphological alterations include shoreline reinforcement and dredging.*

The tool uses a concept of „system capacity" to measure impacts to morphological conditions. In essence, this concept assumes that completely pristine TraC water have a measure of assimilative „capacity", which can be degraded by anthropogenic activities. By determining how much system capacity is used up by different pressures, it is possible to determine the total level of impact on a system at any point in time.

System Capacity - *a measure of the ability of the water environment to absorb morphological alterations. The likelihood (or risk) that morphological and ecological conditions are degraded will increase as system capacity is consumed. This concept does not infer that degradation of the environment is acceptable; rather it assumes that there is a degree to which minor changes can be tolerated by the system.*

It is assumed that different morphological alterations will use up different amounts of system capacity, with the amount of capacity being used dependant on:

- The type of alterations;
- The sensitivity of the water environment to the alterations; and
- The spatial scale of the alterations.

Where a new development is proposed, for instance a marina or some form of shoreline protection, the tools can be used to predict the impact of the proposal on „system capacity". By considering impacts on system capacity, the tool can be used to determine the level of risk presented by a new proposal. This information can then be used to inform regulatory decisions, for instance, to identify where more detailed assessments may be necessary, or to identify where there is a high risk of a deterioration in status, and, therefore, where a regulatory exemption test to determine if the work should proceed on the basis of benefits to human health, human safety or sustainable development may be required.

To help quantify the risk that a new morphological alteration could impair achievement of the ecological objectives of the WFD, a series of „morphological condition limits" have been defined (Section 1.3). Details of the proposed morphological condition limits for TraC waters are provided in the following sections.

Morphological condition limits- *Thresholds of alteration to morphological conditions beyond which there is a risk that the Ecological status objectives of the WFD could be threatened. The limits are expressed in percentage capacity.*

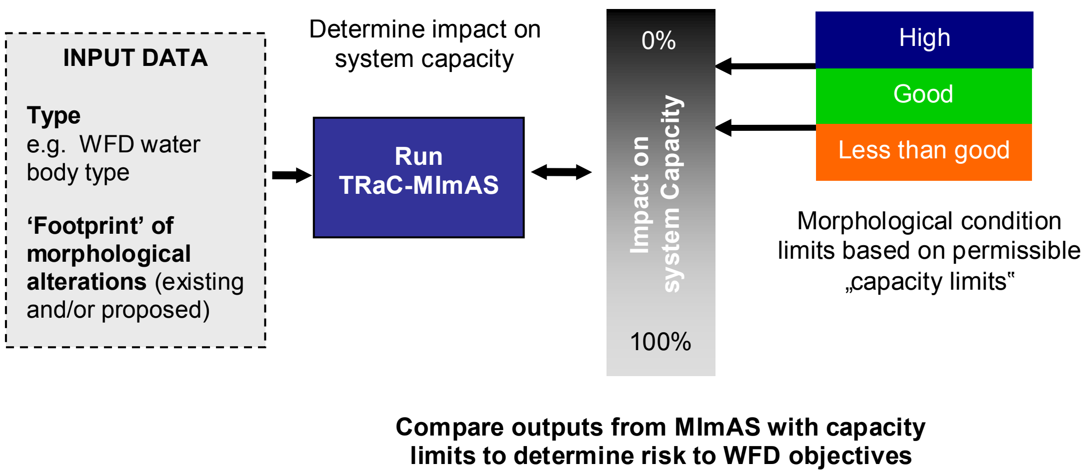


Figure 2 Summary of the capacity principle and links between TraC-MImAS and MCLs.

TraC-MImAS is underpinned by a series of assumptions:

- A TraC water has some capacity to accommodate morphological change without changes to its ecological status.
- There is a relationship between the extent of morphological alteration and the impact on ecological status.
- The response of a water body"s morphology to engineering or other pressures is predictable for that type of water body
- The response of the ecology to morphological change is predictable and depends on the sensitivity of the ecology of the water body.

These assumptions will be examined as part of future testing and validation work (See Section 1.6).

1.3 SUMMARY OF MODULES COMPRISING TraC-MImAS

The TraC-MImAS tool is based on five modules (Figure 3). Collectively the modules provide an assessment of impacts to morphological conditions. All impacts are measured in terms of impacts to „system capacity". Each module is designed to be semi-independent of the others, thereby allowing individual modules to be updated over time as more information becomes available. The modules are briefly described below. More detailed information on each module is presented in the Appendix

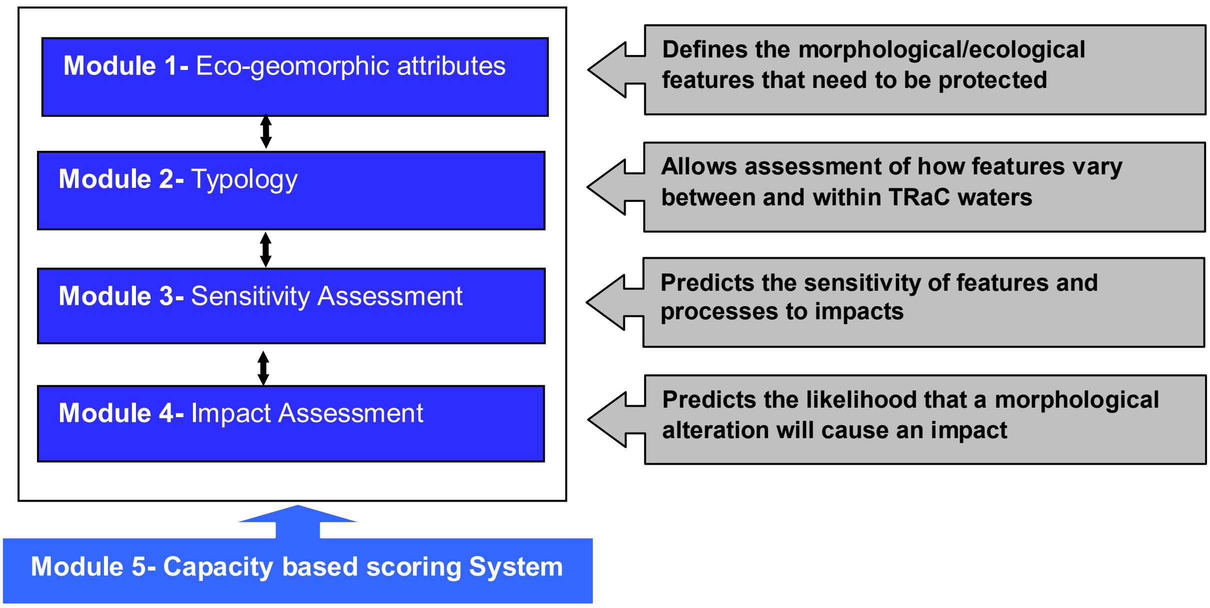


Figure 3 Overview of the modular components of TraC-MImAS.

1. The Attribute Module

This module defines a list of attributes that can be used to assess geomorphic and ecological function and condition as well as a list of potential UK BAP priority habitats which may potentially be impacted upon by a pressure/activity. The attributes are related closely to the morphological quality elements in Annex V of the Directive (Table 1). They cover such things as depth variation, flow, quantity and structure of substrate and bed, and wave exposure. Each attribute was chosen for its role in the direct or indirect support of ecological communities and the supporting processes needed to create and maintain the physical environment on which ecological communities depend. The Ecogeomorphic attributes are divided into three zones- hydrodynamic, inter-tidal, sub-tidal (Table 2) with each zone highlighting habitats for consideration within that zone (i.e. intertidal and saltmarsh; subtidal and seagrass beds). All Attributes were selected in consultation with the technical panel and project steering group. The tool does not require information on the attributes in Table 2. The core input data is pressure and water body type.

Annex V 1.1.3. Transitional Waters	**Annex V 1.1.4. Coastal Waters**
Tidal Regime: • Freshwater flow • Wave exposure	**Tidal Regime:** • Direction of dominant currents • Wave exposure
Morphological Conditions: • Depth variation • Quantity, structure and substrate of the seabed • Structure of the intertidal and sub-tidal zones	**Morphological Conditions:** • Depth variation • Quantity, structure and substrate of the seabed • Structure of the intertidal zone and sub-tidal zones

Table 1 Hydromorphological quality elements for in Annex V of the WFD.

UK BAP priority habitats are listed for each zone (intertidal and subtidal) of assessment. Habitats are identified on their typical zone of occurrence, e.g. saltmarsh being characteristic of the intertidal and seagrass being subtidal.

2. The Typology Module

For TraC-MImAS, the UK TraC typology has been simplified into six types (Table 3). Groupings were based on an assessment of similarities in physical characteristics and similarities in likely responses to morphological alterations. To improve the assessment of morphological responses to alterations, dominant geology has been incorporated into the typing of coastal water bodies. This creates three coastal water body subtypes: sheltered coastal sedimentary, exposed coastal sedimentary and coastal bedrock (sheltered to exposed). These groupings will be subject to further review through ongoing validation and testing of the tool.

The typology allows a simple assessment of the relevance of the attributes (contained in the attribute module) to the different TraC water body types. The typology module further identifies habitats characteristic of each zone (i.e. intertidal and saltmarsh; subtidal and seagrass beds). Where attributes are not relevant, they would be excluded from any assessments carried out on that water body type. For attributes that are relevant to a particular water body type, the assumption is that they will display predictable responses to morphological alterations.

Although typologies are simplified representations of complex and dynamic physical characteristics, they have been shown to be useful when assessing the likely physical and ecological responses to morphological alterations.

Ecogeomorphic Attributes	Definition
Hydrodynamics	**Describes the influence of the tides, waves and freshwater inflow**
Tidal range	*The height that the sea rises and falls over a tidal cycle*
Currents	*Currents associated with the rise and fall of the tide*
Freshwater flow	*Riverine input into TraC Waters, maybe modified by human interference of catchment hydrology/landuse changes*
Flushing/exchange	*The length of time it takes for a transitional water or sea loch to exchange its water*
Salinity/mixing/stratification	*Occurs in transitional waters and sea lochs where freshwater input is important*
Waves	*Waves are important in driving sediment transport processes*
Intertidal Zone	**Describes the size and structure of the intertidal zone**
Geometry	Describes the spatial extent and form of the intertidal zone
Planform	*Aerial view showing planar area of the intertidal zone (2D perspective). Describes the outline and spatial extent, or area of the intertidal zone which can change in response to prevailing coastal processes and/or realignment of the high water mark due to engineering activities.*
Profile	*Cross sectional form of an estuarine channel or gradient of the shoreline.*
Morphological features and substrate	Describes the shape and character of geomorphological features, and the size, structure and sorting of the intertidal sediments
Nature and extent of coastal features	*Topography and geomorphological and vegetation features of the coastal zone e.g. saltmarsh, seagrass, sand dunes, mudflats, sand bars, spits.*
Natural sediment size range	*Is the sediment size distribution natural*
Habitats	**Identifies the habitat types associated with this respective zone**
Coastal sand dunes	*Habitat type present*
Saltmarsh	*Habitat type present*
Mudflat	*Habitat type present*
Continuity and sediment supply	Assesses interruptions to coastal processes and sediment supply
Longitudinal sediment transport processes	*Describes sediment mobilization pathways i.e. transport of material by littoral drift from adjacent water bodies.*
Lateral sediment transport processes	*Includes land to sea connectivity and describes inputs and outputs of sediment from erosion of cliffs, catchment derived input from fluvial sources and material transported from offshore.*
Sub tidal Zone	**Describes the size and structure of the subtidal zone**
Geometry	Describes the spatial pattern and form of the subtidal zone
Planform	*Aerial view showing planar area of the subtidal zone (2D perspective). Describes the outline and spatial extent, or area of the subtidal zone which can change in response to prevailing coastal processes and/or engineering activities.*
Profile	*Cross sectional form of a channel or of the coastal zone perpendicular to the coastline*
Morphological features and substrate	Describes the shape and character of geomorphological features, and the size, structure and sorting of the intertidal sediments
Nature and extent of bed features	*Topography or specific features of the seabed e.g. sand banks, ripples.*
Natural sediment size range	*Is the sediment size distribution natural*
Habitats	**Identifies the habitat types associated with this respective zone**

Reefs	Habitat type present
Modiolus beds	Habitat type present
Seagrass beds	Habitat type present
Maerl beds	Habitat type present
Continuity and sediment supply	Assesses interruptions to coastal processes and sediment supply
Longitudinal sediment transport processes	*Describes sediment mobilization pathways i.e. transport of material by littoral drift from adjacent water bodies.*
Lateral sediment transport processes	*Includes land to sea connectivity and describes inputs and outputs of sediment from erosion of cliffs, catchment derived input from fluvial sources and material transported from offshore.*

Table 2 Proposed set of ecogeomorphic attributes.

TraC Type	General morphological characteristics	MImAS Code
TW6, CW10	TraC Lagoons	TraC lagoons
TW5, CW11,CW12	TraC Sea Lochs.	TraC sealochs
TW1 to TW4	Partially to fully mixed, meso-tidal to macro-tidal, intertidal or shallow subtidal, sand and mud	Transitional meso to macrotidal
CW7 to CW9	Sheltered, micro-tidal to macro-tidal. Sedimentary	Sheltered coastal -sedimentary
CW1 to CW6	Moderately to exposed, Macro-tidal. Sedimentary	Moderately to exposed coastal-sedimentary
CW1 to CW9	Sheltered to exposed, micro to macro-tidal	Coastal bedrock

Table 3 TraC types used in TraC-MImAS.

3. Sensitivity Module

The Sensitivity Module is divided into two parts- ecological sensitivity and morphological sensitivity. Within TraC-MImAS, sensitivity incorporates consideration of the resistance to change (ability to absorb change) and the resilience to change (ability to recover from change). For the morphology component, the assessment considers the intrinsic sensitivities of each attribute to physical disturbances. This is carried out for each TraC water body type. For the ecology component, the assessment considers whether a degradation of community or species integrity is likely to occur in response to a disturbance to individual attributes. Again, this is carried out for each TraC water body type. The ecological assessment considers all WFD biological quality elements- fish, benthic invertebrates and phytoplankton. As with the attribute and typology modules, the sensitivity module also identifies habitats characteristic of each zone which shall require consideration within the assessment via expert judgement and local knowledge.

All assessments within the sensitivity module are based on professional judgement, and were informed by contributions from the technical panel and steering group. This was necessary given the current lack of empirical data on the links between biology and morphology. Testing and validating the sensitivity module will be a priority, and the module will be updated to reflect new evidence. Summaries of all sensitivity assessments are provided in the Appendix.

4. The Pressure Module

This module comprises two components- (i) assessment of the likelihood that a morphological alteration will have an impact on an attribute (contained within the attribute module) and (ii) an assessment of whether impacts are likely to be contained within the vicinity of the pressure, or whether the impact will extend beyond the local vicinity of the pressure. The latter assessment is termed the „zone of Impact". As with other modules, the pressure module also identifies those habitats which are likely to be impacted upon by each respective pressure. Details of these assessments can be found in the Appendix. These assessments are distinct form those contained in the sensitivity module. The sensitivity module assess the intrinsic sensitivity of attributes within different types, the impact assessment is a type independent assessment of likelihood of impacts from different alterations. The pressure and sensitivity modules combine to provide a type specific impact assessment for a range of pressures.

It would not be possible to develop a tool that considered every morphological alteration or design. To reduce the number of morphological alterations considered by TraC-MImAS, a suite of generic alterations that cover the full range of potential physical impacts on TraC waters have been defined. Rules have been developed that allow a wider range of morphological alterations to be mapped to this suite of generic pressures (these rules are described in Section 2.2.2, Table 11).

Fifteen generic pressures have been incorporated (Table 4). They include shoreline pressures such as „hard" engineering for bank protection, and pressures such as barrages and dredging. The Pressure Module is not type specific. All pressures have a corresponding high and low impact category for data input. The difference in response to the pressures between TraC water body types is captured by combining the Sensitivity Module with the Pressure Module.

Specific pressures	Description
Land Claim	Historical (typically > 50 years) enclosure of intertidal or subtidal areas within impermeable banks followed by infilling for use by agriculture, housing, port or industry. The system may have partially recovered to a more "stable" natural condition since the land claim initially took place. Any new enclosure of intertidal or subtidal areas within impermeable banks followed by infilling for use by agriculture, housing, port or industrial use. The modification may destabilise the system.
Historic tidal river realignment	Historical (typically >50 years ago) alteration to course or planform of upper estuaries where the channel remains river-like. Includes straightening and removal of meanders to increase channel gradient and flow velocity (e.g. Ribble Estuary; See van der Wal et al., 2002; Fig 3.). This category can also include land claim.
New tidal river realignment	Any new alteration to course or planform of upper estuaries where the channel remains river-like.
Dredging (capital or maintenance)	Capital dredging for navigation purposes is the excavation of sediments to increase depths in an area, usually but not always for the first time, to accommodate the draft of vessels. May include maintenance dredging for the routine periodic removal of material in approach channels to port and harbour basins to maintain widths and depths in previously dredged areas to ensure the safe access for vessels.
High Voltage (HV) cables and Pipelines	The installation and subsequent protection of any cable (seabed) or pipeline (coastal to marine) for the transfer of electricity or discharge of effluent
Disposal of Dredgings (sea and intertidal)	The deposit of material dredged during maintenance and capital dredging campaigns into the marine environment or onto intertidal and subtidal areas for the purposes of disposal.
Impoundment	Impermeable barriers that extend either across the entire width of an estuary or embayment removing tidal influence (e.g. Cardiff Bay Barrage) or across coastal sounds and straits (e.g. South Ford Causeway, Outer Isles (Figure 10)). A structure that extends across a river channel that is used to impound, measure or alter flow (e.g. weirs, sluices).
Barrages	A semi-permeable impoundment that lets natural processes operate most of the time (e.g. barrage). Storm surge barriers may be built across estuaries in built up areas to reduce the risk of flooding during storm surges (e.g. Thames Barrier). Tidal barrages are constructed across estuaries with strong currents and large tidal range to harness tidal energy (Figure 11).

Flow and sediment manipulation structures	Hard engineering structures built to stabilise waterways for navigation and counter the effects of longshore drift. These include breakwaters, piers, groynes, flow deflectors, training walls etc. Ports, harbours and marinas are protected anchorage sites, often with extensive piers and breakwaters projecting into the adjacent water body (Figure 12).
Shoreline Reinforcement – Hard Engineering	The use of consolidated materials, e.g. rock armour, man made armour, revetments, retaining walls, gabion baskets, seawalls, wharves, quays, sheet piling etc. to protect vunerable coastlines or harbours from erosion (Figure 13).
Shoreline Reinforcement – Soft Engineering	Stabilisation of the shoreline using beach material to maintain beach levels and dimensions. May include synthetic materials (Figure 14).
Flood Defence Embankment	An artificial bank of earth or stone created to prevent inundation of estuarine and coastal floodplains.
Piled Structures	A range of structures raised on one or more foundation structures extending out into the adjacent water body e.g. bridge and pier supports. This category also includes wind turbine monopiles and outfalls (Figure 16).
Tidal devices	Any device which exploits the natural ebb and flow of coastal/marine tidal waters including horizontal axis turbines, cross axis turbines, oscillating hydrofoils and enclosed tips (venturi) energy extraction devices.
Other seabed uses	Any other pressures that could directly affect the bed morphology or substrate character.

Table 4 Definitions of generic categories of morphological alterations used in TraC-MImAS.

It is important to state that maintenance or refurbishment of structures is not considered as an impact where the works involve no alteration to the existing footprint. Therefore, there is no need to consider this type of activity within the tool‟s assessment.

5. The Scoring System

The scoring system combines the information contained in each module to calculate a numerical „impact rating‟. Each morphological alteration contained with the pressure module has its own impact score, which is specific to each TraC water body type. The impact score is calculated for each attribute in turn, and then averaged for attributes within the hydrodynamic, intertidal and subtidal zones. This value is then multiplied by the zone of impact to give an overall impact rating for each morphological alteration (pressure).

The equation used to calculate the impact rating can be summarised as:

Impact Rating	=	Relevance	X	Ecological Sensitivity	X	Morphological Sensitivity	X	Likelihood of Impact	X	Zone of Impact
		Output from typology module		Output from sensitivity module		Output from sensitivity module		Output from pressure module		Output from pressure module

To determine the percentage capacity used within a particular TraC water, the impact weightings are combined with the „alteration footprints‟ of all morphological alterations present within the section of estuarine or coastal water being assessed. An alteration footprint describes the type and extent of a morphological alteration. Different alterations will have different footprints, for instance, the footprint for shoreline reinforcement is the length over which the reinforcement occurs, whereas the footprint for dredging is the area over which dredging occurs. Summaries of the rules for calculating alteration footprints can be found in Section 2.2.2.

The formula used to calculate the capacity consumed by a single pressure, or combination of pressures within a predetermined assessment area/length, can be summarised as:

$$\text{Capacity Used (\%)} = \sum n \left(\frac{\text{Impact rating} \quad \text{X} \quad \text{Footprint of morphological alteration}}{\text{Length/area of assessment unit}} \right) \text{X } 100$$

* See Section 2.1.2 for a description of assessment units

Where n is the number of morphological alterations within the assessed length/area; and ∑ ( ) is the sum of results given by the equation specified in the parenthesis for each of the „n" alterations.

A worked example of the capacity used can be employed for the Loch Bee water body (WB200418). The water body is a „Lagoon" type and the location of the activity is in the subtidal zone. The total subtidal area of the water body is 7km, and the pressure is „Flow & sediment manipulation – submerged (high)" of 0.007857km^2.

The eco-geomorphic attributes for the subtidal zone for a sea loch as defined by the TraC-MImAS tool are:

- **Geometry** (planform & profile)
- **Morphological features and & susbtrate** (nature and extent of coastal features & natural sediment size range)
- **Continuity and sediment supply** (longitudinal sediment transport processes & lateral sediment transport processes); and
- **Habitats** (Sabellaria spinulosareefs, Modiolus beds, Seagrass beds & Maerl beds)

Each of these components is scored for each of the attributes that make up the impact rating. These are outlined below:

	Coastal-Transitional			
	Lagoon			
Ecogeomorphic Attributes	Relevance	Eco sense	Resistance	Generic impact
Subtidal Zone				
Geometry				
Planform	**1**	**1**	**0.5**	**0.25**
Profile	**1**	**0.5**	**0.5**	**0.5**
Morphological features & substrate				
Nature and extent of coastal features	**1**	**1**	**0.5**	**0.5**
Natural sediment size range	**1**	**0.5**	**0.5**	**0.5**
Continuity and sediment supply				
Longitudinal sediment transport processes	**0**	**0.5**	**0.5**	**0.5**
Lateral sediment transport processes	**1**	**0.5**	**0.5**	**0.5**

Habitats				
Sabellaria spinulosareefs	**0**	**0**	**0**	**0.5**
Modiolus beds	**0**	**0**	**0**	**0.75**
Seagrass beds	**1**	**0.5**	**1**	**0.75**
Maerl beds	**0**	**0**	**0**	**0.5**

Each ecogeomorphic attribute has its scores multiplied together, and then the largest impact rating is taken forward for that attribute. Therefore, the scorings taken are:

- Geometry = **0.125**
- Morphological features & substrate = **0.25**
- Continuity and sediment supply = **0.125**
- Habitats = **0.375**

An average of these scores is then taken, producing a Likelihood of impact score of **0.22**.

The Zone of Impact score for Flow & sediment manipulation – submerged (High) in the subtidal zone is **1.5**.

The two multiplied together creates an impact rating score of **0.33**.

The capacity used is calculated as such:

$$\sum n \left(\frac{0.33 \quad \text{x} \quad 0.007857}{7} \right) \text{X } 100$$

= 0.03704 (rounded up to 0.1% for the purposes of the TraC-MImAS tool) % capacity of the water body"s subtidal zone is used by the pressure.

This low score does not use up sufficient capacity to exceed a morphological condition limit and therefore the water body remains in a High status.

HYDRODYNAMICS	Transitional	Transitional or coastal		Coastal		
				Sheltered	Mod-exposed	Shelt-exposed coast
Morphological Alteration	Meso-tidal	Lagoon	Sea loch	Sedimentary	Sedimentary	Bedrock
Land claim – high impact	0.38	0.38	0.38	0.19	0.06	0.06
Land claim – low impact	0.09	0.09	0.09	0.06	0.06	0.06
Historic tidal channel realignment – high impact	0.13	0.09	0.09	0.06	0.06	0.06
Historic tidal channel realignment – low impact	0.06	0.03	0.03	0.03	0.03	0.03
Recent tidal channel realignment – high impact	0.28	0.19	0.19	0.14	0.14	0.14
Recent tidal channel realignment – low impact	0.06	0.03	0.03	0.03	0.03	0.03
Dredging – high impact	0.13	0.13	0.13	0.09	0.09	0.09
Dredging – low impact	0.03	0.03	0.03	0.03	0.03	0.03
HV cable and pipelines – high impact	0.03	0.00	0.00	0.03	0.00	0.00
HV cable and pipelines – low impact	0.00	0.00	0.00	0.00	0.00	0.00
Use of dredged material – high impact	0.03	0.00	0.00	0.03	0.00	0.00
Use of dredged material – low impact	0.00	0.00	0.00	0.00	0.00	0.00
Impoundments – high impact	0.50	0.50	0.50	0.25	0.25	0.25
Impoundments – low impact	0.09	0.05	0.05	0.05	0.05	0.05
Barrages – high impact	0.50	0.50	0.50	0.25	0.25	0.25
Barrages – low impact	0.19	0.19	0.19	0.09	0.09	0.09
Flow and sediment manipulation, submerged – high impact	0.14	0.14	0.14	0.14	0.14	0.14
Flow and sediment manipulation, submerged – low impact	0.03	0.03	0.03	0.03	0.03	0.03
Shoreline reinforcement, hard engineering – high impact	0.19	0.19	0.19	0.09	0.09	0.09
Shoreline reinforcement, hard engineering – low impact	0.06	0.06	0.06	0.03	0.03	0.03
Shoreline reinforcement, soft engineering – high impact	0.03	0.03	0.03	0.03	0.03	0.03
Shoreline reinforcement, soft engineering – low impact	0.00	0.00	0.00	0.00	0.00	0.00
Flood defence embankment – high impact	0.19	0.19	0.19	0.05	0.05	0.05
Flood defence embankment – low impact	0.06	0.13	0.06	0.00	0.00	0.00
Piled structures – high impact	0.19	0.19	0.19	0.14	0.14	0.14
Piled structures – low impact	0.03	0.03	0.03	0.03	0.03	0.03
Tidal devices – high impact	0.03	0.03	0.03	0.03	0.03	0.03
Tidal devices – low impact	0.00	0.00	0.00	0.00	0.00	0.00
Other seabed uses	0.03	0.03	0.03	0.03	0.03	0.03

Table 5 Summary of impact ratings for morphological alterations- Hydrodynamic zone

INTERTIDAL ZONE	Transitional	Transitional or coastal		Coastal		
				Sheltered	Mod-exposed	Shelt-exposed coast
Morphological Alteration	Meso-tidal	Lagoon	Sea loch	Sedimentary	Sedimentary	Bedrock
Land claim – high impact	1.25	0.79	0.79	0.92	1.58	0.33
Land claim – low impact	0.33	0.21	0.21	0.25	0.42	0.08
Historic tidal channel realignment – high impact	0.38	0.23	0.25	0.25	0.46	0.08
Historic tidal channel realignment – low impact	0.22	0.13	0.16	0.16	0.28	0.06
Recent tidal channel realignment – high impact	0.88	0.56	0.56	0.63	1.13	0.25
Recent tidal channel realignment – low impact	0.44	0.28	0.28	0.31	0.56	0.13
Dredging – high impact	0.54	0.46	0.46	0.46	0.46	0.25
Dredging – low impact	0.08	0.08	0.08	0.08	0.08	0.04
HV cable and pipelines – high impact	0.08	0.08	0.08	0.08	0.08	0.04
HV cable and pipelines – low impact	0.02	0.02	0.02	0.02	0.02	0.00
Use of dredged material – high impact	0.41	0.28	0.28	0.28	0.28	0.13
Use of dredged material – low impact	0.19	0.13	0.13	0.13	0.28	0.06
Impoundments – high impact	1.33	0.83	0.83	1.00	1.67	0.33
Impoundments – low impact	0.22	0.13	0.16	0.16	0.28	0.06
Barrages – high impact	1.33	0.83	0.83	1.00	1.67	0.33
Barrages – low impact	0.50	0.31	0.31	0.38	0.63	0.13
Flow and sediment manipulation, submerged – high impact	0.63	0.38	0.41	0.44	0.75	0.13
Flow and sediment manipulation, submerged – low impact	0.17	0.10	0.13	0.13	0.21	0.04
Shoreline reinforcement, hard engineering – high impact	0.75	0.47	0.47	0.56	0.94	0.19
Shoreline reinforcement, hard engineering – low impact	0.17	0.10	0.10	0.13	0.21	0.04
Shoreline reinforcement, soft engineering – high impact	0.69	0.44	0.44	0.50	0.88	0.19
Shoreline reinforcement, soft engineering – low impact	0.17	0.10	0.10	0.13	0.21	0.04
Flood defence embankment – high impact	0.63	0.41	0.44	0.44	0.81	0.19
Flood defence embankment – low impact	0.15	0.27	0.10	0.10	0.19	0.04
Piled structures – high impact	0.75	0.47	0.47	0.56	0.94	0.19
Piled structures – low impact	0.29	0.19	0.19	0.21	0.38	0.08
Tidal devices – high impact	0.00	0.00	0.00	0.00	0.00	0.00
Tidal devices – low impact	0.00	0.00	0.00	0.00	0.00	0.00
Other seabed uses	0.00	0.00	0.00	0.00	0.00	0.00

Table 6 Summary of impact ratings for morphological alterations- Intertidal zone

SUBTIDAL ZONE	Transitional	Transitional or coastal		Coastal		
				Sheltered	Mod-exposed	Shelt-exposed coast
Morphological Alteration	Meso-tidal	Lagoon	Sea loch	Sedimentary	Sedimentary	Bedrock
Land claim – high impact	1.19	0.63	0.88	0.94	1.00	0.56
Land claim – low impact	0.25	0.29	0.29	0.33	0.42	0.08
Historic tidal channel realignment – high impact	0.38	0.20	0.28	0.31	0.38	0.19
Historic tidal channel realignment – low impact	0.13	0.06	0.09	0.09	0.09	0.06
Recent tidal channel realignment – high impact	0.89	0.47	0.70	0.75	0.89	0.52
Recent tidal channel realignment – low impact	0.13	0.00	0.13	0.13	0.13	0.13
Dredging – high impact	0.69	0.63	0.69	0.81	0.50	0.56
Dredging – low impact	0.22	0.17	0.20	0.25	0.16	0.19
HV cable and pipelines – high impact	0.28	0.16	0.25	0.34	0.19	0.22
HV cable and pipelines – low impact	0.19	0.08	0.14	0.22	0.13	0.13
Use of dredged material – high impact	0.47	0.28	0.42	0.47	0.28	0.28
Use of dredged material – low impact	0.23	0.12	0.21	0.23	0.14	0.14
Impoundments – high impact	1.50	0.88	1.13	1.25	1.50	0.75
Impoundments – low impact	0.13	0.06	0.09	0.09	0.09	0.06
Barrages – high impact	1.50	0.88	1.13	1.25	1.50	0.75
Barrages – low impact	0.38	0.22	0.28	0.31	0.38	0.19
Flow and sediment manipulation, submerged – high impact	0.56	0.33	0.47	0.52	0.61	0.38
Flow and sediment manipulation, submerged – low impact	0.20	0.13	0.17	0.20	0.23	0.16
Shoreline reinforcement, hard engineering – high impact	0.38	0.26	0.30	0.33	0.38	0.23
Shoreline reinforcement, hard engineering – low impact	0.06	0.06	0.06	0.06	0.06	0.06
Shoreline reinforcement, soft engineering – high impact	0.34	0.19	0.19	0.31	0.22	0.16
Shoreline reinforcement, soft engineering – low impact	0.13	0.06	0.06	0.13	0.06	0.00
Flood defence embankment – high impact	0.06	0.06	0.06	0.06	0.06	0.00
Flood defence embankment – low impact	0.00	0.00	0.00	0.00	0.00	0.00
Piled structures – high impact	0.56	0.30	0.40	0.52	0.52	0.28
Piled structures – low impact	0.19	0.08	0.11	0.19	0.16	0.09
Tidal devices – high impact	0.31	0.06	0.27	0.28	0.31	0.22
Tidal devices – low impact	0.13	0.03	0.13	0.13	0.13	0.13
Other seabed uses	0.16	0.06	0.13	0.13	0.16	0.09

Table 7 Summary of impact ratings for morphological alterations- Subtidal zone

1.4 MORPHOLOGICALCONDITION LIMITS (MCLs)

To help quantify the risk that a new morphological alteration could impair achievement of the ecological objectives of the WFD, a series of „Morphological Condition Limits" (MCLs) have been defined (See Section 1.1 for a definition of a morphological condition limit).

Morphological condition limits are defined for three TraC zones- hydrodynamic, inter-tidal and sub-tidal zone. Distinguishing between these zones provides regulators with a simple method of identifying which aspect of a TraC water is likely to be impacted. This information would be useful when defining the scope of a more detailed assessment.

The morphological condition limits proposed for these zones are expressed in terms of percentage capacity used as set out in Table 8. Exceeding these limits would indicate a risk to WFD status objectives. Limits for Moderate and Poor conditions will be considered based on evidence from the trials proposed for summer 2007.

The WFD requires regulators to manage for no deterioration in WFD status. Where a deterioration in status is predicted, a regulatory exemption test to determine if the work should proceed on the basis of benefits to human health, human safety or sustainable development may be required. MCLs for all boundaries would help determine where a regulatory exemption test might be required.

	Morphological Condition Limit (% capacity)			
Zone	High*	Good**	Moderate	Poor
Hydrodynamic	**5%**	**15%**	**30%**	**45%**
Intertidal	**5%**	**15%**	**30%**	**45%**
Subtidal	**5%**	**15%**	**30%**	**45%**

Table 8 Proposals for TraC morphology condition limits. Please refer to Section 1.1 for a definition of a morphological condition limit (see below for a definition, in WFD terms, of these boundaries.

The capacity limits in Table 8 are not type specific. The differences in response between TraC water body types are taken into account within the TraC-MImAS scoring system. Likewise, as different pressures consume different amounts of capacity, the limits do not simply mean, for instance, that 15% of the shoreline can be reinforced before a risk to good status is identified.

Table 14 and 15 (Section 3) provides information on what these capacity limits mean in real world terms. These values were created by running TraC-MImAS to determine how much of an individual morphological alteration can take place before the morphological condition limits for a particularly status boundary (high/good and good/moderate) are exceeded.

The values presented in the Tables 14 and 15 are not regulatory standards. They are provided as an illustration of what 5% and 15% mean in real terms. In regulation, TraC-MImAS would be used to assess how combinations of pressures interact to threaten status objectives.

The limits in Tables 14 and 15 are in draft form and their suitability will be reviewed during the field trialling work. Based on the results of the field trialling, the TraC-MImAS and/or the MCLs may be altered to ensure that they reflect, on the basis of best available information, the WFD status definitions summarised in Table 5 (Section 1.6 provides information on the trialling work).

1.5 ROLE OF MORPHOLOGICAL CONDITION LIMITS IN REGULATION

Morphological Condition Limits (MCLs) are intended to provide risk-based guidance to inform regulatory decisions. They would be used to complement existing regulatory methods and form part of a wider decision-making-process for managing TraC waters. Specifically, MCLs are intended to help regulators determine whether the Ecological Objectives of the WFD are threatened. This will inform where more detailed assessments are required, and where a regulatory exemption test may be required. Exemptions enable consideration of over-riding benefits to human health, human safety or sustainable development (Figure 4).

In addition to using Morphological Condition Limits, regulators may use other criteria to determine if WFD objectives are threatened and whether a regulatory exemption would be necessary. This could include the use of formal Environmental Impact Assessments, other detailed assessment work and professional judgement.

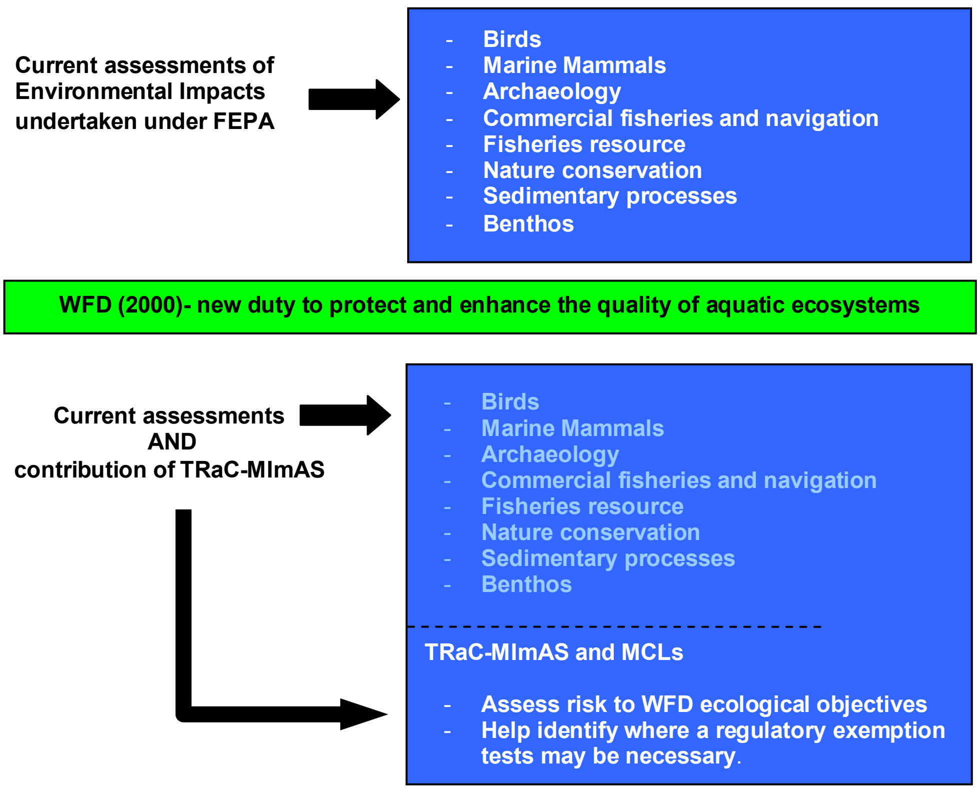


Figure 4 Summary of role of TraC MImAS and MCLs in regulation.

1.6 ROLE OF MORPHOLOGICAL CONDITION LIMITS IN WFD CLASSIFICATION

Under the Water Framework Directive, the UK is required to manage morphological change to ensure that all surface water bodies aim to achieve "Good Ecological Status" and that there is no deterioration in status. In terms of classification, the Directive specifies that hydromorphological quality elements must be explicitly considered when classifying for high status. For other status boundaries, the Directive does not require explicit consideration of hydromorphological features; however, the biological assessments of status must reflect hydromorphological conditions.

TraC-MImAS could be used to inform assessments of whether the condition of morphological quality elements is representative of high status conditions. Additionally, in recognition of the limitations of current biological tools to provide an accurate signal of the quality of morphological conditions, the TraC-MImAS tool could be used to develop risk-based morphology status maps for all status boundaries. These maps would be an extension of the work undertaken under the WFD characterisation exercise, and would identify where ecological conditions could be threatened and where investment might be targeted (through programmes of measures) to improve the quality of TraC waters such that the ecological objectives of the WFD are met. Options for using TraC-MImAS for classification will be investigated through the UKTAG classification work programme.

1.7 ONGOING WORK AND FUTURE REFINEMENTS

A revised version of the TraC-MImAS tool has been developed as part of this project. The trialling results indicate that the development and improvement of the original tool results in assessment outputs which are not materially different from the original tool. A second more basic version of the tool has also been developed with the impact ratings removed so that tool outputs can be generated without the subjectivity inherent in the use of the impact ratings,

Impact ratings for important habitats have been developed for seven habitats. The inclusion of habitats within the TraC-MImAS tool, while straight forward in principle, represents a number of problems in terms of developing a capacity used approach in line with the existing tool functionality. The TraC-MImAS tool will not incorporate these impact ratings for WFD habitats at this stage. Where a pressure has the potential to impact on a WFD habitat then this is flagged in the tool and it suggests expert assessment is required to categorise the actual impact and mitigation required. In the absence of spatial data regarding location and extent of habitats in relation to the proposed activity further work is required to finalise the approach to assessment for these habitats and the development of habitat specific Morphological Condition Limits (MCLs).

Another area for further consideration in the future is how the tool should consider new and existing impounding structures, particularly across straits e.g. Outer Hebrides, and other structures that have the potential to make a significant protuberance into a flow regime whilst having a small footprint. This task wasn"t completed during this project due to difficulty in defining the extent of impact areas for the multitude of structures that fall into these categories.

As many elements of TraC-MImAS tool are underpinned by professional judgment, it will be operated within an „adaptive management" framework. TraC-MImAS will be reviewed as new evidence on the relationships between ecology and hydromorphology become available. Where necessary, the tool will be updated. The ultimate aim will be to test/validate the assumptions underpinning the tools and, where necessary, replace professional judgment with empirically tested data (Figure 6).

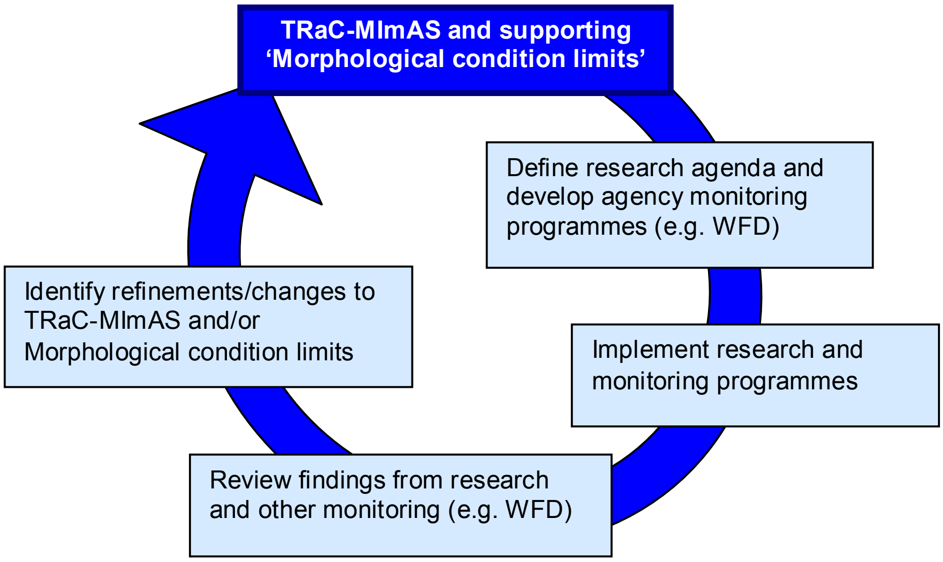


Figure 5 Application of MImAS tool and morphological condition limits within an adaptive framework.

SECTION 2

GUIDE TO USING TraC-MImAS

2.1 USING TraC-MImAS IN REGULATION

2.1.1 General approach

It is envisaged that TraC-MImAS would be applied within a two-stage regulatory screening process. This two-stage process helps support the implementation of an efficient, risk-based regulatory procedure.

Stage 1 - preliminary risk assessment. Within a Stage 1 assessment, TraC-MImAS would be applied at a local-scale to identify low risk proposals that do not threaten ecological status. Proposals that do not threaten Ecological objectives at a local scale would not require a Stage 2 assessment as it has been determined that they are low risk and would not threaten the status of the water body, even in combination with other pressures.

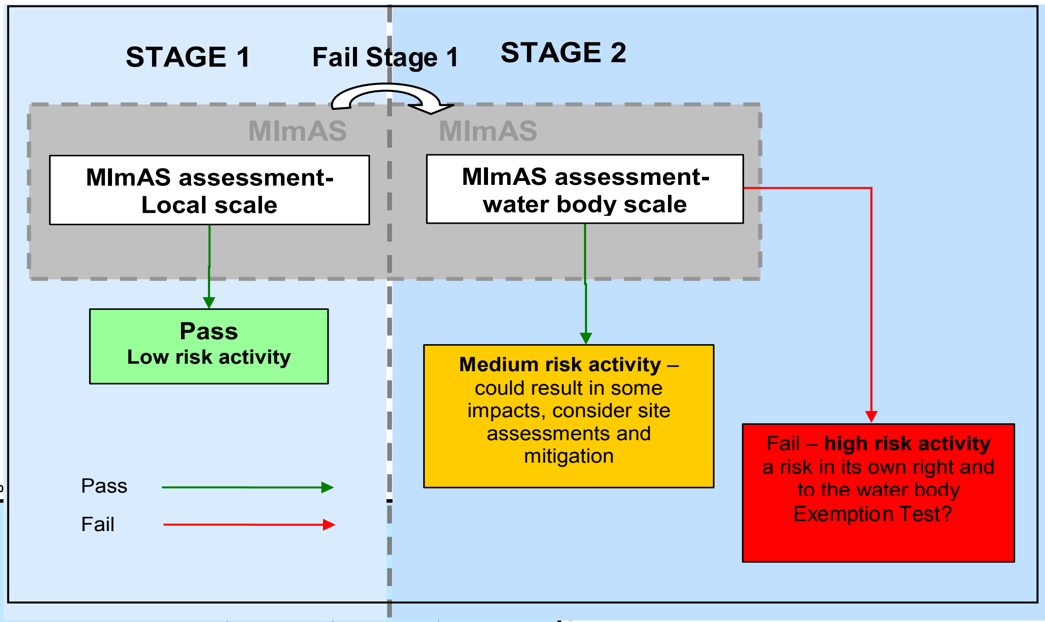
Stage 2 - Water body risk assessment. Reserved for proposals that exceed the morphological condition limits at a local-scale. Within a Stage 2 assessment, TraC-MImAS would be applied at a larger scale to determine if the ecology of a whole water body could be threatened by a morphological alteration, or combination of alterations.

The outputs from the Stage 1 and Stage 2 assessments would help regulators determine:

- Whether a more detailed assessment will be necessary
- The form of regulatory conditions that might be necessary
- When deteriorations in status may need to be managed, for instance, by considering a regulatory exemption on the basis of benefits to human health, human safety or sustainable development.

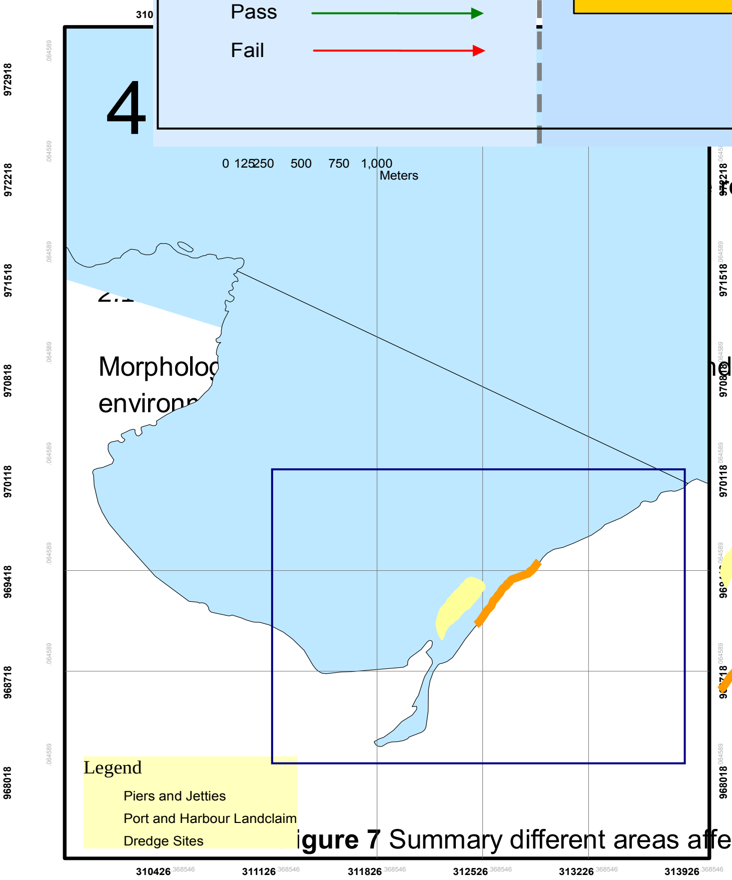
The most detailed assessments would typically be reserved for proposals exceeding the morphological condition limits at a water body scale. Considerations of whether an exemption test was required would be reserved for proposals failing the morphological condition limits at a water body scale (Figure 7).

If the morphological condition limits were failed at a water body scale, additional assessments/surveys would likely be undertaken to validate that the morphological alteration would impact on the ecological status of the water body. The outcome from this could be informed by expert judgment. Where it cannot be demonstrated that the ecological objectives of the WFD <u>are not at risk</u>, a regulatory exemption test would be required.



regulatory screening process.

Morpholog… d/or the inter-tidal, sub-tidal or open water environm…



Dredging- Predominately affecting sub-tidal (or inter-tidal area) area

Shoreline reinforcement- Predominately affecting the shore line.

Figure 7 Summary different areas affected by morphological alterations.

It was necessary therefore to identify two assessment units:

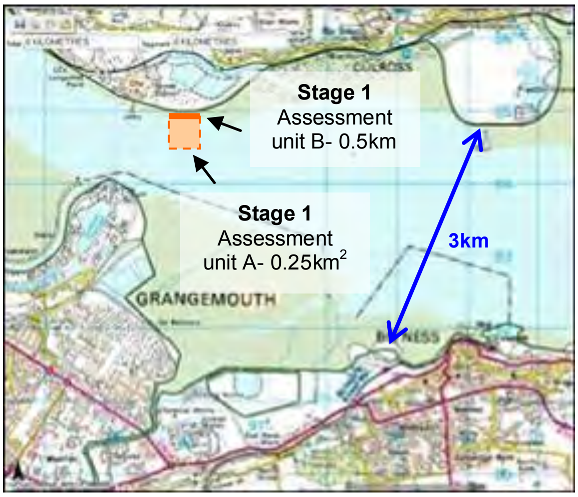
Assessment unit A- an area based assessment for activities predominately affecting inter-tidal, sub-tidal and open water environments; and

Assessment unit B- a linear assessment for activities predominantly affecting the shoreline

As TraC waters vary significantly in size- 15m wide estuarine channel to open water coastal environments- it was necessary to develop a variable assessment unit for undertaking local (stage 1) assessments (Table 9). For water > 0.5km in width at there narrowest part, the assessment units are fixed. When assessments are being carried out in waters < 0.5km in width (e.g. narrow transitional waters), the area based assessment unit (Assessment unit B) should be reduced proportionately to the width of the environment being assessed. In reducing the size of the area based assessment unit, only the axis perpendicular to the shoreline is altered. The linear assessment unit will remain fixed at 0.5km. For new development proposal, assessments would always be centred on the location of the new proposal. If an application for a new modification was greater than the size of the Stage 1 assessment units, then the assessment would be carried out over multiples units (Figure 9).

Waters > 0.5km in width
Assessment unit **A** (Area) - 0.5km^2
Assessment unit **B** (Linear length) - 0.5km
Waters < 0.5km in width
Assessment unit **A** (Area)- channel width * 0.5km
Assessment unit **B** (Linear length) – 0.5km

Table 9 Summary of Assessment units and associated rules.



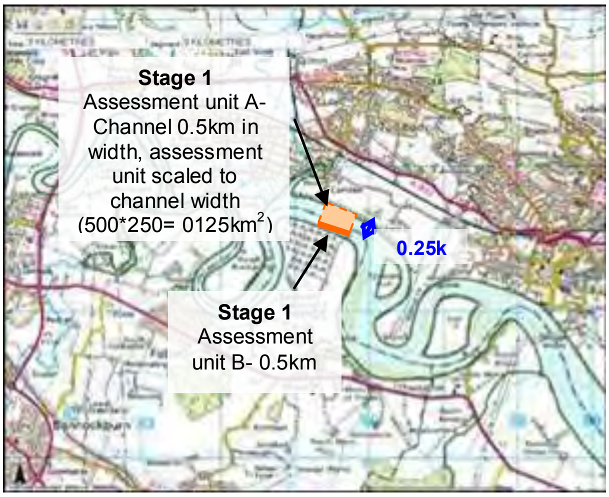


Figure 8 Summary of Stage 1 assessment.

Rules for up-scaling to assess risks to the status of a water body are being developed. It is likely that water body scale assessments (Stage 2) will be based on the application of the TraC-MImAS and associated MCLs to the entire water body area and shoreline length. As water bodies vary significantly in size, the benefits of introducing additional scale-independent rules will be investigated. Any rules developed would include an area based component and a linear shoreline component.

The rules for applying TraC-MImAS for water body scale (Stage 2) assessments could also be used to perform WFD classification assessments.

2.2 INPUTTING DATA AND TraC-MImAS USER INTERFACE

2.2.1 Using MImAS to assess different morphological alterations

As described in Section 1, it would not be possible to develop a tool that considered every engineering activity or engineering design. To reduce the number of activities considered by TraC-MImAS, a suite of generic engineering activities that cover the full range of potential physical impacts on TraC waters have been defined.

To create a suite of generic activities, some activities have been grouped together based on similarities in impacts, i.e. different activities have been assigned to a single generic alteration category (Table 10). Conversely, some more complex morphological alterations (for instance marinas and harbours) must be created by combining combinations of generic activities (Figure 10). Importantly, although the tool cannot consider every type of engineering alterations, or every type of engineering design, the tool is capable of considering variations in the size of different structures.

Generic 'Alteration' category used in MImAS	Other activities covered by this generic category
Capital Dredging	Aggregate extraction
Impoundments	Weirs, sluices
Flow and sediment manipulation structures	Breakwaters, causeways extending across part of an estuary or strait, piers, groynes, flow deflectors, training walls
Shoreline Reinforcement – Hard Engineering	Sea walls, rock armour, man made armour, revetments, gabion baskets, sheet piling
Shoreline Reinforcement – Soft Engineering	Mainly beach nourishment. (Other techniques such as using synthetic geocontainers)
Piled Structures	Bridge and pier supports, wind turbine monopiles, raised outfalls

Table 10 Summary of mapping of morphological alterations into generic alteration categories

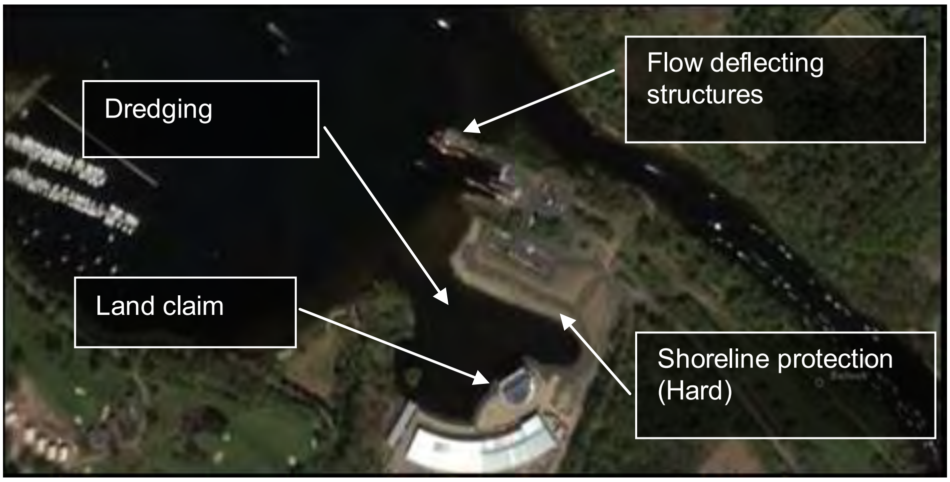


Figure 9 Example of grouping how generic activities can be combined to create more complex activities.

Each pressure has been divided into high and low pressure categories. The purpose of this is predominantly to differentiate between historic pressures and new pressures. Historic pressures are categorised as low impact, due to their existing exposure to the water body (and its likely adjustment to them over time). This includes existing structures and maintenance dredging. New pressures (those to be constructed) are categorised as high impact. These include, for example, a capital dredge or the construction of a new structure.

This historic versus new pressure categorisation applies to the following pressures:

- Land claim;
- Dredging;
- Barrages;
- Flow & sediment manipulation;
- Shoreline reinforcement – hard engineering;
- Shoreline reinforcement – soft engineering;
- Flood defence embankments;
- Piled structures; and
- Tidal devices.

The development of high and low change in impact categories has created a need to define what each pressure now includes. High and low change in impact categories for each activity pressure are stated in Table 11:

Pressure	Low change in impact	High change in impact
Land claim	Historic land claim	New land claim
Dredging	New or extended maintenance dredging	Capital dredging
Barrage / impoundments	Modification to footprint or impoundment height / length of existing structure	New structure
Flow and sediment manipulation	Modification to footprint of existing structure	New structure
Shoreline management – hard	Modification to footprint of existing structure	New structure
Shoreline management – soft	Modification to footprint of existing structure	New structure
Flood defence embankment	Modification to footprint of existing structure	New structure
Piled structures	Modification to footprint covered by existing piled structures	New piled structures
Tidal devices	Single device / demonstrator site	Commercial-scale site
HV cables / pipelines	Sub-bed	Proud of bed
Use of dredged material	New or existing licensed spoil ground	Beneficial use at site other than licensed spoil ground

Table 11 Summary of high and low footprint activities.

2.2.2 Footprint rules

All morphological alterations are input into MImAS by means of an „Alteration footprint". The alteration footprints typically describe the linear length over which a morphological alteration occurs, or the area over which a morphological alteration occurs (Table 12).

Generic Alteration category	Footprint rule
Land Claim	Area of claimed land
Tidal river realignment – low impact (historical)	Length of realignment
Tidal river realignment – high impact (new)	Length of realignment
Dredging	Area over which dredging occurs
High Voltage (HV) cables and Pipelines	Total Length of structure(s)
Use of dredged material (sea and intertidal)	Area over which dredging occurs
Impoundments	Automatic triggering of expert assessment
Barrages	Automatic triggering of expert assessment
Flow and sediment manipulation structures	Total Length of structure(s)
Shoreline Reinforcement – Hard Engineering	Total Length of structure(s)
Shoreline Reinforcement – Soft Engineering	Total Length of structure(s)
Flood Embankment	Total Length of structure(s)
Piled Structures	See Table 12
Tidal devices	Area of „development" area, irrespective of number of tidal devices
Other sea bed uses	Area over which alteration occurs

Table 12 Summary of alteration footprint rules.

For some morphological alterations, it has been necessary to create „footprint rules" to allow data to be entered into TraC-MImAS.

For Piled structures, rather than entering multiple individual footprints for each structure, generic density categories are used (Table 13).

Density category	Number of piled structures	SMALL* Footprint	Medium** Footprint	LARGE*** Footprint
Very high	>50	10	20	40
High	15-50	5	10	20
Moderate	5-15	2.5	5	10
Low	<5	1	2.5	5

* Piled structures <1m diameter
** Piled structures 1-5m diameter
*** Piled structures >5m diameter

Table 13 Footprint rules for piled structures.

For impounding structures (e.g. impoundments and barrages), the limits are based on the proportion of the assessment area that is impounded, for instance the proportion of the water body that is impounded (Figure 11). Table 14 summarises the footprints entered into MImAS.

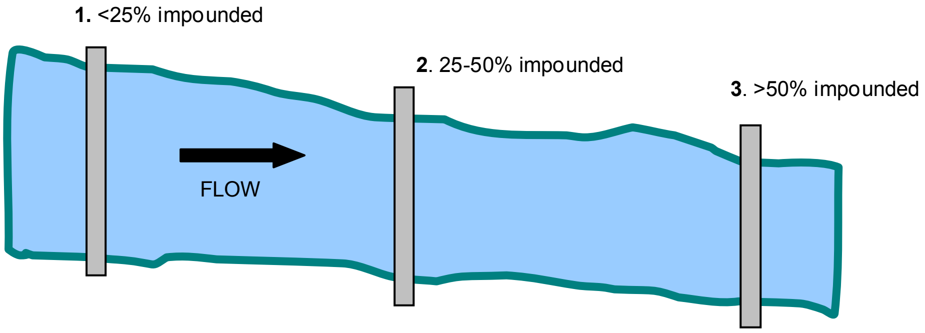


Figure 10 Visualisation of footprint rules for impoundments (see Table 13).

Proportion of assessment area impounded	Footprint Impoundment	Semi-permeable barrier
1- >50%	25	10
2- 25-50%	10	5
3- <25%	5	0

Table 14 Footprint rules for impoundments.

All impounding structures would fail a Stage 1 assessment, regardless of the presence of other alterations. Therefore, if any impoundment is present, entering a nominal figure (can be a random number) into the tool to represent impoundment will automatically trigger the requirement for expert assessment.

For tidal devices (e.g. arrays of energy-generating devices), the limits are based on the „development" area of the devices, the perimeter of which is located at a distance from the outer devices that is equivalent to the device spacing within the array (see **Figure 12**). This represents an overestimation on the actual footprint of the turbines. This is to consider the down current tail effect the turbine will have on the coastal hydromorphological processes. Arrays are designed so that the effects from one device to not affect the tidal stream energy reaching other devices nearby. This is dictated by the overall footprint area of the devices, and not by the density of turbines. Because of the diversity of tidal devices, which would result in a large variety of modelled impacts, it is necessary to create a more general footprint rule.

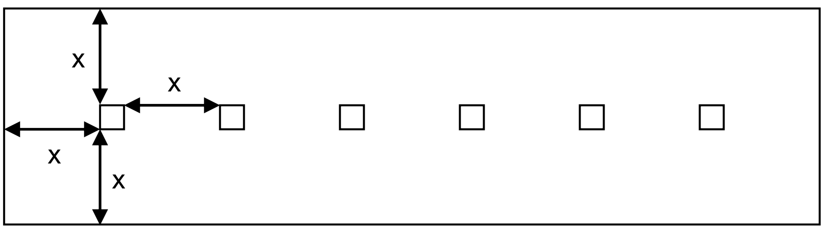
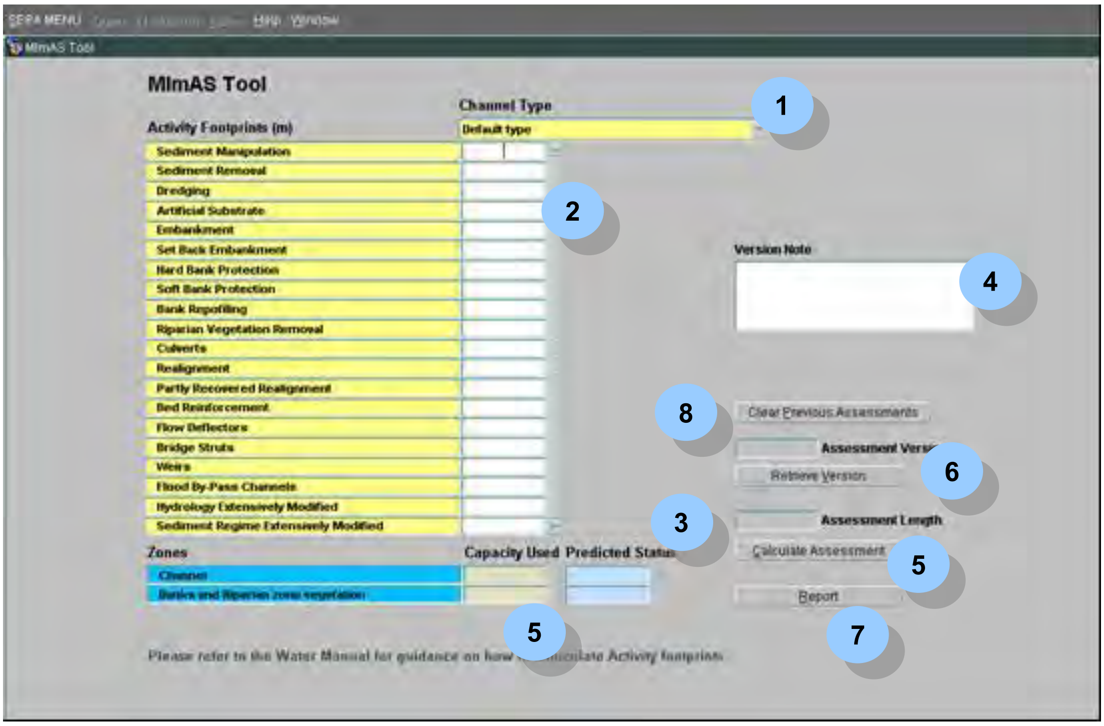


Figure 11 Suggested footprint rule for tidal devices (x = device spacing).

2.2.3 User Interface

Presently, TraC-MImAS is embedded in a series of excel worksheets. The Rivers tool has been bcoded into an Oracle™ application (Figure 12). A snap shot of the River-MImAS tool is provided below.



1. The user selects the „Channel Type" from the drop down list. Please ensure that either type B or Type C is selected.
2. The activity footprint values should be entered in the relevant box in the column with the white background.
3. The default „Assessment Length" value is Xm, though the user is able to change this by entering the new length (metres) in the appropriate item.
4. The „Version Note" item is available for text input relating to the specific Assessment calculation that is to be performed.
5. The Assessment process is activated by selecting the „Calculate Assessment" button. This will result in values being determined and then displayed in the „Capacity Used" and the „Predicted Status" items.
6. Subsequent Assessment calculations can be performed, with the number of these indicated by the value of the „Assessment Version" item. The user is able to retrieve previous Assessment calculations to the screen by entering the required version number in the „Assessment Version" item and selecting the „Retrieve Version" button.
7. A report (PDF File) of the Assessment calculations can be activated by selecting the „Report" button. The report summarises all versions of the current Assessment calculations and includes the information input into the version note box.
8. To start a new Assessment calculation process the user should select the „Clear Previous Assessments" button.

Figure 12 Snapshot of River-MImAS user interface. A similar interface could be created for TraC-MImAS.

SECTION 3

MImAS outputs and Case studies

3.1 OVERVIEW

The following section provides details of key outputs from the TraC-MImAS tool. The section is divided into three parts-

- A summary of outputs from key modules within TraC-MImAS

This section provides insights into the impact ratings produced by TraC-MImAS. These impact ratings are a critical aspect of TraC-MImAS and, when combined with the Morphological Condition Limits, directly influence the limits produced for different morphological alterations.

- A summary of limits on individual morphological alterations

Although TraC-MImAS was developed to assess combination of pressures, the tool can also be used to produce limits on individual activities. These limits represent the amount of a single alteration that would put a TraC water at risk of deteriorating across a WFD status class. These values are not regulatory standards. They are provided to illustrate what the MCL mean in terms real world limits on morphological alterations.

- A selection of case studies demonstrating the application of MImAS to real-world situations

Given the wide variety of different combinations of engineering activities and landscape pressures, it is not possible to provide an overview of all potential scenarios that these limits represent. To provide information on the use of TraC-MImAS to assess multiple applications a series of real-world case studies have been produced.

3.2 SUMMARY OUTPUTS FROM TraC-MImAS MODULES

One of critical elements of the TraC-MImAS tool is the impact ratings that it produces for different morphological alterations. When combined with the capacity-based scoring system and the Morphological Condition Limits, the impact ratings help create limits on activities that can be used to determine risk to WFD status objectives. In developing the TraC-MImAS tool, a significant amount of effort has gone into ensuring that the impact ratings are logical and sensible and based on the best available information. The project team, steering group and technical panel have been involved in developing and agreeing the information underpin the impact assessments.

The impact ratings are created by combining the outputs from the typology modules, sensitivity modules and impact assessment modules. The ratings reflect the relative impact of different activities, on each zone (hydrodynamic, intertidal, subtidal), in each TraC type.

There are around 300 individual impact ratings (15 pressures, 3 zones and 6 types). To summarise the general trends and key aspect of these impact ratings, a series of figures and tables have been produced:

Figure 13- Summary of impact ratings from different activities in a 'Transitional type'

This Figure provides a summary of the impact ratings produced by TraC-MImAS for a particular TraC type (transitional). The figure summarises the relative impact rating assigned to each morphological alteration assessed by TraC-MImAS. The impact ratings are created by combining the information contained in the ecogeomorphic attribute module, the typology module, the sensitivity module and the impact assessment module. In the MImAS tool, impact ratings for three separate zones are produced (hydrodynamic, intertidal, subtidal). <u>For simplicity, the maximum impact rating across these zones is presented. This value is not used in TraC-MImAS; however, it provides a useful summary to help interpret the outputs from MImAS.</u>

Figure 14- Summary of impact ratings from different activities for all TraC types

Similar to Figure 13. In this figure impact ratings for all pressures and all TraC types are shown. This figure highlights the variation in impact ratings for different morphological alterations within TraC types and between TraC types. TraC-types that are more sensitive to a particular impact from a morphological alteration will display a higher impact rating than similar activities in a less sensitive type.

Figure 15- Summary of impact ratings organised by type and zone

TraC-MImAS creates impact ratings for three separate zones (hydrodynamic, intertidal, subtidal). The impact ratings for these zones are directly linked to the Morphological Condition Limits that have been produced for these zones. This figure summarises variations in impact ratings between these zones and between TraC types. Morphological alterations that have a dominant affect on a particular zone will have a high impact rating in that zone.

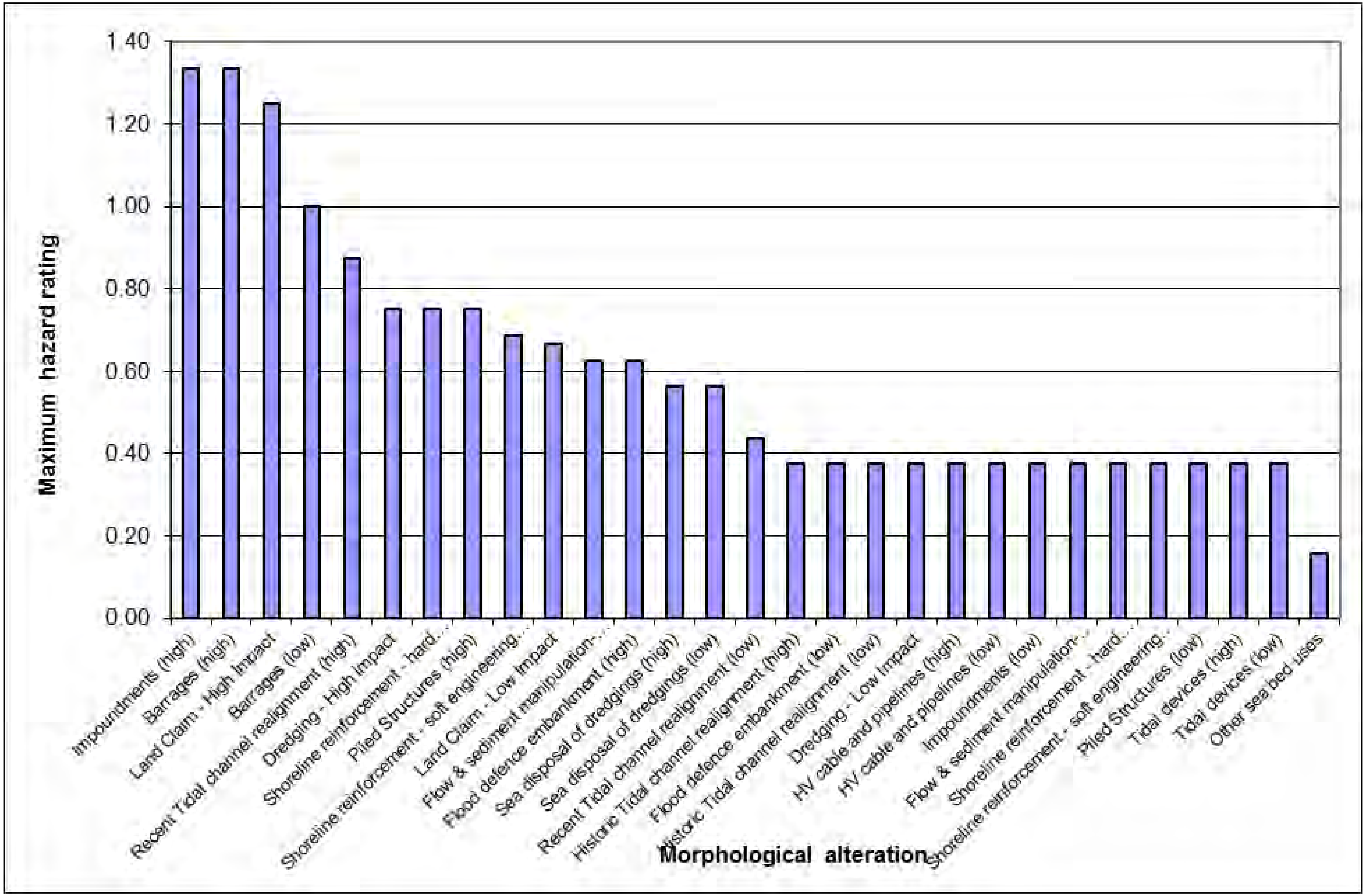
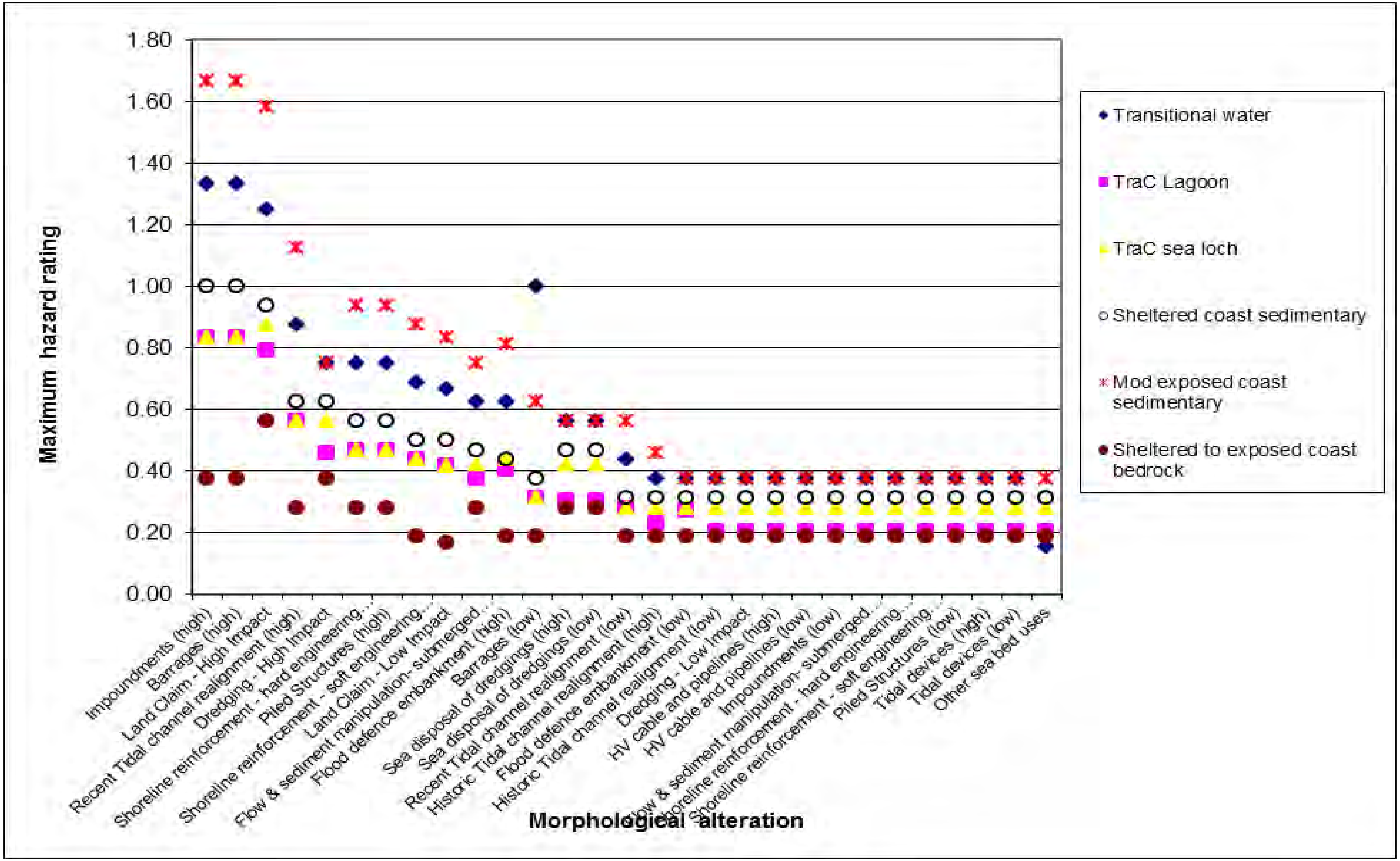


Figure 13 Summary of impact ratings from different morphological alterations in the „Transitional type".



Maximum hazard rating
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Morphological alteration
Impoundments (high)
Barrages (high)
Land Claim - High Impact
Recent Tidal channel realignment (high)
Dredging - High Impact
Shoreline reinforcement - hard engineering...
Piled Structures (high)
Shoreline reinforcement - soft engineering...
Land Claim - Low Impact
Flow & sediment manipulation- submerged...
Flood defence embankment (high)
Barrages (low)
Sea disposal of dredgings (high)
Sea disposal of dredgings (low)
Recent Tidal channel realignment (low)
Historic Tidal channel realignment (high)
Flood defence embankment (low)
Historic Tidal channel realignment (low)
Dredging - Low Impact
HV cable and pipelines (high)
HV cable and pipelines (low)
Impoundments (low)
Flow & sediment manipulation- submerged...
Shoreline reinforcement - hard engineering...
Shoreline reinforcement - soft engineering...
Piled Structures (low)
Tidal devices (high)
Tidal devices (low)
Other sea bed uses
Transitional water
TraC Lagoon
TraC sea loch
Sheltered coast sedimentary
Mod exposed coast sedimentary
Sheltered to exposed coast bedrock

Figure 14 Summary of impact ratings from different activities for all TraC types.

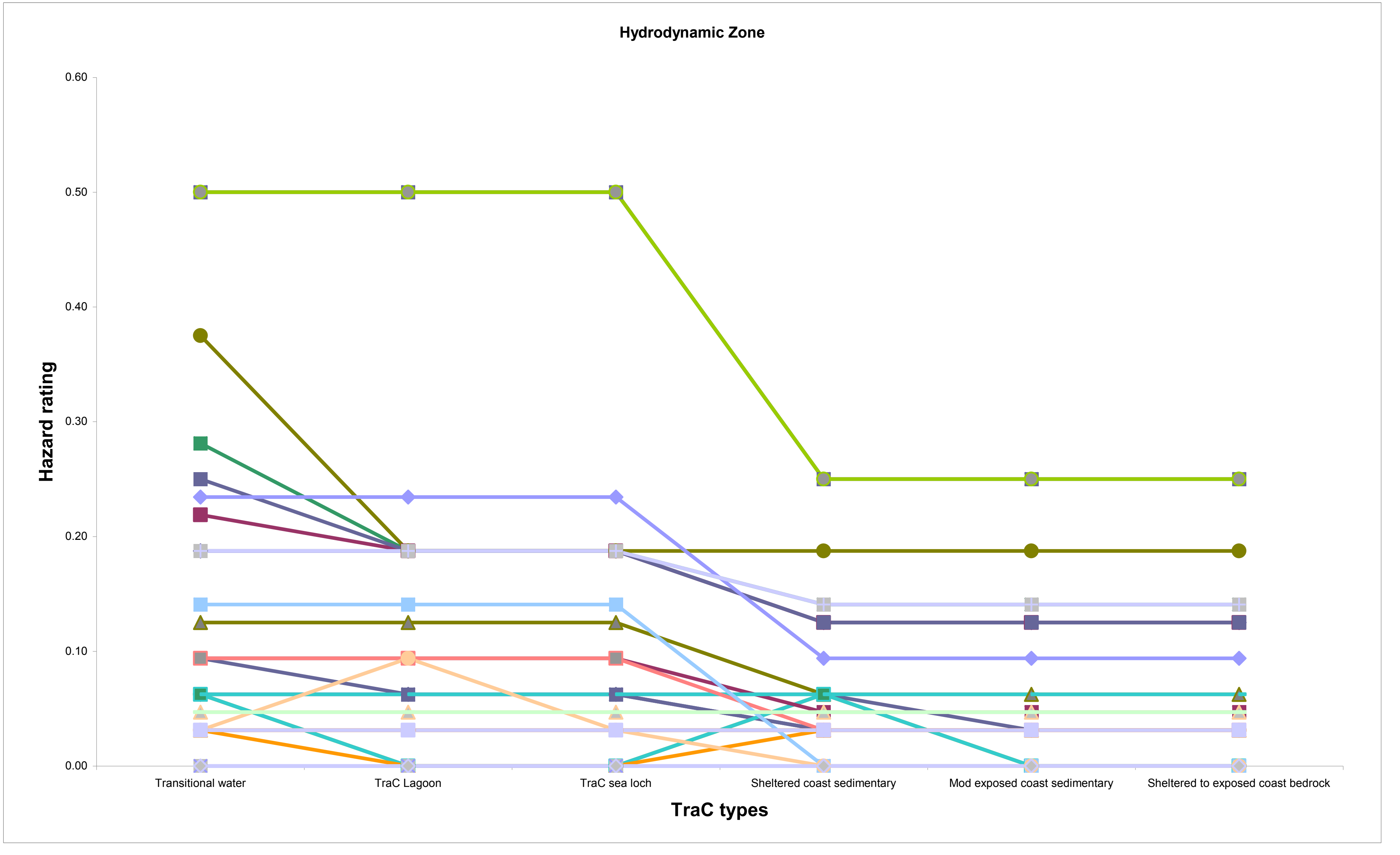


Figure 16 Summary of impact ratings - hydrodynamic zone.

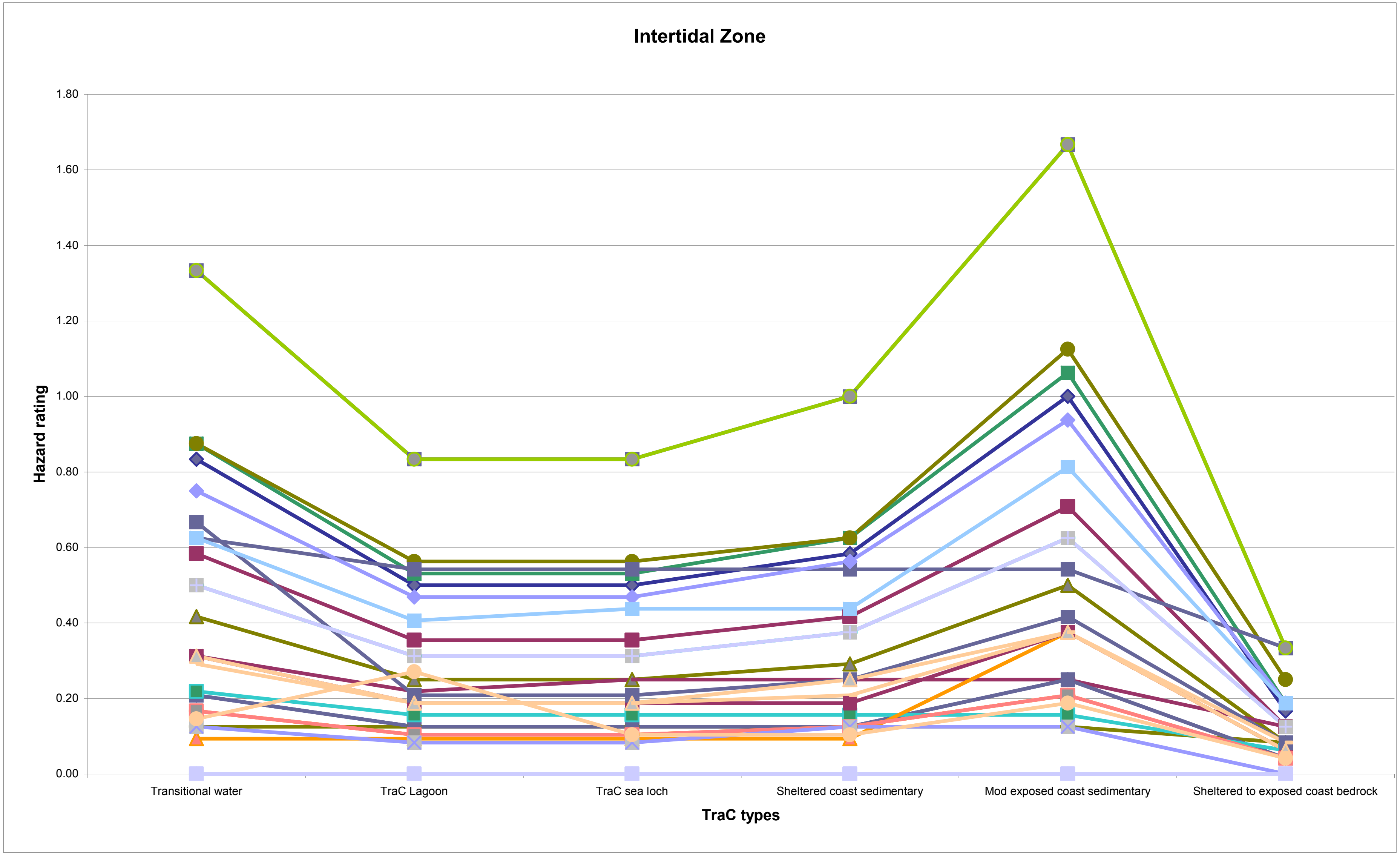


Figure 17 Summary of impact ratings - intertidal zone.

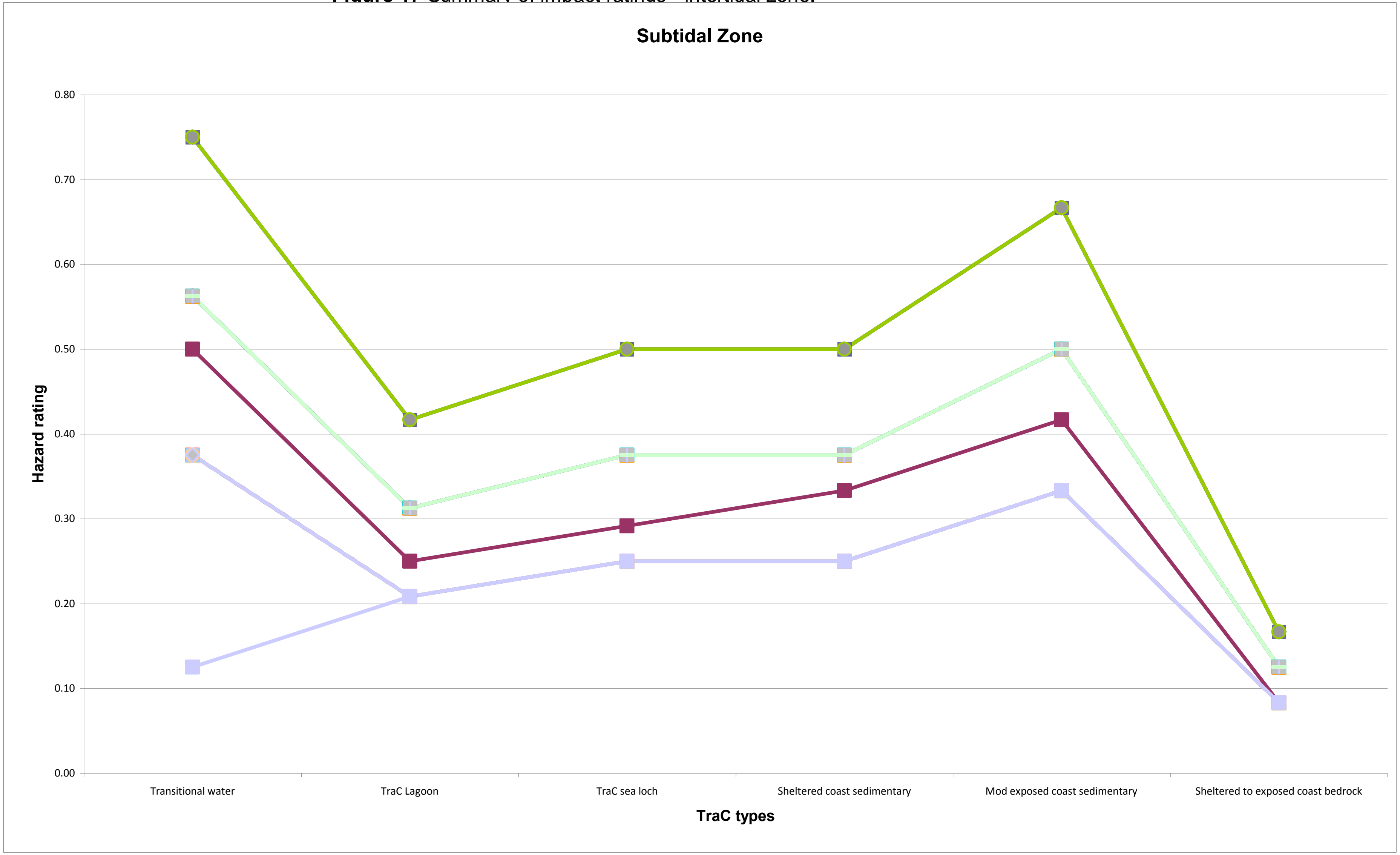
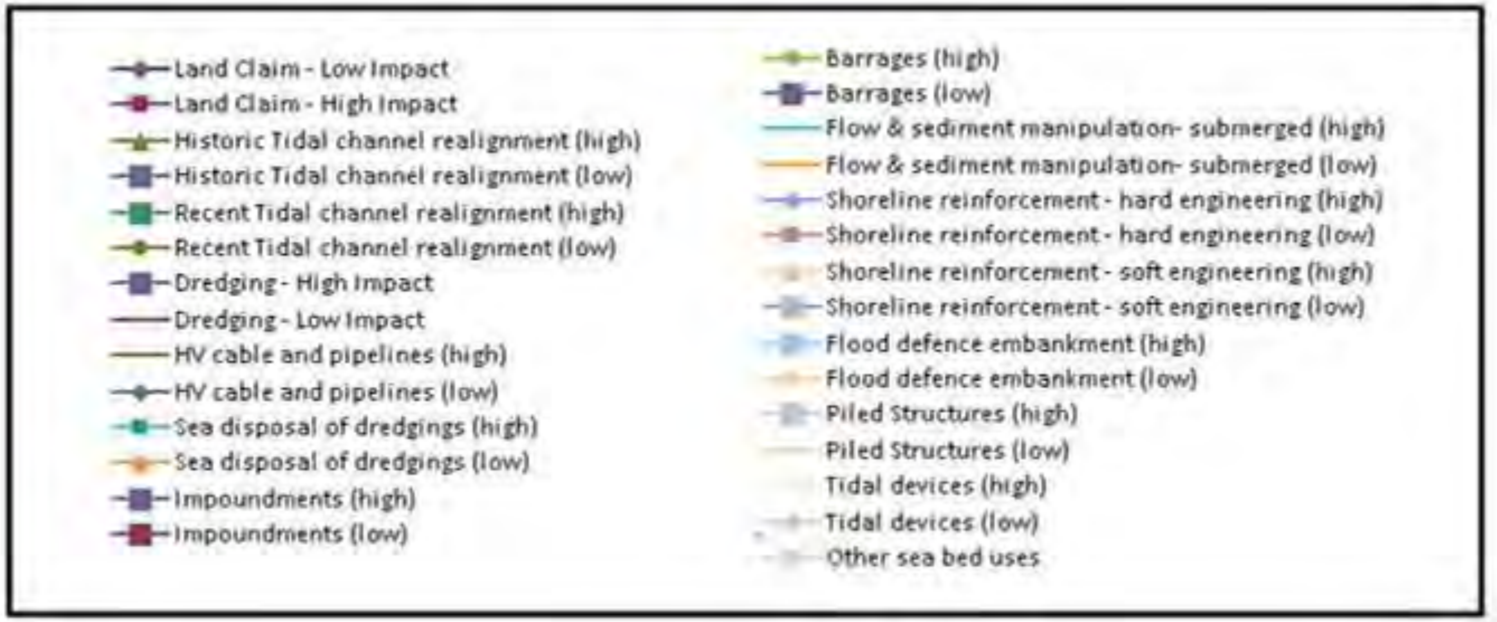


Figure 16 Summary of impact ratings - subtidal zone.



Key to impact ratings shown in Figures 16–18.

3.3 LIMITS ON INDIVIDUAL ACTIVITIES PRODUCED BY TraC-MImAS

Table 15 and 16 provide information on what the Morphological Condition Limits (Section 1.3) mean in real world terms. These values were created by running TraC-MImAS to determine how much of an individual morphological alteration can take place before the morphological condition limits for a particularly status boundary (high/good and good/moderate) are exceeded. This can be achieved by rearranging the equation on page 16 to determine the size of footprint for an individual alteration that would exceed a morphological condition limit. Examples of using MImAS to assess combination of alterations are provided in Section 3.4.

The values presented in the Tables 15 to 16 are not regulatory standards. They are provided to illustrate what 5% and 15% mean in terms of risk-based limits on morphological alterations. In regulation, TraC-MImAS would typically be used to assess how combinations of pressures interact to threaten status objectives. This information would inform where more detailed assessment work is required and where consideration of WFD exemption tests may be necessary.

The limits on individual activities are presented as ***percentage limits***

Percentage limits –These are spatially independent and apply equally to Stage 1 and Stage 2 assessments. For alterations primarily occurring in (or affecting) the hydrodynamic zone or the seabed (intertidal or subtidal), the limits are based on % area of seabed. For alterations primarily affecting the shoreline, the limits are based on % length of shore.

For a Stage 1 assessment, the percentage limits apply to assessment units described in Section 2.1.2. Rules for applying the MCLs to assess risk to water body status are currently being considered, and will form part of the trialling work. For the purposes of illustrating what the morphological condition limits mean in real terms, it should be assumed that the MCLs would be applied directly to a whole water body.

Guide to interpreting the information in Tables 15 and 16

Table 15 indicates that 26.67% high impact capital dredging can occur in a transitional water body before a risk to the High status boundary is identified. In a Stage 1 assessment ($0.5km^2$), this would mean that $0.133km^2$ (26.67% of $0.5km^2$) of dredging could occur before a local-scale risk to WFD objectives would be identified, and a stage 2 assessment undertaken. This assumes that there are no other pressures present within the stage 1 assessment unit. Importantly, this assessment does not consider site specific features of special importance. These would be assessed through other regulatory procedures- e.g. an assessment of risks to conservation objectives.

If an application for more than $0.15km^2$ of dredging was received, a Stage 2 assessment would be undertaken to determine if the water body was placed at risk. If the water body was $40km^2$ in size and no other pressures were present, $10.67km^2$ of dredging could occur before a risk to the High status objective is identified (26.67% of $40km^2$). If greater than $10.67km^2$ of dredging was proposed, a more detailed assessment would be undertaken, possibly including an EIA. A separate examination of whether the Ecological objectives of the water body are threatened may also be undertaken. Where it is demonstrated that the ecological objectives are threatened, a regulatory exemption test would be required to determine if the work should proceed on the basis of benefits to human health, human safety or sustainable development.

PERCENTAGE HIGH CLASS LIMITS FOR STAGE 1 ASSESSMENt (%)	Transitional	Transitional or coastal		Coastal		
				Sheltered	Mod-exposed	Shelt-exposed coast
Morphological Alteration	Meso-tidal	Lagoon	Sea loch	Sedimentary	Sedimentary	Bedrock
Land claim – high impact	13.33	21.82	20.00	20.00	10.91	35.56
Land claim – low impact	13.33	13.33	13.33	26.67	17.78	26.67
Historic tidal channel realignment – high impact	5.71	8.89	8.89	8.00	4.44	20.00
Historic tidal channel realignment – low impact	11.43	17.78	17.78	16.00	8.89	40.00
Recent tidal channel realignment – high impact	9.23	10.91	10.91	10.91	10.91	20.00
Recent tidal channel realignment – low impact	60.00	60.00	60.00	60.00	60.00	120.00
Dredging – high impact	26.67	26.67	26.67	53.33	53.33	53.33
Dredging – low impact	34.29	40.00	48.00	48.00	26.67	120.00
HV cable and pipelines – high impact	12.31	17.78	17.78	17.78	17.78	35.56
HV cable and pipelines – low impact	26.67	40.00	40.00	40.00	17.78	80.00
Use of dredged material – high impact	3.75	6.00	6.00	5.00	3.00	15.00
Use of dredged material – low impact	22.86	40.00	32.00	32.00	17.78	80.00
Impoundments – high impact	3.75	6.00	6.00	5.00	3.00	15.00
Impoundments – low impact	10.00	16.00	16.00	13.33	8.00	40.00
Barrages – high impact	8.00	10.00	10.00	11.43	6.67	20.00
Barrages – low impact	4.00	6.32	6.32	5.45	3.16	15.00
Flow and sediment manipulation, submerged – high impact	6.67	10.67	10.67	8.89	5.33	26.67
Flow and sediment manipulation, submerged – low impact	22.86	40.00	32.00	32.00	17.78	80.00
Shoreline reinforcement, hard engineering – high impact	5.71	8.89	8.89	8.00	4.44	20.00
Shoreline reinforcement, hard engineering – low impact	11.43	17.78	17.78	16.00	8.89	40.00
Shoreline reinforcement, soft engineering – high impact	8.00	10.91	10.91	10.91	6.15	20.00
Shoreline reinforcement, soft engineering – low impact	34.29	18.46	48.00	48.00	26.67	120.00
Flood defence embankment – high impact	17.14	26.67	26.67	24.00	13.33	60.00
Flood defence embankment – low impact	12.31	17.78	17.78	17.78	17.78	35.56
Piled structures – high impact	26.67	40.00	40.00	40.00	17.78	80.00
Piled structures – low impact	22.86	40.00	32.00	32.00	17.78	80.00
Tidal devices – high impact	3.75	6.00	6.00	5.00	3.00	15.00
Tidal devices – low impact	13.33	21.82	20.00	20.00	10.91	35.56
Other seabed uses	13.33	13.33	13.33	26.67	17.78	26.67

Table 15 Percentage high Class Limits for a Stage 1 assessment (%)

PERCENTAGE GOOD CLASS LIMITS FOR STAGE 1 ASSESSMENT (%)	Transitional	Transitional or coastal		Coastal		
				Sheltered	Mod-exposed	Shelt-exposed coast
Morphological Alteration	Meso-tidal	Lagoon	Sea loch	Sedimentary	Sedimentary	Bedrock
Land claim – high impact	40.0	65.5	60.0	60.0	32.7	106.7
Land claim – low impact	40.0	40.0	40.0	80.0	53.3	80.0
Historic tidal channel realignment – high impact	17.1	26.7	26.7	24.0	13.3	60.0
Historic tidal channel realignment – low impact	34.3	53.3	53.3	48.0	26.7	120.0
Recent tidal channel realignment – high impact	27.7	32.7	32.7	32.7	32.7	60.0
Recent tidal channel realignment – low impact	180.0	180.0	180.0	180.0	180.0	360.0
Dredging – high impact	80.0	80.0	80.0	160.0	160.0	160.0
Dredging – low impact	102.9	120.0	144.0	144.0	80.0	360.0
HV cable and pipelines – high impact	36.9	53.3	53.3	53.3	53.3	106.7
HV cable and pipelines – low impact	80.0	120.0	120.0	120.0	53.3	240.0
Use of dredged material – high impact	11.3	18.0	18.0	15.0	9.0	45.0
Use of dredged material – low impact	68.6	120.0	96.0	96.0	53.3	240.0
Impoundments – high impact	11.3	18.0	18.0	15.0	9.0	45.0
Impoundments – low impact	30.0	48.0	48.0	40.0	24.0	120.0
Barrages – high impact	24.0	30.0	30.0	34.3	20.0	60.0
Barrages – low impact	12.0	18.9	18.9	16.4	9.5	45.0
Flow and sediment manipulation, submerged – high impact	20.0	32.0	32.0	26.7	16.0	80.0
Flow and sediment manipulation, submerged – low impact	68.6	120.0	96.0	96.0	53.3	240.0
Shoreline reinforcement, hard engineering – high impact	17.1	26.7	26.7	24.0	13.3	60.0
Shoreline reinforcement, hard engineering – low impact	34.3	53.3	53.3	48.0	26.7	120.0
Shoreline reinforcement, soft engineering – high impact	24.0	32.7	32.7	32.7	18.5	60.0
Shoreline reinforcement, soft engineering – low impact	102.9	55.4	144.0	144.0	80.0	360.0
Flood defence embankment – high impact	20.0	32.0	32.0	26.7	16.0	80.0
Flood defence embankment – low impact	51.4	80.0	80.0	72.0	40.0	180.0
Piled structures – high impact	36.9	53.3	53.3	53.3	53.3	106.7
Piled structures – low impact	80.0	120.0	120.0	120.0	53.3	240.0
Tidal devices – high impact	11.3	18.0	18.0	15.0	9.0	45.0
Tidal devices – low impact	68.6	120.0	96.0	96.0	53.3	240.0
Other seabed uses	11.3	18.0	18.0	15.0	9.0	45.0

Table 16 Percentage good Class Limits for a Stage 1 assessment (%).

3.4 APPLICATION OF TraC-MImAS TO ASSESS COMBINATIONS OF PRESSURES

MImAS can also be applied to assess combinations of activities and determine whether these combinations exceed the defined morphological condition limits. Given the wide variety of different combinations of engineering activities and landscape pressures, it is not possible to provide an overview of all potential scenarios that these limits represent. To provide information on the use of TraC-MImAS to assess multiple applications a series of real-world case studies have been produced.

Each case study assesses a combination of activities through MImAS and determines whether this combination of activities would exceed the morphological condition limits. To carry out these assessments, data on footprints of the existing and proposed morphological alterations were input into the TraC-MImAS tool to calculate the capacity used. The examples include both stage 1 screening and stage 2 water body assessments. It should be recognised that the GIS data does not include exhaustive data on all pressures, thus the assessments may be underestimating impacts.

Case study 1 - Stage 1 assessment of existing morphological alterations.

Case studies 2 and 3 - Stage 1 (Local scale) assessment of existing morphological alterations and an assessment of a suite of proposed alterations. Proposed alterations are based on previous FEPA licenses.

Case studies 4 to 7 - Stage 2 (water body scale) assessments of existing morphological alterations

Case studies 7 to 9 - MImAS was also run on a selection of provisionally designated heavily modified water bodies as a check to see that the designations and MImAS results (case studies 7-9) were in agreement.

Case Study 1	Newburgh Quay, Ythan Estuary (WB ID 200113)
Water body Area	2.6 km^2
TraC Type	TW2 (Partly mixed or stratified, meso or polyhaline, mesotidal, intertidal or shallow subtidal, predominantly sand and mud).
	
MImAS Scale of Assessment	Stage 1. Preliminary assessment scale - 0.25 km^2 (red box)
MImAS Type	Transitional
Existing Alterations	
Quay (land claim)	0.01km^2
Zone	**Capacity Used**
Hydrodynamics	0.7% (Below 5% high status MCL)
Intertidal	1.9% (Below 5% high status MCL)
Subtidal	1.6% (Below 5% high status MCL)
Overall Status	**High**

The Ythan estuary is one of the least modified estuaries in Scotland with little evidence of industry apart from at the quay at Newburgh. The width of the estuary at this location is 0.35 km. The present degree of modification would be consistent with high ecological quality.

Case Study 2	**Port Bannatyne (WB ID 200030)**
Water body Area	24.3km^2
TraC Type	CW8 (Sheltered, meso-tidal)
	
MImAS Scale of Assessment	Stage 1. Preliminary assessment scale - 0.25 km^2 (red box)
MImAS Type	Coastal, sheltered, sedimentary
Existing modifications	
Existing jetty	0.002 km^2
Zone	**Capacity Used**
Hydrodynamics	0% (Below 5% high status MCL)
Intertidal	0% (Below 5% high status MCL)
Subtidal	0.1% (Below than 5% high status MCL)
Current Status	**Not at risk (High status)**
New modifications	
Proposed new pier	0.003 km^2
Proposed capital dredging	0.01 km^2
Zone	**Capacity Used**
Hydrodynamics	0.2% (Below 5% high status MCL)
Intertidal	1.6% (Below 5% high status MCL)
Subtidal	1.4% (Below 5% high status MCL)
Predicted Status	**Not at risk (High status)**

Port Bannatyne is located on the Isle of Bute and is located in the Rothesay water body in the Firth of Clyde. This stage 1 assessment is based on a FEPA licence application for the disposal of capital dredgings as part of a proposed marina development. The case study assesses the capacity used by existing modifications before assessing these in combination with the proposed engineering works. The capacity used by the existing jetty, and the proposed new pier and capital dredging would be consistent with high ecological quality and no further assessment would be required. However, if a new proposal were received that would exceed the 5% (high status) limit, a risk of a deterioration in status would be identified, and further assessment of the proposal to determine if the water body was at risk would be undertaken.

Case Study 3	**Don Estuary to Souter Head (Aberdeen) (WB ID 200105)**
Water body Area	50.2 km^2
TraC Type	CW5 (Moderately exposed, meso-tidal)
	
MImAS Scale of Assessment	Stage 1. Preliminary assessment scale - 0.25 km^2 (red box)
MImAS Type	Coastal, moderately exposed to exposed
Existing Modifications	
Hard shoreline reinforcement	0.5km
Groynes	0.5km
Zone	**Capacity Used**
Hydrodynamics	17% (Exceeds good stats MCL)
Intertidal	63% (Exceeds good stats MCL)
Subtidal	50% (Exceeds good stats MCL)
Current Status	**Less than good**
New Modifications	
Proposed beach nourishment	0.6 km
Proposed breakwaters	0.2 km
Zone	**Capacity Used**
Hydrodynamics	23% (Exceeds good stats MCL)
Intertidal	100% (Exceeds good stats MCL)
Subtidal	74% (Exceeds good stats MCL)
Predicted Status	**Less than good**

This case study is a stage 1 assessment based on a FEPA licence application to replenish the beach at Aberdeen. The intertidal area at Aberdeen beach has been subject to a large degree of modification in the past with installation of man made armour and a groyne field. Due to ongoing problems of coastal erosion it was proposed to replenish the beach with sediment dredged from the South Esk Estuary at Montrose. The works to stabilise the beach also included the installation of rock „t" head groynes. The existing modifications fail the preliminary assessment and therefore would require a stage 2 assessment at the water body scale.

Case Study 4	Peterhead (WB ID 200131)
Water body Area	$46km^2$
TraC Type	CW2 (Exposed, meso-tidal)
	
MImAS Scale of Assessment	Stage 2. Water body assessment scale
MImAS Type	Coastal, exposed, bedrock
Existing modifications	
Port and Harbour land claim	$0.5\ km^2$
Dredging	$0.1\ km^2$
Spoil Disposal	$0.6\ km^2$
Zone	**Capacity Used**
Hydrodynamics	0.1% (Below 5% high status MCL)
Intertidal	0.2% (Below 5% high status MCL)
Subtidal	0.2% (Below 5% high status MCL)
Overall Status	**High**

* Not all pressures picked up from GIS. Likely to be at High Status according to TraC MImAS.

This stage 2 assessment considers the existing modifications at Peterhead. The present degree of modification would be consistent with high ecological quality. However, if a new proposal were received that would exceed the 5% (high status) limit, a risk of a deterioration in status would be identified, and further assessment of the proposal to determine if the water body was at risk would be undertaken.

Case Study 5	**Lower Forth Estuary (WB ID 200435)**
Water body Area	38.6km^2
TraC Type	TW2 (Partly mixed or stratified, meso or polyhaline, mesotidal, intertidal or shallow subtidal, predominantly sand and mud).
	
MImAS Scale of Assessment	Stage 2. Water body assessment scale
MImAS Type	Transitional
Existing modifications	
Port and harbour land claim	1.5 km^2
Dredging	0.3 km^2
Bridges	6 large in channels supports
Zone	**Capacity Used**
Hydrodynamics	0.7% (Below 5% high status MCL)
Intertidal	2.5% (Below 5% high status MCL)
Subtidal	2 % (Below 5% high status MCL)
Overall Status	**High**

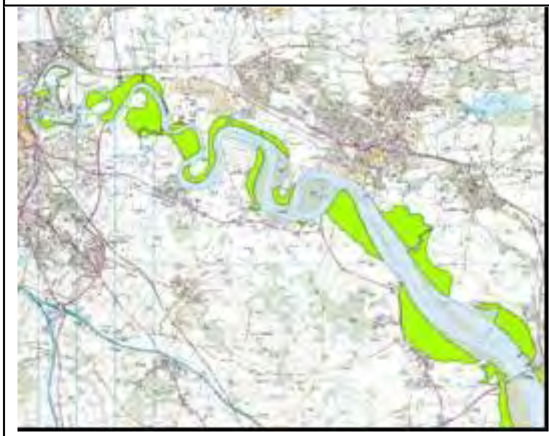
* Not all pressures picked up from GIS. Likely to be at High Status according to TraC MImAS.

The lower Forth Estuary consists of a straight channel with the Rosyth naval dockyard being the only area of significant land claim. Unlike the upper and middle Forth Estuary water bodies, this water body is not designated provisionally heavily modified. Based on the available information, this stage 2 water body assessment puts the overall status of the upper Forth at high status.

Case Study 6	**Montrose Basin (WB ID ~ 200079)**
Water body Area	8.5km^2
TraC Type	TW2 (Partly mixed or stratified, meso or polyhaline, mesotidal, intertidal or shallow subtidal, predominantly sand and mud).
	
MImAS Scale of Assessment	Stage 2. Water body assessment scale
MImAS Type	Transitional
Existing modifications	
Maintenance dredging	0.2 km^2
Bridges with piers	2.7 km
Agricultural land claim	0.2 km^2
Port and harbour land claim	0.4 km^2
Flood defence embankment	3.1km
Zone	**Capacity Used**
Hydrodynamics	1.8% (Below 5% high status MCL)
Intertidal	8.2% (Below 15% good status MCL
Subtidal	4.4% (Below 5% high status MCL)
Overall Status	**Good Status***

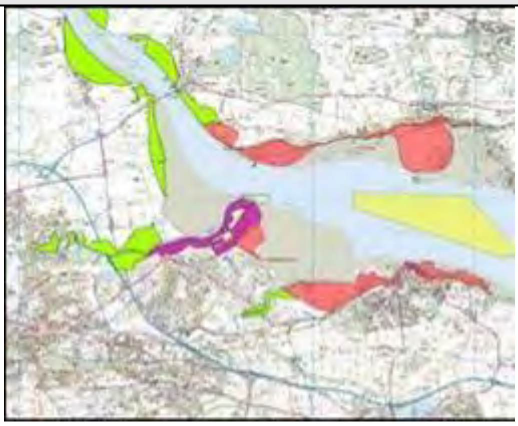
* Not all pressures picked up from GIS. Likely to be at Good Status according to TraC MImAS.

Montrose Basin is the estuary of the South Esk. There is land claim within the main basin and port and harbour development alongside the channel which drains the basin. This stage 2 water body assessment suggests that the basin is likely to be at good status.

Case Study 7	**Upper Forth Estuary (WB ID 200437) (Provisional heavily modified)**
Water body Area	9.7km^2
TraC Type	TW2 (Partly mixed or stratified, meso or polyhaline, mesotidal, intertidal or shallow subtidal, predominantly sand and mud).
	
MImAS Scale of Assessment	Stage 2. Water body assessment scale
MImAS Type	Transitional
Existing modifications	
Agricultural land claim	7.6 km^2
Zone	**Capacity Used**
Hydrodynamics	12% (Below good stats MCL)
Intertidal	34% (Exceeds good stats MCL)
Subtidal	29% (Exceeds good stats MCL)
Overall Status	**Less than good***

* Not all pressures picked up from GIS. Likely to be at less than Good Status according to TraC MImAS.

The upper Forth Estuary consists of a meandering channel fringed by significant areas of land claimed for agricultural purposes. Owing to these modifications the water body is designated provisionally heavily modified. A stage 2 assessment puts the status of the upper Forth at less than good status.

Case Study 8	**Middle Forth Estuary (WB ID 200436) Provisional Heavily Modified**
Water body Area	38.2km^2
TraC Type	TW2 (Partly mixed or stratified, meso or polyhaline, mesotidal, intertidal or shallow subtidal, predominantly sand and mud).
	
MImAS Scale of Assessment	Stage 2. Water body assessment scale
MImAS Type	Transitional
Exisitng modifications	
Agricultural land claim	3.2 km^2
Recent Industrial land claim	6.8 km^2
Dredging	0.4 km^2
Sea disposal	4.9 km^2
Zone	**Capacity Used**
Hydrodynamics	9% (below good stats MCL)
Intertidal	30% (Exceeds good stats MCL)
Subtidal	21% (Exceeds good stats MCL)
Overall Status	**Less than Good***

* Not all pressures picked up from GIS. Likely to be at less than Good Status according to TraC MImAS.

The middle Forth Estuary contains significant land claim for industrial and port and harbour purposes along with the Bo‟ness sea disposal site. Owing to these modifications the water body is designated provisionally heavily modified. A stage 2 assessment puts the status of the middle Forth at less than good status.

Case Study 9	**Inner Clyde Estuary (WB ID 200510)** **Provisional heavily modified**
Water body Area	4.4km^2
TraC Type	TW2 (Partly mixed or stratified, meso or polyhaline, mesotidal, intertidal or shallow subtidal, predominantly sand and mud).
	
MImAS Scale of Assessment	Stage 2. Water body assessment scale
MImAS Type	Transitional
Existing modifications	
Port and Harbour Land Claim	5.1 km^2
Dredging	0.5 km^2
Zone	**Capacity Used**
Hydrodynamics	18% (Exceeds good stats MCL)
Intertidal	54% (Exceeds good stats MCL)
Subtidal	45% (Exceeds good stats MCL)
Overall Status	**Less than Good**

The Inner Clyde has been extensively canalised in the past and contains extensive areas of land claim for port and harbour purposes. Owing to these modifications the water body is designated provisionally heavily modified. A stage 2 assessment puts the status of the Inner Clyde at less than good status.

SECTION 4

Conclusions

To help regulators quantify the risk that a new morphological alteration could impair achievement of the ecological objectives of the WFD, a series of „Morphological Condition Limits" (MCLs), and a tool to determine where these condition limits could be threatened (TraC-MImAS), have been developed.

Morphological condition limits- *Thresholds of alteration to morphological conditions beyond which there is a risk that the Ecological status objectives of the WFD could be threatened. The limits are expressed in percentage capacity.*

Morphological Condition Limits (MCLs) are intended to provide risk-based guidance to inform regulatory decisions. They would be used to complement existing regulatory methods and form part of a wider decision-making-process for managing TraC waters. Specifically, MCLs are intended to help regulators determine whether the Ecological Objectives of the WFD are threatened. This will inform where more detailed assessments are required, and where a regulatory exemption test may be required. Exemptions tests enable case specific consideration of benefits to human health, human safety or sustainable development.

Morphological condition limits have been defined for three TraC zones- hydrodynamic, inter-tidal and sub-tidal zone. Only MCLs for the High/Good and Good/Moderate boundaries are being considered at this time. The WFD requires regulators to manage for no deterioration in WFD status, and work is ongoing to define MCLs for other status boundaries.

In addition to using Morphological Condition Limits, regulators may use other criteria to determine if WFD objectives are threatened and whether a regulatory exemption would be necessary. This could include the use of formal Environmental Impact Assessments, other detailed assessment work and professional judgement.

A similar approach is already in use in Scotland (River-MImAS) and a Lake-MImAS tool is under development.

The TraC-MImAS tool and associated morphological condition limits are currently in draft form. A programme of field trialling and formal peer review will be undertaken over the summer of 2007. Based on the results of this work, a thorough review of the performance of the tool and morphological condition limits will be undertaken.

As many elements of TraC-MImAS tool are underpinned by professional judgment, it will be operated within an „adaptive management" framework. TraC-MImAS will be reviewed as new evidence on the relationships between ecology and hydromorphology become available. Where necessary, the tool will be updated. The ultimate aim will be to test/validate the assumptions underpinning the tools and, where necessary, replace professional judgment with empirically tested data

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APPENDIX 1

TraC MImAS: SUMMARY OF MODULES

2.1 REVIEW OF MODULES COMPRISING TraC-MImAS

The TraC-MImAS tool comprises five modules (Figure 19). Collectively the modules provide an assessment of impacts to morphological conditions. All impacts are measured in terms of impacts to „system capacity". Each module is designed to be semi-independent of the others, thereby allowing individual modules to be updated over time as more information becomes available. The modules are briefly described below.

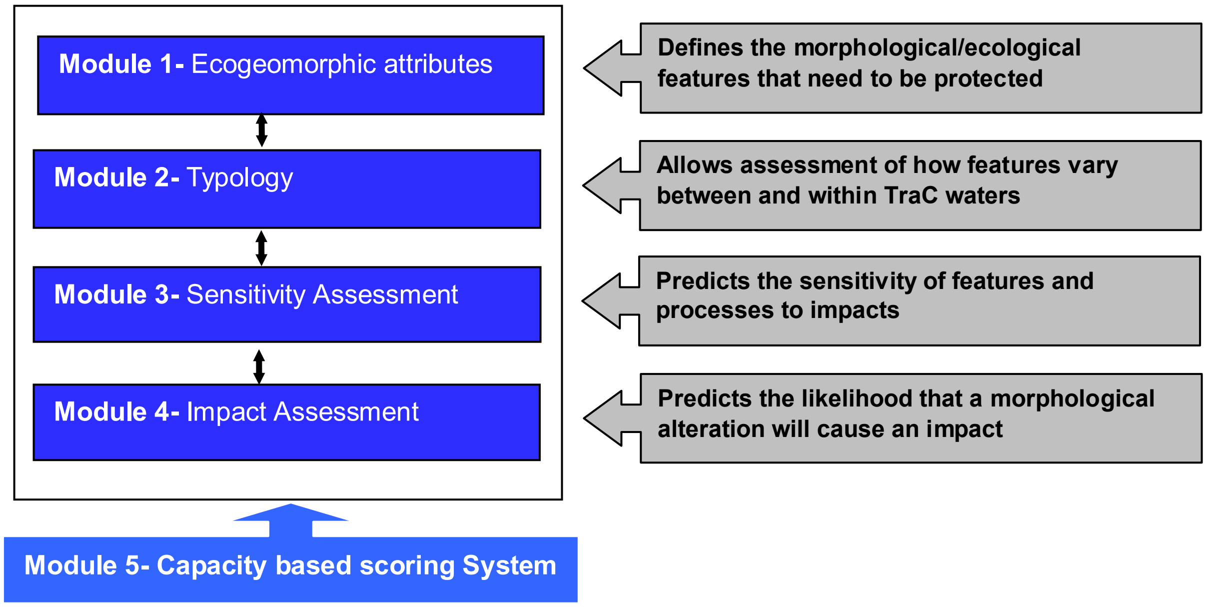

Figure 18 **Overview of the modular components of TraC-MImAS.**

Figure 20 provides a breakdown of stages involved in developing the modules comprising TraC-MImAS and the associated MCLs. Highlighted on the right of the diagram are those steps which have, or will, be subject to contributions from the technical panel, steering group and peer review. The iterative nature of the development process is vital to building consensus in the value of the approach and increasing confidence in the tool performance.

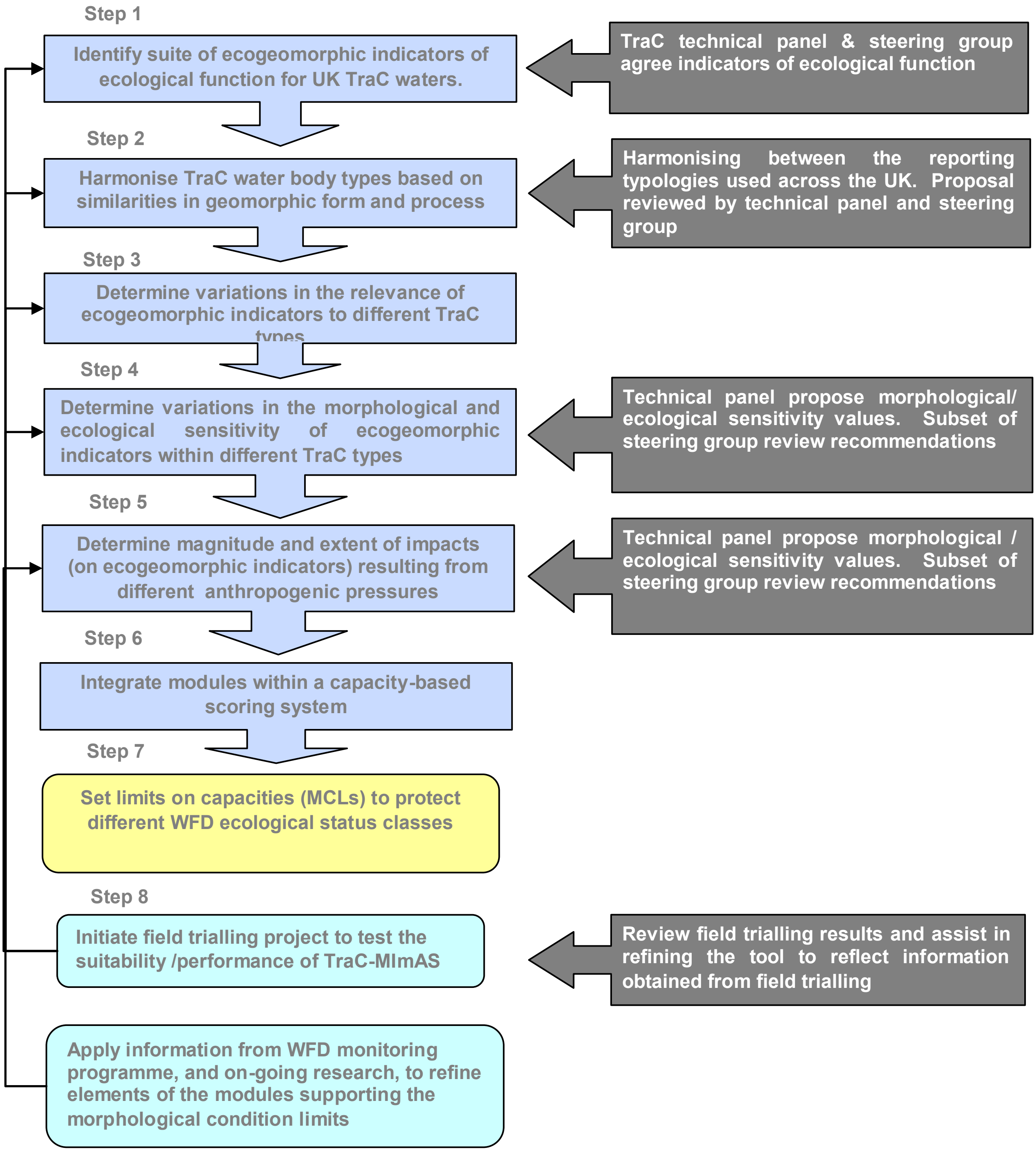

Figure 19 **Summary of steps involved in determining MCLs for UK TraC water bodies.**