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Academic Year: 2016 - 2017

Supervisor: Dr. Andrew B. Gill
December 2016

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ASSESSING HABITAT OUTCOMES OF FLOODPLAIN FOREST
RESTORATION: CASE STUDY AT THE OUSE VALLEY PARK

Supervisor: Dr. Andrew B. Gill
December 2016

This thesis is submitted in partial fulfilment of the requirements for
the degree of Doctor of Philosophy
***(NB. This section can be removed if the award of the degree is
based solely on examination of the thesis)***

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ABSTRACT

The research project for this PhD set out to provide a best practice example of bringing together industry (Hanson Heidelberg Cement Group), a charitable body (The Parks Trust), non-departmental public body (Environment Agency) and academia (Cranfield University). The Parks Trust (landowner) and Hanson (quarry operator) worked together with the vision of creating a new floodplain forest landscape along a 1 km reach of the River Great Ouse following extraction of gravels from the site. It was the first project of its kind in the United Kingdom where planning permission was obtained specifically for the creation of a floodplain forest habitats post quarrying. The aim of the PhD research was to determine appropriate ecological approaches to apply to the assessment and future monitoring of habitat outcomes of a floodplain forest restoration project at a mineral extraction site.

A central element of the research was the design of a scientifically justified monitoring programme, with key variables determined being: soil characteristics, water quality, vegetation development, site topography and water table level data. An Adaptive Monitoring Framework (AMF) was chosen to set the proposed monitoring within which was complemented with the hypothesis - *The ratio of wet/dry vegetation within the floodplain forest is determined by the site topography and water table level.* The hypothesis was tested by analysis of the key variables through fieldwork and existing data sources supplemented with a study of the water table level interaction with two typical floodplain forest tree species (*Salix viminalis* and *Populus trichocarpa x deltoides*) in a glasshouse experiment. Findings from the field and experimental research were then used within a spatially based landscape ecology scenario approach to identify the most suitable areas of the study site for specific species planting according to soil-water levels and topography in the floodplain forest. Outputs of this research enhance understanding of the key aspects to consider when assessing floodplain forest re-creation/restoration and enable guidelines and recommendations to be developed for land managers based on a long-term and an adaptive ecological monitoring approach. These management

guidelines and recommendations based on a systematic scientific approach applied within the research should be appropriate to other similar restoration projects. The research provides the background evidence on what should be measured to determine the environmental changes of the floodplain forest habitat restoration as it develops towards restoration success.

Keywords:

Water table level, topography, Adaptive Monitoring Framework (AMF), restoration success, landscape approach, novel ecosystem.

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“No eres lo que logras, eres lo que superas”

TABLE OF CONTENTS

ABSTRACT	i
ACKNOWLEDGEMENTS	iii
LIST OF FIGURES	viii
LIST OF TABLES	xii
LIST OF ABBREVIATIONS	xv
1 Introduction	1
1.1 Floodplains, floodplain forest and other wetted land- the current view	2
1.1.1 Ecosystem services and benefits provided by floodplain forests.....	4
1.1.2 Restoration practices for floodplains forests in recent years	6
1.1.3 The need for monitoring in floodplain forest projects	12
1.1.4 Restoration project success.....	13
1.2 Aim and objectives of the research project	23
1.2.1 Overall Aim	23
1.2.2 Objectives	23
1.3 Layout of the thesis	24
2 Literature review	27
2.1 What do floodplain forests need?	27
2.1.1 Water flows in a floodplain forest.....	27
2.2 Determining success of restoration projects: novel ecosystems.....	29
2.2.1 How to assess restoration success: main ecosystem attributes to consider	35
2.2.2 The link between hydrological processes and vegetation	38
2.3 Existing methodology for determining self-regeneration	42
2.3.1 Recruitment Box method for woodlands: cottonwoods and willows .	43
2.3.2 Sum Exceedence Values (SEVs): grasslands.....	46
2.3.3 Recruitment Box Method (RBM) vs. Sum Exceedence Value (SEV)	47
2.3.4 National Vegetation Classification	47
2.4 Restoration appraisal: monitoring approaches.....	48
2.4.1 Adaptive Monitoring Framework-hypothesis for uncertainty.....	49
2.4.2 Long-term monitoring.....	50
2.4.3 Successful long-term monitoring programmes	51
2.4.4 Long-term monitoring failure	52
2.5 Determining spatially relevant changes of land use and vegetation	52
3 Introduction to the field site	55
3.1 Floodplain forest site at Ouse Valley Park	55
3.1.1 Site History and background.....	55
3.1.2. Proposed Woodland mixes for the Floodplain forest at Ouse Valley Park.....	61

3.1.3. Existing data from within and in close proximity to the floodplain forest.....	65
3.2 Baseline data: key variables selection criteria.....	70
3.3 Adaptive Monitoring Framework.....	72
3.3.1 Proposed survey design	84
3.3.2 Proposed sampling locations and frequency of sampling.....	100
3.3.3 Final Survey Design.....	102
3.3.4 Field methods and baseline results for selected key variables.....	103
3.4 Discussion	122
4 Hydrological dynamics in the floodplain forest.....	127
4.1 Introduction.....	127
4.1.1 Response of floodplain forest tree species to different water table regimes examples.....	128
4.2 Methods: gathering hydrological data in the floodplain forest	130
4.3 Results	135
4.3.1 Discharge values at the River Great Ouse	135
4.3.2 Manual water table readings.....	136
4.3.3 Automatic loggers	138
4.3.4 Rainfall data at Ouse Valley Park.....	140
4.3.5 Drainage level assessment.....	140
4.4 Discussion	141
5 Glasshouse experiment	147
5.1 Introduction to the experiment: water level and plant response	147
5.1.1 Introduction to the pilot study.....	148
5.2 Methods.....	148
5.2.1 Methodology for setting up the pilot study	148
5.2.2 Glasshouse experiment	155
5.3 Results	162
5.3.1 Results of the initial pilot study	162
5.3.2 Results of the glasshouse experiment.....	164
5.4 Discussion	179
6 Landscape approach	183
6.1 Introduction.....	183
6.1.1 Landscape restoration approaches	184
6.1.2. Critic of previous work	189
6.1.3 Models used to represent spatio-temporal landscape variability	190
6.1.4 Key components for the landscape level representation: the case study of the floodplain forest.....	191
6.2 Methods.....	191
6.2.1 Data analysis	193
6.3 Results	195
6.4 Discussion	203

7 Discussion & Conclusion	207
7.1 Overview discussion.....	207
7.1.1 Assessing habitat outcomes in a dynamic ecosystem.....	209
7.1.2. The importance of habitats and species in the floodplain forest....	211
7.2 Monitoring programme	212
7.2.1 Examples of good management practices.....	213
7.2.2 Suggested steps for floodplain forest landscape managers	215
7.3 Advantages and disadvantages of the research project	218
7.4 Final conclusion.....	219
REFERENCES	223
Appendix A List of datasets that are of relevance to the study	257
Appendix B Data gathered within the floodplain forest in the past.....	259
Appendix C Birds and Fish spotted in the floodplain forest.....	261
Appendix D Elevation profile for the west-east transects.....	263
Appendix E Elevation profile for the north-south transects	268
Appendix F Soil Texture triangle for the samples collected in the floodplain forest.....	273
Appendix G Vegetation species expected in the floodplain forest (Street, 2002)	274
Appendix H The 3D image of the floodplain forest.....	280
Appendix I Contour line map of the floodplain forest	281
Appendix J Loggers fieldwork equipment and material inventory and description.....	282
Appendix K Shoot and root length outputs using ImageJ software for selected cuttings for leaf area and biomass in the glasshouse experiment	284
Appendix L Leaves area determination, binary images and outlines for selected cuttings in the glasshouse experiment	285
Appendix M Designed monitoring programme.....	294

LIST OF FIGURES

Figure 1-1 Substantial examples of floodplain forest in Great Britain	7
Figure 1-2 Map of remaining European floodplain forests based on data from United Nations Environment Programme-World Conservation Monitoring Centre	8
Figure 1-3 Thesis structure showing division of parts and chapters	26
Figure 2-1 The 'Recruitment Boxes' for riparian cottonwoods and willows.....	45
Figure 2-2 Sum Exceedence Value derivation from a hydrograph as generated by a hydrological model..	46
Figure 3-1. New created floodplain forest boundary at the Ouse Valley Park ..	56
Figure 3-2 Proposed planting areas of the floodplain forest..	59
Figure 3-3 Proposed access routes for the floodplain forest..	60
Figure 3-4 Floodplain forest proposal by Dave Southgate	64
Figure 3-5 The Adaptive Monitoring Framework	73
Figure 3-6 Proposed diagram showing the key variables and an indicative list of measurable parameters.	81
Figure 3-7 The hypothesised relationship between wet/dry vegetation versus elevation and water table level.....	83
Figure 3-8 Digital Elevation Model (DEM) in mAOD for the floodplain forest obtained through Kriging interpolation technique.....	87
Figure 3-9 Maps of errors in mAOD derived from the interpolated surface shown in Figure 3-8 by using kriging technique	88
Figure 3-10 Transects lines from west to east along the floodplain forest	90
Figure 3-11 Transects lines from north to south along the floodplain forest	91
Figure 3-12 (a) Box plot showing the elevation (m) ranges for the set of selected transects running from west to east. (b) Box plot showing the elevation (m) ranges running from north to south along the floodplain.....	93
Figure 3-13 Elevations points' distributed per strata.....	97
Figure 3-14 (a) Box plot representing elevation in the floodplain. (b) Histogram representing elevation points versus number of observations in the floodplain.....	99
Figure 3-15 Ortho-rectified aerial photo taken by UAV in 2013 and final environmental monitoring sampling points.	104

Figure 3-16 (a) Total Organic Carbon (TOC) (%). (b) Total Nitrogen (TN) (%). (c) Dry matter content (%). (d) Water content in soil (%). (e) Phosphorus soluble in sodium hydrogen carbonate solution (μ P). (f) mg/kg Potassium extractable. (g) mg/kg of Magnesium extractable. (h) Particle size distribution (%)	110
Figure 3-17 Invasive species Swamp stonecrop or New Zealand pigmyweed (<i>Crassula helmsii</i>).	112
Figure 3-18 Averaged monthly values of: Total Oxides of Nitrogen (TON) (mg N/l). (b) Conductivity (μ S). (c) pH. (d) Phosphorus (μ g/l). (e) Total Suspended Solids (TSS) mg/l of suspended material. (f) Phosphate-P (mg P/l). (g) Ammonium (mg N/l)..	119
Figure 3-19 Operator launching the UAV in December 2013.	121
Figure 3-20 Diagram showing the research components carried out in the floodplain forest case study and associated research.	126
Figure 4-1 Manual and automatic water table and barologger locations and coordinates.....	131
Figure 4-2 Data logger and dipwell tube	132
Figure 4-3 Levellogger model 3001.	134
Figure 4-4 Averaged discharge regime for 42 years (1969-2011) of the River Great Ouse at Newport Pagnell	136
Figure 4-5 Manual water table readings gathered in 9 locations	137
Figure 4-6 Relative water table values obtained automatically from 9 loggers.	139
Figure 4-7 Rainfall data (mm) vs. Water Table Depth (cm).	140
Figure 5-1 (a) Pots in compartment (b) Small Linux computer monitoring shoots and buds development of some pots in the compartment. (c) Unrooted <i>S. viminalis</i> and <i>P. trichocarpa x deltoides</i> shoot development.....	150
Figure 5-2 (a) Picture of cuttings taken by the small Linux computer out of the compartment in the glasshouse (b) Unrooted <i>P. trichocarpa x deltoides</i>	151
Figure 5-3 Example of photograph used for leaf area determination with <i>S. viminalis</i> leaves	153
Figure 5-4 Image converted to Binary with <i>S. viminalis</i> leaves.....	154
Figure 5-5 'Show Outline' output with <i>S. viminalis</i> leaves. Note red numbers are the polygon numbers listed in the 'show results'	155
Figure 5-6 Water-table depth systems: A-Flooded, B-Wet and C-Dry	158

Figure 5-7 Nigel Janes (Water technician at Cranfield University) selects randomly one cutting for root washing at the glasshouse facilities in the 4 th week of cuttings growth.....	159
Figure 5-8 Root length determination using ImageJ with number 145 <i>S. viminalis</i> shoot with C-Dry water treatment in the glasshouse experiment	160
Figure 5-9 Outputs gathered from 1 st -16 th March 2014. (a) Ambient temperature (°C): from 1 st to the 10 th of March 2014 internal temperature displayed in red (under the plastic sheet) and external temperature displayed in blue (in the glasshouse facilities). (b) Relative humidity (%). (c) Relative light values. (d) Small Linux computer.....	162
Figure 5-10 Cuttings growth status on the 6 th week of glasshouse experiment	165
Figure 5-11 Root biomass (g) of <i>P. trichocarpa x deltoides</i> and <i>S. viminalis</i> with three different water treatments: A-Flooded, B-Wet and C-Dry	168
Figure 5-12 Wet leaves biomass (g) of <i>P. trichocarpa x deltoides</i> and <i>S. viminalis</i> with three different water treatments: A-Flooded, B-Wet and C-Dry.....	169
Figure 5-13 Dry leaves biomass (g) of <i>P. trichocarpa x deltoides</i> and <i>S. viminalis</i> with three different water treatments: A-Flooded, B-Wet and C-Dry.....	171
Figure 5-14 (a) Root biomass (g) of Poplar (<i>P. trichocarpa x deltoides</i>) with three different water treatments over time. (b) Root biomass (g) of Willow (<i>S. viminalis</i>) with three different water treatments over time.	172
Figure 5-15 (a) Wet leaves biomass (g) of Poplar (<i>P. trichocarpa x deltoides</i>) with three different water treatments over time. (b) Wet leaves biomass (g) of Willow (<i>S. viminalis</i>) with three different water treatments over time...	174
Figure 5-16 (a) Dry leaves biomass (g) of Poplar (<i>P. trichocarpa x deltoides</i>) with three different water treatments over time. (b) Dry leaves biomass (g) of Willow (<i>S. viminalis</i>) with three different water treatments over time...	175
Figure 6-1 Model diagram of how a water body is created	194
Figure 6-2 Landscape category coverage (%)......	195
Figure 6-3 Landscape category coverage (mAOD) in the floodplain forest for June 2013.	197
Figure 6-4 Landscape category coverage (mAOD) in the floodplain forest for October 2013.	198
Figure 6-5 Landscape category coverage (mAOD) in the floodplain forest for January 2014.	199

Figure 6-6 Landscape category coverage (mAOD) in the floodplain forest for April 2014.....	200
Figure 6-7 Landscape category coverage (mAOD) in the floodplain forest for June 2014.	201
Figure 6-8 Landscape category coverage (mAOD) in the floodplain forest for October 2014.	202

LIST OF TABLES

Table 1-1 Ongoing sites involving habitat creation and restoration after quarry works in Great Britain.....	17
Table 3-1 Proposed Habitat Woodland types of the floodplain forest.....	62
Table 3-2 Number of records per database or studies within and in close proximity to the floodplain forest study area.....	66
Table 3-3 Samples type inherent in any monitoring framework.....	72
Table 3-4 Proposed parameters and methods.	75
Table 3-5 Justification per measurable parameters as part of the monitoring framework designed in context of the Adaptive Monitoring Framework.....	78
Table 3-6 Information per stratum in the floodplain forest in 2012.....	96
Table 3-7 Proposed number of sample size per stratum and frequency (sampling time) per key variables in the monitoring framework proposed for the 50 ha..	101
Table 3-8 Sampling points sampled in some areas of the floodplain forest and frequency per key variables in the monitoring framework after site constraints.....	103
Table 3-9 Particle Size Distribution (%)	107
Table 3-10 Inventory of species identified 17 th of June 2013.....	111
Table 3-11 TON (mg/l of suspended material) per sampling point and date ..	114
Table 3-12 Conductivity (µS) values per sampling point and date.....	114
Table 3-13 pH values per sampling point and date	115
Table 3-14 Phosphorus (µg/l) per sampling point and date.....	116
Table 3-15 TSS (mg/l of suspended material) per sampling point and date...	116
Table 3-16 Phosphate-P (mg P/l) values per sampling point and date.....	117
Table 3-17 Ammonium (mg N/l) values per sampling point and date	118
Table 4-1 Data loggers and barologger characteristics	133
Table 5-1 Pilot study root washing and leaf area and leaf biomass events	151
Table 5-2 Glasshouse experiment calendar time	157
Table 5-3 Score values for leaves and roots ranking system	161
Table 5-4 Final scored (S) classification for cuttings.	161
Table 5-5 Pilot study results.....	163

Table 5-6 Leaves outputs using ImageJ software for selected cuttings for leaf area and leaf biomass in the glasshouse experiment.	165
Table 5-7 ANOVA results for root biomass (g)	168
Table 5-8 ANOVA results for wet leaves biomass (g).....	170
Table 5-9 ANOVA results for dry leaf biomass (g).....	171
Table 5-10 rANOVA results for root biomass (g)	173
Table 5-11 rANOVA results for wet leaf biomass (g)	174
Table 5-12 rANOVA results for dry leaf biomass (g).....	176
Table 5-13 Ranking/scoring system to classify <i>P. trichocarpa</i> x <i>deltoides</i> and <i>S. viminalis</i> cuttings status..	176
Table 7-1 Suggested steps and its applicability to the floodplain forest case study as an example	215

LIST OF ABBREVIATIONS

A	Flooded water table treatment
ADCP	Acoustic Doppler Current Profiler
AMF	Adaptive Monitoring Framework
ANOVA	Analysis of Variance
ARBOR	Answer for Restoring the Bank of the River
ATTZ	Aquatic/Terrestrial Transition Zone
B	Wet water table treatment
BAP	Biodiversity Action Plan
C	Dry water table treatment
CASiMIR	Computed Aided Simulation Model for In-Stream flow & Riparia
CT	Computed Tomography
CU	Cranfield University
DEFRA	Department for Environment, Food and Rural Affairs
DEM	Digital Elevation Model
DM&S	Digital Mapping & Survey
DTC	Decision Tree Classification
EA	Environment Agency
EHS	Ecological Habitat Survey
EQR	Ecological Quality Ratio
FPC	Flood Pulse Concept
GIS	Geographic Information Systems
GQH	General Quality Assessment
HAP	Habitat Action Plan
HBEF	Hubbard Brook Experimental Forest
H-DEM	Huston's Dynamic-Equilibrium Model
HQA	Habitat Quality Assessment
HMS	Habitat Modification Score
IAMs	Integrated Assessment Models
IDW	Inverse Distance Weighted
MA	Millenium Ecosystem Assessment
MAFF	Ministry for Agriculture, Fisheries and Forestry
mAOD	Metres Above Ordnance Datum
NAM	Nature After Minerals
NFPD	National Fish Population Data
NGO	Non-Governmental Organization
NNR	National Nature Reserve
NVC	National Vegetation Classification

P	Poplar cutting
PIM	Planning, Implementing and Monitoring principle
PRAGMO	Practical River Restoration Appraisal Guidance for Monitoring Options
rANOVA	Repeated Measures Analysis of Variance
RBM	Recruitment Box Method
RCC	River Continuum Concept
RE	River Ecosystem
RHS	River Habitat Survey
RRC	River Restoration Centre
RSPB	Royal Society for the Protection of Birds
SAP	Species Action Plan
SCOPE	Scientific Committee On Problems of the Environment
SER	Society for Ecological Restoration
SEVs	Sum of Exceedance Values
SM	Scenario Modelling
SMRRT	Simple, Measurable, Reliable, Relevant, Timely
TIN	Triangulated Irregular Network
TOC	Total Organic Carbon
TON	Total Oxides of Nitrogen
TPT	The Parks Trust
TSS	Total Suspended Solids
UAV	Unmanned Aerial Vehicle
UK	United Kingdom
UK-BAP	United Kingdom Biodiversity Action Plan
UK-NEA	United Kingdom National Ecosystem Assessment
UNEP- WCMC	United Nations Environment Programme- World Conservation Monitoring Centre
USFWS	United States Fish & Wildlife Service
W	Willow cutting
WFL	Water Fluctuations Level
WTD	Water Table Depth

1 Introduction

Climate change has been linked to significant alterations to the hydrological dynamics within our landscapes in the form of increased flooding, storms and droughts that cost those affected an estimated 70 billion US\$ per year (OECD, 2003). To study how flows and flooding affect the landscape it is necessary to understand the interactions between land use and soils, surface permeability, water levels and the hydrological cycle (Reynard *et al.* 2005).

Floodplain forests and wetlands are considered as appropriate for an adapted management approach to flood risk. Floodplains distribute contemporary floodwaters, providing significant relief that may result in standing (lentic) or flowing (lotic) water in wet environments (Lewin & Ashworth, 2013). Playing a vital role in channel hydraulics, sediment transport and nutrient filtration (Naiman & Decamps, 1997), floodplain forests also provide habitat, corridors and refugia for numerous species of flora and fauna (Kath *et al.* 2014). Floodplains are important when considering flooding particularly in the future yet they have been degraded so there is a need to reintroduce floodplain systems and to understand the outcomes of trying to bring them back (as in the case study of using floodplain forests). However, the durability and efficiency of flood risk management is reliant upon suitable adaptation to an uncertain future (OECD 2003; Kuklicke & Demeritt, 2016; Smit *et al.* 2000). The degradation of floodplains has been linked to perturbations in biophysical function (Jurskis, 2005), canopy condition (i.e. leaf mortality and branch dieback, Cunningham *et al.* 2011), biodiversity (Horner *et al.* 2009; Elmore *et al.* 2006) (Cooper *et al.* 2003). Floodplain degradation is connected to the rapid decay in freshwater biodiversity; the principal reasons for this outcome are species invasion, habitat alteration, pollution, flow and flood control. In Europe, floodplain forests are considered to be among the most threatened natural ecosystems, listed in Annexe I of the European Habitats Directive as being a “priority forest habitat type” (Hughes, 2003). The focus of this study is to identify, review and evaluate the key variables determining the wetted habitat and landscape of a recreated floodplain forest to restore typical features and enable future management.

1.1 Floodplains, floodplain forest and other wetted land- the current view

Floodplains are generally defined as “areas that are periodically inundated by the lateral overflow of rivers and lakes, and/or by direct precipitation or groundwater; the resulting physicochemical environment causes the biota to respond by morphological, anatomical, physiological, phenological, and/or ethological adaptations, and produce characteristic community structures” Junk *et al.* (1989).

Floodplain forests are included within the eight broad habitat types assessed in the UK- National Ecosystem Assessment (UK-NEA, 2011). They are inhabited by a wide variety of species and provide unique linear landscapes, which have high species diversity and are highly productive. Floodplains do not constitute a single habitat type, but may be composed of wet woodland, wet grassland or other habitats, and are, in many cases, a mosaic of habitat types (Acreman *et al.* 2011).

However, other areas of land are inundated at some point in the year, hence there are a variety of definitions and classifications of floodplains and wetlands. For instance, UK-NEA (2011) defines wetland as areas of marsh, fen, peatland, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres. UK-NEA considers floodplains (natural or managed) as a wetland type and at the same time classify wetland habitat into coastal and floodplain grazing marsh (i.e. periodically inundated grassland occurring over flat areas of floodplains and the most studies of their Wetland systems), fen, lowland raised bog and reedbed (the second most studied Wetland system after floodplains). According to Lewis (1990), wetlands contain areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support a prevalence of vegetation typically adapted for all life in saturated soil conditions. Other authors, such as Craft & Casey (2000) distinguish between floodplain wetland and depressional wetland types in the study of sediment and nutrient

accumulation in Georgia (USA). According to these definitions, floodplain forests and wetland ecosystems are developed in saturated or inundated conditions with or without an associated river or lake and support vegetation adapted to waterlogged conditions.

Floodplain forests have significantly declined in extent due to agricultural practices, anthropogenic activities, levee and dam construction and urban development. As floodplain forests represent a unique habitat, losses and variations in habitat attributes could pose severe problems for wildlife, particularly birds that rely upon these habitats. There is a primary need to restore and preserve aquatic and riparian habitats while the opportunity to do so still remains. Floodplain forest degradation is closely connected to the decline in freshwater biodiversity, the principal reasons for which are habitat alteration, flow and flood control, species invasion and pollution. The need to preserve floodplain forests and to restore hydrological dynamics and riparian vegetation communities is critical. Otherwise, extinction of aquatic and riparian species can be expected within the coming years. In addition, floodplains are the most species-rich environments known (Ward *et al.* 1999) and the water bodies generated within them create a wide variety of species at different successional stages, thereby forming habitat mosaics throughout the floodplain forest.

Floodplain forests present a special type of opportunity for research, representing a single, clearly defined habitat type in contrast to the other types of wetted land, so from a management perspective there is a clear target of the type of habitat characteristics that are being aimed at in the PhD research that is the subject of this thesis. Also, there are very few opportunities to study such a site (i.e. real case study), giving the chance to assess habitat structure through succession and hydrological preferences in a newly created ecosystem.

For the PhD research the focus was on the floodplain forest ecosystem of a proposed floodplain forest at Manor Farm in Ouse Valley Park (Old Wolverton, Milton Keynes, United Kingdom) (SP 80635 42135), which was planned

following extraction of gravels from the site and was being used as rough pasture for occasional livestock grazing. The case study on which this PhD research was focussed worked within this context and is regarded as an example of best practice of bringing industry (Hanson), conservation NGOs (The Parks Trust), non-departmental public body (Environment Agency) and academia (Cranfield University) together to assess habitat outcomes within a newly created site which would assist in flood management and enhance biodiversity. It is also considered as the first floodplain forest project of its kind in the United Kingdom (River Restoration Centre, 2007) where a floodplain forest (owned by The Parks Trust (TPT)) was newly created following gravel extraction by Hanson. The field site, its historical and existing status plus an outline of the planned site management are further described in Chapter 3.

1.1.1 Ecosystem services and benefits provided by floodplain forests

Wet woodland occurs on poorly drained or seasonally wet soils, usually with alder (*Alnus sp.*), poplar (*Populus sp.*), birch (*Betula sp.*) and willows (*Salix sp.*) as the predominant tree species, but sometimes including ash (*Fraxinus sp.*), oak (*Quercus sp.*), pine (*Pinus sp.*) and beech (*Fagus sp.*) on the drier riparian areas; it is found on floodplains, as successional habitat on fens, mires and bogs, along streams and hill-side flushes, and in peaty hollows (UK- Biodiversity Action Plan, 2008). Baker *et al.* (2009) discussed that the presence of wet woodland can significantly increase the hydraulic roughness of a floodplain when compared to alternative land uses.

Floodplains in general transport water, organic matter and organisms within and between riparian zones. The key floodplain forest ecosystem services as defined by the Millennium Ecosystem Assessment (MA) (Carpenter *et al.* 2009) are: provisioning, cultural, regulating and supporting services. The main provisioning services are food, direct use of water, crops, livestock, farming of dairy, beef and sheep products, fibre, peat, navigation, bioenergy and health products. Properly managed livestock grazing in floodplain forests may help to reduce fire hazards by controlling the amount and distribution of grasses and

other potential sources of fuel. Livestock grazing also has benefits to plant life and wildlife.

In a floodplain forest there could be mixed open grasslands and woodlands that are generally dominated by non-native and/or invasive annual grasses and herbs. Controlled grazing may help to reduce non-native and/or invasive grasses proliferation. Sometimes vegetation communities, under lack of management, may tend to discourage the germination and growth of native plants by using up most of the available water and nutrient resources in the soil and by producing large amounts of thatch. Livestock grazing helps to control the growth of the non-native species so that other desirable plants (native species) can regenerate successfully and coexist in a floodplain forest. Many species may require grazing in order to maintain viable populations. Regarding the benefits to wildlife, well-managed livestock grazing raises the diversity of habitats accessible to wildlife species. Some species may benefit from the vegetation management performed by livestock. In addition, these types of forested ecosystems are recognised as providing a wide range of ecosystem services, both consumptive and non-consumptive, such as food, conservation and recreation and can also contribute to flooding regulation, erosion and sedimentation control and determining water quality, while removing pollutants (UK-NEA, 2011).

Examples of regulating services are climate regulation, water regulation, water quality regulation, flood regulation and fire hazard regulation; cultural service examples are recreation and tourism, aesthetic values, cultural heritage, spiritual values, education and health benefits (Brown *et al.* 2011). Other important services provided include floodwater storage, groundwater recharge, timber production and pollution control (Hughes, 2003). The ecosystem services delivered by floodplains are inextricably linked to hydrology (Morris *et al.*, 2009). The hydrological regime of a floodplain determines what will grow there and how it can be used (Posthumus *et al.* 2010).

Wherever they occur, floodplain forests provide value for wildlife. Peterken and Hughes (1995) state that flood disturbance generates a variety of land forms,

which in turn allow a variety of woodland types to co-exist with a mosaic of open vegetation; the disturbance itself helps to maintain a range of successional stages.

This section has highlighted the ecosystem services and the benefits obtained from the presence of a floodplain forest. There are however, few examples of floodplain forest projects being created particularly following gravel extraction. The case study for this PhD represented a unique opportunity in Great Britain to address some of the knowledge gaps in assessing and understanding change in these valuable ecosystems.

1.1.2 Restoration practices for floodplains forests in recent years

Floodplain forests are limited in extent. In England the only substantial examples of appear to be the strips of “Ancient and Ornamental” Woodland, which line the Beaulieu River and Highland Water in the New Forest (McVean, 1956, Tubbs, 1986, Gregory, 1992 cited in Peterken and Hughes, 1995) and Skipton in North Yorkshire. In Scotland the most extensive floodplain forests lie along the lower reaches of the river Spey (Lewin and Weir, 1977) that drains a large and relatively wild catchment in northeast Scotland and remains strongly braided for 3 km above its mouth (Figure 1-1).

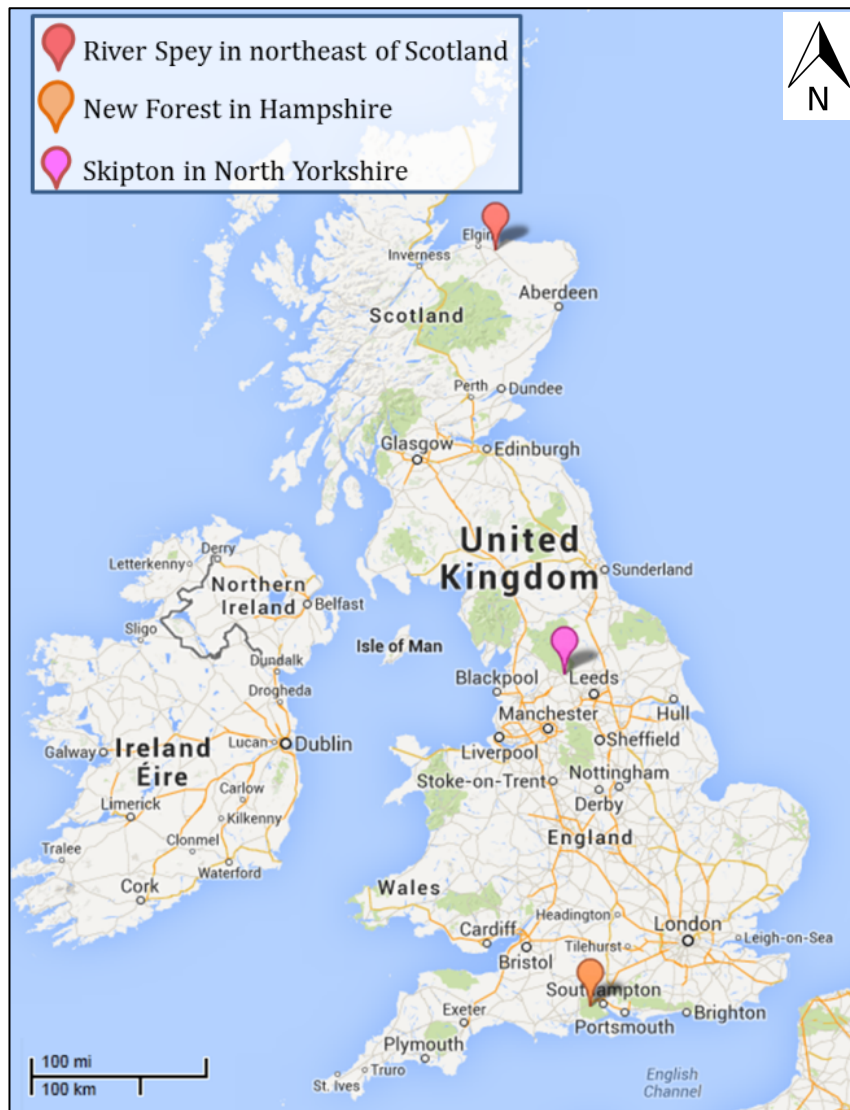


Figure 1-1 Substantial examples of floodplain forest in Great Britain.

Figure 1-2 shows the remaining European floodplain forests highlighting alluvial and moist lowland forests including Mediterranean wet lowland and alluvial forests and scrub (based on UNEP-WCMC, 2000 and Girel *et al.*, 2003). The other obvious fact is that floodplain forests are today rarely found right across Europe (Figure 1-2), however historically their occurrence was much more widespread. The large rivers of Europe were characterised by islands but over the period of major human interference, many have become dominated by incision and narrowing so that they are now characterised by single-thread and relatively simple channel forms (Gurnell & Petts, 2002).



Figure 1-2 Map of remaining European floodplain forests based on data from United Nations Environment Programme-World Conservation Monitoring Centre (UNEP-WCMC) (2000) and Girel *et al.*, (2003). The nature park Kopački Rit of the Danube and Drava Rivers in north-eastern Croatia, Rheinvorland-Sud on the upper Rhine (Germany), the Bourret on the Garonne (France), the Lenzen on the Elbe in Brandenburg (Germany), La Basse on the Seine (France) are some examples of existing floodplain forests in Europe.

Owing to the decline of floodplains forests worldwide primarily as a result of changing hydrology (Tockner & Stanford, 2002), habitat restoration schemes have been proposed and developed. Some of the requirements for the restoration of floodplain woodlands can be delivered through site and reach scale restoration projects with reasonably predictable ecological outcomes (Hughes *et al.* 2001).

Regarding current levels of restoration and restoration practices, the creation of “new” floodplain channels is one of the common restoration techniques used to reconnect main-stem and floodplain habitats and it is a form of habitat enhancement that involves active construction of new floodplain channels (Pess *et al.* 2005). There are examples of floodplain forest restoration projects worldwide with similar goals of implementing restoration practices in floodplain forests. For instance, La Grange Reach of the Illinois River (USA), in the middle sub reach, contains the 2 ha (i.e. 5,400 acres) Emiquon Floodplain Restoration Project Site. This was an agricultural drainage and levee district purchased by the Nature Conservancy (Sparks and Braden, 2007), where they are assessing the managed connection to the river as a preferred option. The stakeholders involved in this project expect to use the lessons from the Emiquon Restoration as a model for other floodplain restoration projects. The key lessons were that when they put the effort to restore the wetland by planting native trees, spreading grassland seeds and connection to the river, a natural ecosystem returned to life.

The Lilly ARBOR (Answer for Restoring the Bank Of the River) Project was a 20 ha floodplain forest restoration experiment along the White River in downtown Indianapolis (USA) that produced effective methods of restoring river margins and improving water quality in central Indiana; the project looked mainly at the potential use of advanced monitoring technologies to understand better water management and quality. The ARBOR project demonstrated that the long-term effect of increased awareness through education and environmental activities will help to combat pollution while improving water quality and the environment overall (Tedesco and Salazar, 2006). This example reflects the importance of

setting objective frameworks, creating awareness through education and of the guarantee of fluent communication between stakeholders before starting a restoration project. For the current research project, sharing information of the floodplain forest with local users and between stakeholders was identified as crucial early in the plans and provided the rationale of why restoring a floodplain forest (managed or unmanaged) was important.

The Long Eau River project in Manby (Lincolnshire, Great Britain) combined 16 ha of floodplain restoration with river channel enhancement and marginal habitat creation (River Restoration Centre, 2014). This example demonstrated improved flood protection performance through a process of relocating flood banks that were previously located along the riverbank. Three sites were chosen along the river and at each site the flood bank was removed and a flood storage area created on adjacent land. It could serve as a reference for creating flood storage areas in floodplain forests to alleviate floods and increase flood protection.

The Ewijk floodplain along the Waal River (Rhine branch) in the Netherlands is an example of how natural succession of an artificially created pioneer condition can result in a heterogeneous floodplain and reforested landscape (Geerling *et al.* 2013, cited in Maddock *et al.* 2013, p. 401). This case study proves that natural succession along with successful regeneration is possible in ecosystems that have been altered or disturbed somehow (i.e. artificial ecosystem, quarry works etc.).

These four examples show the importance placed on the ecological restoration of the associated floodplain and may be used as lessons for further applications on similar restoration projects. Kauffman *et al.* (1997) state that “Ecological restoration” is the re-establishment of processes, functions, and related biological, chemical, and physical linkages between the aquatic and associated riparian ecosystems; it is the repairing of damage caused by human activities. Examples described above talk about implementing restoration practices in floodplain forests restoration sites worldwide. Different practices have been employed, such as river channel enhancement, natural succession

and potential advanced monitoring in order to achieve similar restorations goals. However, the reason behind their restoration efforts is scarce and in some cases appears biased. The examples have relied on ecological restoration literature and contribute to the knowledge (i.e. build the overall picture regarding what can be done to restore a floodplain forest) of different floodplain forest restoration practices carried out wide-ranging, but there is a lack of standard practice or guidance.

Standards are needed because progress in the science and practice of river restoration has been hampered by the lack of agreed upon criteria for judging ecological success (Palmer *et al.* 2005). The lack of well-accepted and supported funding criteria does not give any incentive to restoration practitioners to assess restoration habitat outcomes. It would be beneficial to provide frameworks or standards by improving methods available and by measuring the ecosystem services of various restorative approaches, although this would require organized national-level reporting systems. Restoration projects plan to maintain or raise ecosystem services provided while protecting river-floodplain systems. There is a growing interest in applying restoration techniques to alleviate environmental problems, although there is still little agreement on what constitutes a successful restoration effort. There is also an important need to ensure that the monitoring and/or framework of a restoration scheme are robust enough to meet the aims of the project or its potential applicability to similar restoration projects.

A call is desirable to move to a clearer and more systematic approach to habitat restoration that considers appropriate goals linked to target species or suites of species, as well as the ecological, financial, and social constraints on what is possible (Miller and Hobbs, 2007). The approach selected is not one that fits all. Nevertheless generic questions can be included in the process of deciding which restoration management practices are important and contribute most to the re-establishment of desirable habitat communities within a given case study. This is the overall approach that set the context for the PhD research in the floodplain forest at Ouse Valley Park.

1.1.3 The need for monitoring in floodplain forest projects

Floodplain forests are highly dependent on the hydrology of the site that they grow on. Water tables provide the conditions for floodplain forest species seedlings to propagate and contribute to the woodland community establishment. The associated rivers to the floodplain forest play an important role in defining different flow levels and creating the suitable hydrological conditions for regeneration and for the propagules material to disperse.

Some species can however take a long time to develop by natural regeneration, and may need longer periods of time to settle or require some form of management assistance. In all of this it is essential to have an appropriate knowledge base where floodplain forest surveying and monitoring play a crucial role.

In terms of monitoring changes within a floodplain forest site, there will be differences depending on the variable(s) being monitored. Floodplains in general have been well studied and a number of lessons can be taken from these studies. For instance, Baxendale *et al.* (2014) used a plant trait-based approach to understand differential plant species responses to plant-soil feedbacks, especially in mixed-species environment; as a conclusion, soils conditioned by the fast-growing community had higher nitrogen availability than those conditioned by the slow-growing community. The study carried out by Ryser and Lambers (1995) was aimed at establishing which attributes determine the performance of slow growing grass *Brachypodium pinnatum* and the fast growing *Dactylus glomerata* grass under different N and P availabilities; they concluded low biomass of *D. Glomerata* is the pivotal trait responsible for its faster growth whereas the high biomass of *B. Pinnatum* resulted in a lower nutrient requirement due to a slower turnover (i.e. in the long term this is an advantage under poor nutrient conditions). Boldt-Burisch *et al.* (2015) investigated the influence of spatial root and nodule distribution of grass and legumes species on soil nitrogen accumulation; a positive relationship of higher plant densities associated with higher root densities that were all associated with significantly higher soil nitrogen content relative to non-vegetated areas

was found. These outcomes demonstrate the importance that root systems play in soil nitrogen input in the early stages of ecosystem development during re-vegetation by natural succession. Appropriate monitoring should capture the specific growth and the development rate of the species within in the floodplain forest over time and it should be able to assess habitat outcomes after the restoration in terms of vegetation properties.

Although natural regeneration is the best method to encourage vegetation within the floodplain, some species may need assistance and therefore be planted or seeded. There are some typical floodplain forest tree species such as birch of the genus *Betula sp.* (family Betulaceae), willow of the genus *Salix sp.* (family Salicaceae), cottonwood of the genus *Populus sp.* (family Salicaceae) and ash of the genus *Fraxinus sp.* (family Oleaceae), which have light seeds that are dispersed by the wind. Alder of the genus *Alnus sp.* (family Betulaceae) has seeds that float on water and will probably therefore colonise a site after the river has flooded and filled any new stream channel. Other tree species such as oak of the genus *Quercus sp.* (family Fagaceae), hazel of the genus *Corylus sp.* (family Betulaceae), elder of the genus *Sambucus sp.* (family Adoxaceae) and hawthorn of the genus *Crataegus sp.* (family Malinae) are dispersed by birds and small mammals and may take longer to arrive (Street, 2002). All this means that in addition to species planted or seeded the colonisation of floodplain species may be supplemented as these species present good mechanisms of seed dispersal.

With all these potential species developing in a floodplain forest environment it is necessary to consider the main factors that will determine where they will grow (i.e. particular site: wet area, dry area etc.). This will be determined by the relationship between the water levels and the plants preferred environmental attributes.

1.1.4 Restoration project success

The main goal of restoration is to be successful in achieving the habitat outcomes being restored for. There is, however, apparent uncertainty regarding how to quantify the success of a floodplain forest restoration project. Mitsch and

Gosselink (1993), suggested that hydrological considerations are the most important because flooding patterns and nutrient additions to the floodplain will fundamentally affect the success of any floodplain forest restoration initiative. Many parameters could be considered for inclusion in restoration success criteria, but these are often ambiguous or hard to measure. Success criteria need to relate clearly back to specific restoration goals (Hobbs and Harris, 2001).

Success in floodplain forest restoration/regeneration is uncertain but success in any restoration, creation, and enhancement project ideally requires that criteria, preferably quantitative, be established prior to commencement of these activities (Lewis, 1990). Key variables such as hydrology of the site, river flow, erosion and deposition patterns, soil wetness and seed propagation and dispersal may need to be taken into account.

Determining the overall success of a restoration project is extremely difficult in particular because the definition of “success” is yet unclear; it may take decades to establish the success or failure (Tockner *et al.*, 1998; Schiemer *et al.*, 1999 cited in Skinner *et al.*, 2008, p- 194). Adams *et al.* (2005) also recognized that the success of river restoration projects is constrained by a lack of connection between the ecological and socio-economic factors in planning; they suggested that the best sites for restoration are those with high ecological potential and low demographic and economic constraints. Researchers have concluded that a restoration project cannot be successful if quantitative goals and success criteria have not been established during project planning (e.g. Palmer *et al.* 2005; Zedler 2013). In this case study, the focus was on the ecological outcomes (analysis of hydrology, topography, response of tree species to water table levels etc.) rather than ‘demographic patterns’ (i.e. human population densities, intensity of land use and level of urbanization) and economic constraints and incentives (i.e. land prices). For a floodplain restoration project it is a hard task to assess success owing to the complexity of these ecosystems, which are highly dynamic over time. Hence, a scientifically robust and dynamic approach to assessing the habitat changes over time is considered the most

suitable for the appropriate determination of floodplain forest restoration outcomes and subsequent management.

The variability in the type of ecosystem degradation and the specificity of restoration goals can challenge restorationists' ability to generalize about approaches that lead to restoration success (Heneghan *et al.* 2008). In the context of this thesis success was not specifically the main focus, albeit it is one application that is implicit in the research. Based on the current state of knowledge regarding defining success in restoration. It was concluded that demonstration of success (or not) was not possible without other additional research. However, the approach taken in this PhD provides a basis on which to potentially look at aspects of success and the research outputs are part of the success determination.

Examples of restoration after quarrying in Great Britain

Project at Ouse valley Park was a rare example of site restoration/rehabilitation associated with mineral extraction (i.e. quarrying) and as such provided further knowledge to add to the small amount that is known about such sites. Restoration after quarrying has the potential to enhance biodiversity and to provide public benefit (Davies, 2006). Nature After Minerals (NAM) (www.afterminerals.com) works to restore quarries for people and to raise awareness of the benefits that these high-quality restorations on mineral sites can offer to people and wildlife. NAM works in partnership with RSPB (Royal Society for the Protection of Birds) and aims to operate closely with mineral planners and industry to help nature before, during and after minerals extraction. Both make substantial contributions to priority habitats and species, in particular to the England Biodiversity Strategy 2020 targets and provide richer places for people to enjoy. NAM and RSPB cooperate with local authorities and industry based on conservation interests mainly to establish an approach to restore priority habitats at a landscape ecological scale. There are case studies in NAM, which involve simultaneously gravel extraction phases with post-restoration practices that lead to encourage wildlife enhancement. Some of these case studies involving both sand and gravel extraction along with

subsequent or simultaneous restoration (e.g. habitat creation) on going in United Kingdom are displayed in Table 1-1. Most of the restoration sites goals were focussed on trying to create particular habitats such as wet woodland, reedbeds, standing open waters, coastal and floodplain grazing marsh, lowland meadows, purple moor grass, rush pastures, upland oakwood, lowland dry acid grassland and lowland heathland.

One of the best examples of successful restoration practice after quarry extraction is Great Linford Wildfowl Reserve in Buckinghamshire. It lasted 20 years, covering 300 ha and involving wet and dry digging. It is a good practice example as it shows how beneficial results can be obtained from these types of quarry restoration in the long term. The project turned the relative biological desert left after mineral extraction into a high quality wildlife conservation area tailored specifically to the requirements of breeding ducks (Giles, 1992a). Furthermore, it demonstrated that carrying out gravel extraction and post-restoration practices have the benefit of transforming poor areas into rich habitat mosaics increasing biodiversity and the appeal to birds. The importance of the link between the hydroperiod and waterbird abundance (i.e. species richness) is well known. Sebastián-González and Green (2014) carried out the first waterbird study associated with wetlands in Southern Spain (i.e. Doñana, one of the Europe's most important wetland complexes), to address the importance of pond size, depth, and isolation independently of confounding variables such as pond shape; it showed the varied responses from different bird groups and demonstrated the importance of varying depth, location, and isolation to enhance community abundance and diversity. This example supports the existing bird-pond association that co-exist in wetlands.

Table 1-1 below displays the extent within Great Britain of gravel extraction work and post or simultaneous restoration to improve wildlife and increase biodiversity. Sites included have the following in common with the floodplain forest restoration at Ouse Valley Park: (1) gravel extractions with post-restored habitat creation and (2) promoting enhanced biodiversity to generate benefits for wildlife. Some sites are similar in extension to the case study of the

floodplain forest (i.e. Condovery Quarry in Shropshire, Farham Quarry in Surrey, Mere farm in Cheshire or Theale Quarry in Berkshire). The resulting habitat (s) created at each site attempt to achieve similar goals of recreating similar habitats.

Table 1-1 Ongoing sites involving habitat creation and restoration after quarry works in Great Britain. Line in bold displays the current case study used as part of this PhD research.

Site	Size (ha)	Location	Habitat(s) that could be created
Allerton Road Extension	2.60	North Yorkshire	Wet woodland
Barton Quarry	284.50	Staffordshire	Reedbeds and wet woodland
Bradley Fen, Whittlesey	9.99	Cambridgeshire	Reedbeds, wet woodland and standing open waters
Brockholes	106.16	Lancashire	Coastal and floodplain grazing marsh, lowland meadows and wet woodland
Colne Fen	144.59	Cambridgeshire	Coastal and floodplain grazing marsh and wet woodland
Condovery Quarry	50.90	Shropshire	Lowland meadows and wet woodland
Farham Quarry	49.99	Surrey	Coastal and floodplain grazing marsh, lowland meadows, purple moor grass and rush pastures, upland oakwood and wet woodland
Freehay	30.66	Staffordshire	Lowland dry acid grassland and wet woodland
Hilton Park	36.80	Staffordshire	Lowland heathland, purple moor grass and rush pastures and wet wetland
Floodplain forest at Ouse Valley Park	49.85	Buckinghamshire	Reedbeds, standing open waters, wet woodland
Manor Park (north)	39.60	Staffordshire	Reedbeds and wet woodland
Manor Park (south)	27.40	Staffordshire	Reedbeds and wet woodland

Site	Size (ha)	Location	Habitat(s) that could be created
Mere Farm	41.14	Cheshire	Lowland heathland and wet woodland
Middleton Hall (south)	264.22	Warwickshire	Coastal and floodplain grazing marsh, lowland meadows, purple moor grass and rush pastures, upland oakwood and wet woodland
Moneymore	186.10	Staffordshire	Lowland dry acid grassland, lowland heathland and wet woodland
Needingworth	972.72	Cambridgeshire	Reedbeds, standing open waters and wet woodland
Newington Quarry	9.90	Nottinghamshire	Reedbeds and wet woodland
Shardlow	154.96	Derbyshire	Reedbeds, standing open waters and wet woodland
Shardlow Extension	88.98	Derbyshire	Reedbeds, standing open waters and wet woodland
Sleap Airfield Quarry	162.40	Shropshire	Purple moor grass and rush pastures, reedbeds and wet woodland
Sutton Courtnay	264.60	Oxfordshire	Coastal and floodplain grazing marsh and wet woodland
Sutton Courtnay Extension	29.80	Oxfordshire	Coastal and floodplain grazing marsh and wet woodland
Theale PA5	12.68	Berkshire	Reedbeds, standing open waters and wet woodland
Theale Quarry	51.64	Berkshire	Purple moor grass and rush pastures, reedbeds, standing open waters and wet woodland
Town Farm Quarry Extension	23.20	Devon	Coastal and floodplain grazing marsh lowland meadows and wet woodland
Trentham Quarry	127.50	Staffordshire	Lowland heathland, lowland meadows, purple moor grass and rush pastures and wet woodland
Ure Valley	91.53	North Yorkshire	Coastal and floodplain grazing marsh, lowland meadows, purple moor grass and rush pastures and wet woodland

Site	Size (ha)	Location	Habitat(s) that could be created
Washington Sand Quarry, Storrington	7.20	West Sussex	Reedbeds, standing open waters and wet woodland
Worton Rectory Farm	152.93	Oxfordshire	Purple moor grass and rush pastures, reedbeds, standing open waters and wet woodland
Croxall River Restoration Project	2.45	Staffordshire	Reedbeds
Pentney Quarry Extension	90	Norfolk	Reedbeds and wet woodland
Langford Lowfields	175	Nottinghamshire	Reedbeds
Nosterfield	56	North Yorkshire	Coastal and floodplain grazing marsh and standing open waters
Middletown Lakes	163	Staffordshire	Coastal and floodplain grazing marsh and standing open waters

Source: Nature After Minerals (2013)

Habitat creation and novel ecosystem concept

These examples in the table above are regarded as restoration projects after quarry works but some of them, including Ouse Valley Park, should arguably be regarded as habitat creation. Whilst TPT were looking to 'restore floodplain forest' habitat (following its creation) it is not known whether this site was actually a floodplain in the past, although there were examples in the nearby surrounding area. Also the gravel extraction and the subsequent landscaping are, in effect, a result of habitat creation. Hence the ecosystem that develops may be targeted as a floodplain forest but whether it becomes that or becomes a novel system needs to be determined. It is important for TPT to establish whether what is created actually meets the original objectives.

Laarmann *et al.* (2015) stated that post-mining restoration sites often develop novel ecosystems as soil conditions are completely new and ecosystem

assemblage can be spontaneous even on afforested sites. These novel ecosystems that develop after quarry works are very dynamic, and may be changed significantly with any disturbances or management practices. As a consequence, their development over time is not easily predicted. However, their evolution and composition may help to set up restoration goals. In these types of restoration projects where gravel extraction or other anthropogenic environmental activities are involved, it is crucial to design a monitoring programme to understand the ecological changes and plan further management practices. It is likely that it may be very difficult or costly to return such ecosystems to their previous state, and hence consideration needs to be given to developing appropriate management goals and approaches (Hobbs *et al.* 2006).

Natural succession is encouraged, especially if these “after quarry” sites are small in extension and there is not a specific time limit for restoration. There is a debate, triggered by Van Andel (2013) focused on whether or not “traditional” restoration approaches (aiming to restore historical species assemblages, ecosystem structures, and functions) are still relevant, which could imply that novel ecosystems should currently be considered as new reference systems, including their recently naturalized non-native species. Most of these modified ecosystems are dynamic and restoration goals cannot be based on static attributes (Hobbs and Harris, 2001). The desirable goals to achieve should focus on the desired features for the ecosystem in the future, rather than in relation to what goals were in the past. This is mainly because it is easier to achieve the goals and characteristics of the new ecosystem rather than restore the disturbed areas to the initial state.

It is expected within the floodplain forest that diversity will encompass a wide range of species. TPT have produced two documents on which they focus: “Our commitment to Biodiversity” (The Parks Trust, 2010) and Biodiversity Action Plan” (BAP) (The Parks Trust, 2011). The first document explains what as an organisation they are seeking to achieve, the concept of biodiversity, the various habitats they have and the broad measures they are taking to enhance

biodiversity (including biodiversity policy). The second document contains the specific actions TPT is taking to promote the cited biodiversity. BAP includes 10 Habitat Action Plans (HAPs) and 15 Species Action Plans (SAPs). Regarding HAP, it includes information such as status, national status, local status, ecology and issues, conservation management objectives, summary of key measures and indicators, recent activities, proposed activities, desirable activities and legal protection of habitats. For instance, “Ditches and Small Watercourses” and “Rivers and Streams” are included as habitats that should be present in the floodplain forest at Ouse valley Park. Other HAPs included are Ancient Semi-Natural Woodlands, Plantation and Planted Woodland, Scrub, Parkland and Agricultural Hedgerows, Veteran and Notable Trees, Ponds, Reedbeds and Meadows (The Parks Trust, 2011).

SAPs includes the same information as HAPs but applied to species. Some desirable SAPs included by the TPT are: Narrow-leaved Everlasting-pea (*Lathyrus sylvestris*), Bumblebees (*Bombus species*), Black Hairstreak (*Satyrrium pruni*), Silver-washed Fritillary (*Argynnis paphia*), Small Blue (*Cupido minimus*), Great Crested Newt (*Triturus cristatus*), Grass snake (*Natrix natrix*), Slow Worm (*Anguis fragilis*), Common Lizard (*Zootica vivipara*), declining birds in the urban landscape, wetland birds, raptors, European Badger (*Meles meles*), Otter (*Lutra lutra*) and Noctule Bat (*Nyctalus noctula*).

Only a few species were identified as using the floodplain forest around the channels site during the three-year research project (e.g. Grey heron (*Ardea cinerea*), moorhen (*Gallinula chloropus*), mute swan (*Cygnus olor*) and its cygnets). Other protected species identified within the area were bats (*Common noctule*), barn owls (*Tyto alba*) and badgers (*European badger*). A habitat assessment carried out in 2002 did not identify UK Biodiversity Action Plan (UK-BAP) priority habitats or species present within the site except the Common Pipistrelle (*Pipistrellus pipistrellus*).

Within the project little was known about the management interventions that were required to conserve the dynamics of the habitats being restored. This, in great measure, depended on the hydrology of the site (e.g. water table levels)

and its temporal variability. It was important to gain specific knowledge on the water table regime to better understand the hydrological dynamics and its relationship with vegetation assemblages of a floodplain forest. As an on-going project, habitat related variables were likely to be modified during the gravel extraction. Hence, existing information prior to gravel extraction was useful to assess the dynamic processes in relation to the initial conditions (i.e. baseline values) of the site once quarry works commenced, but the changes occurring following the creation of the floodplain needed to be determined following a robust and adaptive programme of research, hence the PhD research.

1.2 Aim and objectives of the research project

1.2.1 Overall Aim

The overall aim of the research was to determine appropriate ecological approaches to apply to the assessment and future monitoring of habitat outcomes of a floodplain forest restoration project at a mineral extraction site.

1.2.2 Objectives

The specific objectives of the PhD study were to:

1. Develop and Design a hypothesis driven Adaptive Monitoring Framework (AMF) for application to understand site restoration and management for ecological outcomes. This objective included reviewing the existing monitoring for restoration appraisal and development of the best approaches and practices based on up-to-date case studies and knowledge.
2. Determine the key parameters required to set an ecologically relevant baseline against which to assess change in vegetation development within the floodplain forest. Fundamental to the AMF were the collection of baseline data on the newly created floodplain forest after gravel extraction works finished. These baseline data were represented by key variables identified through the research in order to test the following hypothesis:

“The ratio/distribution of planted vegetation associated with wet and dry soils within the floodplain forest is determined by the site topography and the water table level.”

3. Assess the baseline hydrological dynamics at the floodplain forest. This objective focused on gathering key hydrological information relating to likely changes within the newly created floodplain forest.
4. Determine measurable parameters of the relationship between water levels and typical floodplain forest vegetation response. Following the hydrological baseline study a glasshouse experiment was used to study

the interaction between hydrology and example tree species growth under controlled conditions.

5. Integration of results using a novel landscape approach. This research consisted of the creation a spatial-based scenario tool to predict the potential development at the floodplain forest site based on hydrological dynamics and topography.

These five objectives were then used to inform about future appropriate management practices to implement in the floodplain forest.

1.3 Layout of the thesis

The thesis has been structured into three linked parts, containing seven chapters (Figure 1-3 Thesis structure showing division of parts and chapters) plus references, acknowledgements and appendices.

The first part (Chapters 1 and Chapter 2) constitutes the introduction to the research project. Chapter 1 describes current knowledge of floodplain forests and specifically defines them; what they encompass, local and international examples why they are so important and the need to monitor them; what ecosystem services and benefits they provide and up-to-date examples of successful restoration projects. Success, dynamic equilibrium and the concept of novel ecosystems are introduced here. More extended debate regarding these terms are further described in Chapter 2. Chapter 1 focuses as well on the idea of self-regeneration in floodplains forests and the most common restoration technique to be put into practice. The project aims and objectives are defined. Chapter 2 covers the main literature review of the research project. It describes the current methods available to support successful regeneration according to the relationship between hydrological processes and vegetation assemblages. It assesses how to monitor floodplain forest restoration projects according to current knowledge, by including the key attributes to monitor, allocation of river flows and water table level replenishment in the site.

The second part (Chapter 3, Chapter 4, Chapter 5 and Chapter 6) focuses on the key research reported in the thesis. Chapter 3 introduces the field site, a

scientifically robust sampling strategy complemented by a hypothesis-driven Adaptive Monitoring Framework (AMF) designed for the current floodplain forest creation project to deal with uncertainty. Successful, long-term monitoring and failure of monitoring approaches proposed for the floodplain forest are discussed. It describes the key variables selected, sampling locations and sample frequency to set an ecologically relevant baseline. Chapter 4 assesses the baseline hydrological dynamics at the floodplain forest. Chapter 5 proposes a glasshouse experiment to investigate the growth and development responses of two typical floodplain forest species to different water levels. Integration of results using a novel landscape approach is covered in Chapter 6.

The final part of the thesis (Chapter 7) provides an overview discussion of the contribution to knowledge and overall conclusions of this PhD research linking the key factors and spatial ecology outputs. It presents a set of recommendations and guidelines based on the floodplain forest study and more widely the potential applicability to similar case studies considering the interaction of plant communities' growth with topography and hydrology.

A Compact Disk with a copy of the thesis in pdf format (for Acrobat reader) is attached at the end of the thesis.

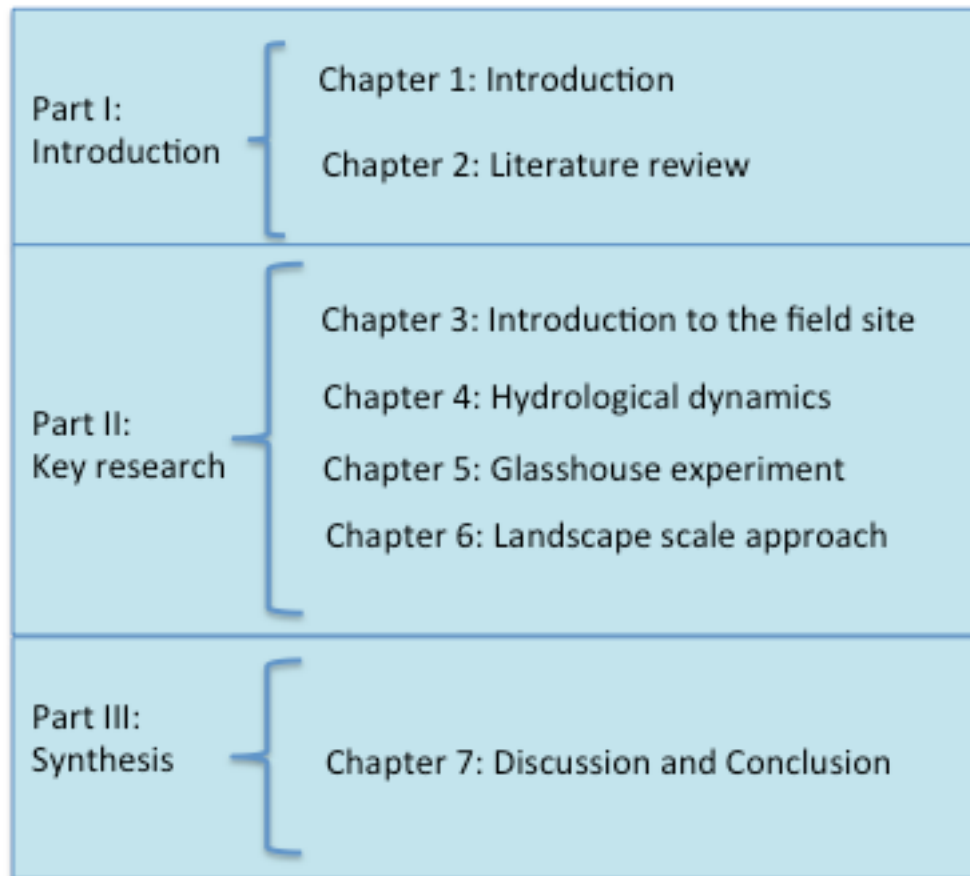


Figure 1-3 Thesis structure showing division of parts and chapters.

All chapters have been formulated in a discursive and traditional way with headings and sub-headings.

2 Literature review

2.1 What do floodplain forests need?

In general terms, floodplain forests need floods. Floods recharge the floodplain water table and provide seedlings with access to moist soils, create new sites for plant recruitment, flush organic material such as woody debris, deposit nutrients onto the floodplain and disperse seeds of riparian plants (Richter and Thomas, 2007). Ecological processes within a floodplain include sediment and deposition patterns, hydrological regime (i.e. flow allocation), nutrient cycling and biological interactions. Hughes (2003) highlights that river flows maintain and replenish water tables, cause channel movement and sediment deposition and consequently promote the establishment of seedlings. Hence, the importance of river flows and the existence of open sediments sites for tree establishment in a floodplain forest. Establishment of seedlings can also be done through animal dispersion or by direct application of seeds in the growing season as part of site management intervention.

2.1.1 Water flows in a floodplain forest

Water flows are responsible for processes such as sediment erosion and deposition, which plays an important role in floodplain forests because different sediment types provide varied niches for vegetation regeneration (Hughes, 2003). Those niches create the media where the seeds may succeed and then species communities may have the opportunity to proliferate in the floodplain forest. In addition, sedimentation is “an essential process along the margins of river channels as newly created alluvial bars are prime regeneration sites for many species of floodplain vegetation” (Hughes *et al.* 2008). Determining how many and how frequently flooding events inundate a floodplain to a sufficient depth for the transport of fine sediment onto the floodplain, is an essential step in any floodplain restoration.

Hughes and Rood (2003) reviewed approaches for flow allocation to restore European floodplains and described some of the methodologies currently in use to implement them. These are flushing flows, floodplain maintenance flows (e.g.

Kondolf, 1998 and Whiting 1998), the recruitment box model (Mahoney and Rood, 1998), the multiple flow methodology (Hill *et al.* 1991) and the bottom-up approaches, top-down approaches and combined approaches developed in South Africa and Australia (Swales and Harris, 1995, King and Louw, 1998, Arthington, 1998, Brizga, 2000, Arthington *et al.*, 2000, King *et al.* 2003). All these approaches have in common the study of the temporal dynamics of the hydrological regime for the estimation of flow allocation regimes.

Whiting (1998) studied the quantification of flows required to maintain a floodplain and gave an example of how to make an estimate of these flows. He stated that the process or processes by which the floodplain forest is built determine the magnitude of the necessary maintenance flows. Rood *et al.* (2003) illustrate this finding by altering the patterns of instream flow regulation to carry out a successful partial restoration. Other authors such as Acreman *et al.* (2003) prefer modelling based approaches and the interpretation of results to assess the hydrological impacts of hypothetical floodplain restoration projects. Finally, Hughes and Rood (2003) suggest planning river flows over a decadal time frame. Other studies looking at ecological processes that are helpful for restoration appraisal encompass nutrient richness and productivity cycles in river floodplain sites. Spink *et al.* (1998) state that the nutrient supply of a site can be either related to factors associated to the river itself or to site-specific factors such as the flooding regime experienced by that site.

Flood Pulse Concept (FPC) and the River Continuum Concept (RCC)

Existing theories try to explain the ecological patterns and features that are associated with river systems and flood events. One of the main theories is the Flood Pulse Concept (FPC), which relies on the fact that the annual flood pulse is the most significant aspect of a river's ecosystem. The FPC describes the dynamic movement of water in river ecosystems and the interaction in the existing transition area between the river and the floodplain itself. Another key theory that tries to describe changes in the flora and fauna within river ecosystems is the River Continuum Concept (RCC).

FPC is based mainly on large tropical lowland rivers; the concept is extended to temperate areas by including information derived from lowland floodplains (Tockner *et al.* 2000). The FPC differs from the River Continuum Concept (RCC), which is based on the hypothesis that a continuous gradient of physical conditions exists from headwater to mouth (Vannote *et al.*, 1980). Tockner *et al.* (2000) have expanded the FPC to more fully integrate temperate river-floodplain systems. The main aim of their research was to expand the FPC to temperate river-floodplain systems. They used as an example three semi-natural European floodplains that have been examined widely in recent times: (1) the Val Roseg (a glacial floodplain in Switzerland), (2) the River Tagliamento in northeast Italy (river corridor in central Europe) and (3) the River Danube (Alluvial Zone National Park in Austria). These river-floodplain systems stand for a variety of general temperate floodplain classes. Tockner *et al.* (2000) emphasised the importance of the interaction between temperature and flow as physical drivers in a river-floodplain forest system through developing the FPC. More scientific evidence regarding the FPC and its applicability to European floodplain forests needs to be gathered. RCC is an alternative theory to FPC. Because of the criticism of the FPC (i.e. apply to temperate and tropical areas only), some flood managers prefer the RCC. However, Junk *et al.* (1989) argue that the RCC is not sufficient because it is based on research done on small temperate streams and has mistakenly been applied to all water systems.

2.2 Determining success of restoration projects: novel ecosystems

The changes associated with river flows may create new habitat opportunities or bring organisms into a site that were not there previously, particularly at a newly developed site like the case study at Ouse Valley Park. There is then the potential for what could be described as a novel ecosystem development. These novel ecosystems will need relevant update of conservation and restoration standards and practices away from the traditional place-based focus on existing communities. According to Hobbs *et al.* (2006), novel ecosystems do not emerge *de novo*. Instead they arise from 'within' pre-existing ecosystems

that are naturally dynamic, both over long and short time-scales. They suggest looking for the best way to manage these novel ecosystems, and use them for profit to society — either as individual ecosystems or in their wider landscape context. Novel ecosystems are composed of non-historical species that may result after species invasion and/or anthropogenic activities such as quarry works.

Restoration projects often state that they have a focus on “success” but this needs to be carefully defined. Kentula (2000) defines *success* (in terms of landscape) as a measure of how restoration (or management, in general) has contributed to the ecological integrity of the region or landscape and to the achievement of goals such as the maintenance of biodiversity. The use of all definitions of success is eventually confined by the current status of the science of restoration ecology and by our capacity to apply that knowledge to take management decisions and to verify measurable success criteria. The concept of ecological restoration proposes that choices are determined by the current state of the ecosystem in relation to biotic and abiotic boundaries. In order to get any measure of “success” there is a need to collect the right information (i.e. baseline, monitoring programme etc.) to build a picture of whether success will occur. Many indicators may be considered in restoration criteria, but these are often unclear or difficult to measure; they require linking certainly back to precise restoration goals. The restoration ecologists play an important role by merging science, management practices and policies.

A good example of purposely improving restoration projects and their outcomes, comes from the Secretariat for the Environment of the State of São Paulo (Brazil) who enacted a legal instrument to drive planning and to assess whether the goals and targets of mandatory ecological restoration were being achieved. This new legal framework was expected to promote greater restoration success by using three ecological indicators: (1) ground coverage with native vegetation; (2) density of native plants spontaneously regenerating; and (3) number of spontaneously regenerating native plant species (Chaves *et al.* 2015). It is well known that native plants are key in these types of restoration projects and that

this innovative legal instrument constitutes a potential tool for assessing restoration success in restoration projects. In contrast to looking at native species only, Richardson *et al.* (2007) examined the biogeography and the determinants of composition and structure of riparian vegetation in temperate subtropical regions under three scenarios: (1) system affected by invasive plants; (2) system uninvaded but with flood generated incursion of alien plants and (3) system affected by both invasions and engineering interventions. Hamman *et al.* (2013) state that the restoration of disturbed ecosystems is challenging and often unsuccessful, particularly when non-native plants are abundant.

Dickinson *et al.* (2015) developed a practical and inexpensive technique to quantify changes in horizontal forest complexity, which could be used to assess vegetation-based changes at a site. It uses satellite or aerial imagery and facilitates stakeholder participation in the adaptive management process. This technique could determine if current restoration projects are successfully achieving their spatial restoration goals (i.e. by checking how forest spatial patterns change over time). Aerial images of the case study site used within the present research could help to determine how habitat outcomes are developing and be used to improve communication of progress with the stakeholders. Metcalf *et al.* (2015) described the important role of trust in restoration success projects; they state that practitioners can use forums for communications, coordinate activities to engage public and stakeholders' participation, to offer opportunities for dialogue and use small-scale projects to demonstrate that success is possible. It is vital to ensure fluent communication between all parties involved in restoration projects (i.e. stakeholders, restoration practitioners, local users, scientific communities etc.). Wilson *et al.* (2011) indicated that the likelihood of restoration success was determined as a probability that restoration action at each site would succeed or fail; if restoration at a site fails, it is returned to the pool of sites for consideration for restoration in the following year and sites that failed in the previous time scale will be automatically reselected in the next time scale.

Ecologically significant evolutionary change occurring over tens of generations or fewer, is now widely documented in nature (Carroll *et al.* 2007); these findings counter the long-standing assumption that ecological and evolutionary processes occur on different time-scales, and thus that the study of ecological processes can safely assume evolutionary stasis. The fact that evolution occurs on ecological time-scales contributes with new opportunities for integrative approaches to quantify success in many restoration cases. Even though there are methods available to estimate when specific species or vegetation communities will succeed under specific target conditions, determining the overall restoration success of a project (i.e. novel ecosystem floodplain restoration project) during the three year PhD timeline was not achievable (i.e. when considering the changes over which ecological time-scales equilibrium/success might occur). This is because the definition of “success” is an imprecise term that has not been defined yet for floodplain forests. It is a hard task to assess restoration success in a novel ecosystem, which is changing over time; these floodplain habitats are dynamic as they are constantly changing in response to fluvial and successional processes (Everard, 1998). Research regarding success criteria is ongoing and information on what to do to achieve success in restoration projects is being gathered. New concepts and models from complex systems theory are being introduced to help expand the approaches to quantify restoration success in restoration ecology (Anand and Desrochers, 2004).

New approaches to defining success are on their way. Catford *et al.* (2013) developed ways to predict novel ecosystems by following a set of recommendations. These recommendations were as follows: (1) use process models to predict characteristics of future ecosystems, (2) use functional groups to predict types of communities, (3) use of analogue systems and (4) incorporate information about taxon migration rates. For the case study described in this research, it was decided to gather existing and baseline information of the floodplain forest (Chapter 3 and Chapter 4) as part of a monitoring programme to implement a landscape approach for predicting habitats (Chapter 6).

Whatever a particular activity is named (restoration, creation, rehabilitation, repair or other re-words), the clear enunciation of goals is essential for its success, and the ability to assess the progress toward success (Hobbs and Harris, 2001). Although ecological restoration takes a long period of time to make predictions of future ecosystem features, it is a potentially useful approach for the development of adaptation frameworks and environmental planning. Therefore, the success in restoration projects depends on the use of an adaptive and effective process of reaching to mutually agreed restoration goals.

Dynamic systems are often best restored through the geomorphological and ecological processes that drive habitat change (e.g. in more physically active systems such as coastal and floodplain systems; Hughes *et al.* 2012). Nevertheless, the associated uncertainty in quantifying restoration success suggests that an open-ended view of likely ecological outcomes has to be taken. The riparian systems that compose floodplain forest are strongly subject to a dynamic equilibrium.

Restoration goals are dynamic (i.e. flexible goals for biodiversity conservation under disturbances and significant changes). Restoration activities are often aimed at establishing processes that lead to self-sustaining ecosystem dynamics (Jentsch, 2007); in addition, another challenge for restoration is to understand ecosystem dynamics as a function of spatial and temporal interrelations of event regimes. Jentsch (2007) pointed that in a restored site all species are often in one age state as seedlings establish or are planted at the same time. Restoration practitioners need to plan for a tenable habitat mosaic of all species age and stages and for the dynamic processes that compose this mosaic. It is a challenge deciding which one is the spatial and temporal scale of a disturbed ecosystem that leads to a dynamic equilibrium.

As a consequence it is expected that a created floodplain forest will always be in transition until it reaches some sort of dynamic equilibrium (i.e. key variables values will vary less over time). The major factors in this are:

- i) Large transition periods before the system reaches equilibrium.

- ii) Site-specific conditions.
- iii) Large list of restoration approaches that can be implemented to address a single problem.

Transition periods occur when systems change from a state of A (before the restoration) to a new one B (after the restoration). In many cases, reaching the equilibrium B may take decades. Site-specific conditions will determine the recovery rate of the ecosystem. For example, systems with high temporal variability will take longer to reach equilibrium than systems with low temporal variability where little change is expected over time. Finally, the ecosystem will recover at a different rate depending upon the restoration technique employed.

The use of dynamic equilibrium has already been applied to other fields such as geomorphology to explain the topography of erosional landscapes (Hack, 1960). Other authors, such as Pollock *et al.* (1998) support Huston's dynamic-equilibrium model (DEM) (Huston, 1994) of species diversity, which predicts the effects of productivity and disturbance on diversity patterns. Huston's DEM explains how disturbance and productivity influence species richness; the model predicts that when the opposing forces of disturbance and productivity are in dynamic equilibrium, diversity will be high (Huston, 1979, 1994). Yet, it is not clear whether the predictions of the DEM are applicable in systems undergoing such fundamental changes in diversity and disturbance patterns (Pollock *et al.* 1998) such as those occurring in the floodplain forest case study used within the PhD research here.

Tuljapurkar and Semura (1977) establish general criteria for the occurrence of dynamic equilibrium states in Simple Ecosystem Models (SEM); they concluded that in the absence of any perturbations, the mix of species would tend towards a static equilibrium state, where it is likely that only dominant species would survive. In the analysis of Tuljapurkar and Semura (1977), a periodic perturbation ought to produce a dynamic equilibrium state where the chances of weak species coexisting with dominant species ought to be greater than the corresponding chances of coexistence in a static equilibrium state. As it has been discussed at the beginning of this chapter (section 2.1), floodplain species

are dependent on flows, then it may take centuries for a new dynamic equilibrium to be attained by channel and floodplain adjustments to the new flow regime (Petts, 1985).

2.2.1 How to assess restoration success: main ecosystem attributes to consider

Evaluating restoration is not a straightforward process. It includes extensive debates surrounding what characterizes successful restoration and how best to measure it (Wortley *et al.* 2013). Several authors have looked at developing guidelines to assess restoration success. The Society for Ecological Restoration International (SER, 2004) produced a Primer including ecosystem attributes to be considered when evaluating restoration success but it is not yet clear what they consider success in restoration processes. They listed the question of what is meant by “recovery” in ecological restoration, and made the statement that an ecosystem has recovered (i.e. restored) when it contains sufficient biotic and abiotic resources to continue its development without further assistance or subsidy (i.e. resilience to environmental stress and disturbances). Ruiz-Jaen and Mitchell Aide (2005) have reviewed articles published in *Restoration Ecology* (Vols. 1[1]-11[4]) to determine how restoration success has been evaluated in restoration projects. They addressed what ecosystem attributes were assessed and how these measures were used to determine restoration success. They concluded that there is no study that has measured all the SER Primer attributes, but most studies include at least one measure in each of three general categories of the ecosystem attributes: diversity, vegetation structure and ecological processes. The evaluation of these attributes can reflect the recovery trajectory and self-maintenance of restored ecosystems (Ruiz-Jaen and Mitchell Aide, 2005). In this PhD research project the rationale for the selection of variables or attributes was mainly based on the stakeholders’ interests (i.e. The Parks Trust and Environment Agency). More information of the selection criteria for key variables is further described in Chapter 3.

Diversity is related to both the ecotonal situation of the habitat within the target area and to their physical heterogeneity (Hughes *et al.* 2008). It is generally

measured by determining richness and abundance of organisms within different trophic levels (Nichols & Nichols 2003; Weiermans & Van Aarde 2003 cited in Ruiz-Jaen and Mitchell Aide, 2005, p. 569). Hellowell (2012) suggests the use of indices of community diversity, as communities may be modified by perturbations of the environment and the degree of change in the structure. In terms of diversity, Ruiz-Jaen and Mitchell Aide (2005) state that plants are the preferred group of many authors, although some studies of diversity also included records on fauna. Yet, "vertebrates are more frequently studied than plants or invertebrates in conservation biology projects" (Clark and May 2002, cited in Ruiz-Jaen and Mitchell Aide 2005). SER (2004) suggests the comparison of the restored ecological patterns to reference values for restoration appraisal; comparing reference values over time will help to quantify the success. Ruiz-Jaen and Mitchell Aide (2005) state that most studies compared restoration success with one or more reference sites to capture the dynamics and variability of natural ecosystems. Other authors, such as Woolsey *et al.* (2007) state that restoration success is evaluated by comparing indicator values before and after restoration measures have been undertaken.

Despite the fact that novel ecosystems are by definition "new ecosystems", it may be feasible to use ecosystems with related attributes to help making predictions in the future. Reference ecosystems for setting final goals of restoration projects should represent the entire range of histories and regimes of disturbance within a same type of ecological region (Suganuma and Durigan, 2015). Gould (2012) reported the findings of a study that compared landscape functionality and vegetation in post-mining rehabilitation with reference to native forests on the Weipa bauxite plateau (northern Australia); vegetation succession was discussed in the context of post-mining rehabilitation and its implications for rehabilitation techniques. Temperton *et al.* (2014) suggested that long-term ecological research would be needed in new reference sites to study and assess a broad suite of biogeochemical processes. The possibility of using reference sites for the present case study has been considered, but in a rapidly changing ecosystem (i.e. novel or no-analog), it is difficult to find a

suitable reference site that meet our preferences. This is why the early collection of data in any restoration project is key for making future predictions.

White and Walker (1997) distinguish between the two most common forms of reference information. These are historical data from the site to be restored and contemporary data from reference sites (sites chosen as good analogs of the site to be restored). Still there are limitations to both. For instance, historical data reference information of the site could be incomplete and individual reference sites can be difficult to find. Multiple sources of information will help to understand how these ecosystems vary.

Other ecological processes of interest to assess restoration success are those describing biological interactions (e.g. herbivory, dispersal, pollination, predation, or parasitism) such as the use of Black Hairstreak (*Satyrrium pruni*) as a nectar source by bumblebees (*Bombus*) or the interactions between Narrow-leaved Everlasting-pea (*Lathyrus sylvestris*) and different pollinators (i.e. different species of invertebrates including beetles, weevils, caterpillars and bumblebees) (The Parks Trust, 2011).

Successful restoration projects are those where a varied range of ecological processes maintain the functioning of the ecosystem in equilibrium. As an example of both success and failure in restoration projects, Woolsey *et al.* (2007) developed guidelines for assessing river restoration success through the comparison of indicator values; the Thur River, Switzerland was successful in achieving “provision of high recreational value”, “lateral connectivity” and “vertical connectivity” but failed to meet the objectives “morphological and hydraulic variability” and “near natural abundance and diversity of fauna”. Even though these guidelines are applied to river restoration, they may be used as reference for floodplain restoration projects and their associated rivers (i.e. floodplain-river systems).

Overall, when talking about success refers to attributes or indicators to measure within a specific project. The assessment of these attributes or indicators over time should benefit management decision-making that will, in turn, contribute to restoration success. It is about setting goals, which will lead to restoration

success in a project. As restoration success was considered a difficult parameter to measure and due to the timescale of this PhD, the focus was on assessing habitat (i.e. vegetation) outcomes. Measurements of vegetation are most commonly used in evaluations of restoration projects; with less frequent analysis of soils, fauna, and hydrologic characteristics (Kentula, 2000). It is more practical to focus on vegetation regeneration, as it has a quicker response to hydrology alterations. Some examples of experiments measure the interaction between vegetation (i.e. tree genus species commonly found at floodplain forests) and hydrology parameters such as water table level. Results from these experiments provide the rationale related to the conditions for growth of seedlings for typical floodplain tree genus and serve as a reference for designing a study to assess habitat outcomes and achieve successful regeneration.

2.2.2 The link between hydrological processes and vegetation

Over recent years, intensification in river management practices (i.e. groundwater extraction, channelization of banks, levee construction, quarry works etc.) has resulted in significant changes to natural patterns of sediment deposition, bank erosion, water table, river flow and frequency, timing and intensity of floods. These modifications have affected negatively on the regeneration capability of European floodplain forest genera such as Poplar (*Populus sp.*) and Willow (*Salix sp.*). As a consequence, communities of these pioneer species are declining and even disappearing from floodplain-river systems.

Much of the knowledge of the impact of moisture on seedling development of diverse riparian tree species arises from water table manipulation experiments. The results of such experiments are useful in clarifying the respective sensitivities of specific riparian tree species to drought stress. Results gathered could also assist in informing ecologists and managers how water table levels affect tree species in regulated river reaches.

Understanding the importance of water levels on plant functional response is crucial for seedling success. A number of authors have used experimental

approaches to determine plant-water relationship. There have been several experiments regarding hydrological interaction with floodplain forest species carried out over the last decade. For instance, Everitt (1968) was a pioneer author who used cottonwood (Poplar genera) in an investigation of the history of a floodplain; based on his findings, Everitt (1968) concluded that the germination and growth of the cottonwood was intricately related to the discharge of the river, movement of the channel and development of the floodplain.

Guilloy *et al.* (2011) examined seedlings survival and growth of White willow (*Salix alba*) and Black poplar (*Populus nigra*) under different abrupt drops in water table levels using an experimental facility; they concluded that abrupt drops in water table level did not stimulate *Populus nigra* and *Salix alba* growth but favoured the survival of the most resistant individuals. Hughes *et al.* (1997) studied the response of Grey Alder (*Alnus incana*) to a variety of water table drawdown rates in two different sediments types; they found that the highest growth was measured in well-drained sandy loams under 1 cm/day and 3 cm/day water table decline ranges. Araya *et al.* (2010) studied the dry biomass differences between two wet grassland species Meadow fescue (*Festuca pratensis*) and Common sedge (*Carex nigra*) to subjected water-table depths; results showed differences in growth response between the two species in monoculture to five set water-table depths (50, 150, 250, 350, and 450 mm below ground surface), with the production optima coinciding. However, in mixture their optima were displaced and the optimum for *Carex nigra* shifted toward the higher water-table elevation and *Festuca pratensis* to the lower plants like cottonwoods (*Populus angustifolia*) that are able to colonize higher elevation zones and would tolerate more abrupt rates of water-table change. Whereas plants like the sandbar willow (*Salix exigua*), which are naturally established at lower elevations, would require more gradual rates of stage change (Amlin and Rood, 2002). In an initial study, Amlin and Rood (2001) grew seedlings of *Salix exigua*, *Salix lutea*, *Populus balsamifera*, and *Populus deltoides* under different water-table decline rates. In a second study, Amlin and Rood (2002) investigated the comparative tolerances of two riparian willows,

Sandbar willow (*Salix exigua*) and Drummond's willow (*Salix drummondiana*), and two cottonwoods, Narrowleaf cottonwood (*Populus angustifolia*) and Balsam poplar (*Populus balsamifera*) to water-table decline rates; they concluded that the willow and cottonwood were similarly affected by abrupt water-table decline, although willow was somewhat more vulnerable than cottonwood.

Another glasshouse experiment to uncover how vegetative (seedlings) and non-vegetative (cuttings) propagules of Black Poplar (*Populus nigra*) responded to a range of water table drawdown rates in two different sediment profiles from two different rivers in the Rhône River Basin, France (the Drac and Isère Rivers) was described by Barsoum and Hughes (1998). The sediments from the Isère River were predominantly sandy silts while the sediments from the Drac River were predominantly coarse and fine sands with some gravel. They found that cuttings and seedlings grown in the Isère sediment with rapid water table drawdown rates and seedlings in Drac sediment with a fluctuating water table were the more successful plants by the end of the experiment.

The effects of three elements of Water Level Fluctuations (WLF) (flooding depth, duration and frequency; Casanova & Brock, 2000) on the window of opportunity for recruitment and seedling community diversity of ten common Dutch species (*Eupatorium cannabinum* L., *Epilobium hirsutum* L., *Filipendula ulmaria* L., *Lythrum salicaria* L., *Lycopus europaeus* L., *Mentha aquatica* L., *Alisma plantago-aquatica* L., *Phragmites australis* (Cav.) Steud., *Sagittaria sagittifolia* L. and *Typha angustifolia* L.) were investigated by Sarneel *et al.* (2014); as a main conclusion, WLF can be used a management tool to stimulate plant recruitment and seedling diversity in riparian wetlands. Souch and Stephens (1998) quantified a series of parameters that lead to relationships between water use and biomass production; they used three drought treatments (none, medium and severe) applied to three container-grown with three hybrid poplar clones (Beaupré, Trichobel and Ghoy); they quantified a series of parameters that lead to relationships between water use and biomass production. All these examples highlight that the relationship between water

levels and plant responses can effectively be understood through glasshouse experiments.

Other studies carried out at sites as field experiments on sites, aimed to quantify the response of Fremont's cottonwood (*Populus fremontii*), Goodding's willow (*Salix gooddingii*) and Saltcedar (*Tamarix ramosissima*) to different water table dynamics and to clarify factors that are likely to be important in determining plant response (Shafroth *et al.* 2000); they concluded that plant response is interceded by soil texture, precipitation-derived soil moisture, physiological adaptations to water stress. The responses of *Populus deltoides* subsp. *monilifera* morphology, growth, and mortality to water stress resulting from sustained water table decline were quantified by Scott *et al.* (1999); they concluded quantitative information on the timing and extent of morphological responses and mortality of *Populus* to the rate, depth, and duration of water table declines.

All studies cited above provide important context and the rationale on useful ways to study the functional response of the tree species and provide the basis needed to carry out an experiment in a glasshouse (Chapter 5). These studies highlighted above, clearly show how the relationship between vegetation development and soil wetness can be analysed using a experimental approach.

In addition to glasshouse experiments, other approaches exist as part of field experiments that relate hydrology of a site to tree species growth. Araya (2007) analysed the distribution of plant species in relation to water regime at regional level using Ellenberg values. Ellenberg scores are subjective indices relating plant distribution to environmental factors; for soil and water availability the scores range between 1 and 12, where for example 2 indicates a plant adapted to very dry site while 10 indicates a plant adapted to very wet soils; as a conclusion, the hydrological niches within coexisting species of a community explain the ecology of plant water relations.

Another iterative approach based on ecological and hydraulic modelling techniques in order to identify an optimum scenario aiming to reflect the potential of plantings (softwood woodlands such as *Salix sp.*) in a certain area

without exceeding critical water levels was developed by Leyer *et al.* (2012); they provided an approach complemented with a solution to overcome the conflicts in river-basin management that hinder the reestablishment of the threatened floodplain forests in Europe. Martin and Stephens (2006) studied the effect of soil factors and water stress on the growth and biomass production of willow (*Salix viminalis* L.) on a clay landfill cap soil; their research suggests that reasonable biomass production from willow on Oxford clay landfill caps would be dependent on the application of nutritional amendment to the soil at these sites.

A new conceptual approach for analysing the interrelationship among plant succession, morphology, and hydrological impacts was presented by Formann *et al.* (2014); they suggested classifying process types, to compare them with natural reference conditions that will help assessment of the river and definition of management strategies.

These examples will not indicate if the regeneration has been successful or not but will help as a reference in designing our experiments and setting the objectives of the research and establishing the guidelines for the case study site project and further restoration projects (i.e. through the study of cuttings development regeneration success under different water table depth conditions).

2.3 Existing methodology for determining self-regeneration

In past studies success of regeneration has been evaluated through the assessment of vegetation (i.e. tree genus) species (e.g. *Populus sp.* and *Salix sp.*) and their relationship with water table level oscillations as discussed below in section 2.3.2 (i.e. Recruitment Box method for cottonwood and willows and The Sum Exceedence Values for grassland).

Gowing and Spoor (1998) suggested that the distribution of many plant species is largely determined by the long-term water regime of a site. Soil water regime can differ significantly within a single field and indeed on a scale of 10 m; the hydrological process mainly drives vegetation growth and structure. The water

table for example affects plants in two different ways: directly by providing water and oxygen to the roots and indirectly by regulating nutrient availability and temperature in the soil and managing the sward (Gowing and Spoor, 1998). Rood *et al.* (2003) states that it is the water level rather than the flow that is relevant for most riparian processes such as seedling recruitment.

Self-regeneration can only successfully occur when the conditions are adequate for seedlings to be established. Several authors have looked at the variables conditioning self-regeneration. For example, Hughes and Rood (2001) suggest that successful regeneration depends on a window of opportunity providing just the right conditions for establishment following germination (e.g. a long enough period without flooding for seedlings to become established and grow to a height which will take them above the level of the next flood).

Most of the literature review supports the idea of self-regeneration in floodplain forest restoration projects. There are some stretches in Western Europe that still contain dynamic and self-regenerating floodplain forests (Moss and Monstadt, 2008); however, Hughes (2003) declares that in many locations, self-regenerating forests have been considered unproductive and as a result they have been replaced with extra productive forestry plantations (often using hybrid poplars) within the floodplain forest zone.

2.3.1 Recruitment Box method for woodlands: cottonwoods and willows

Based on the idea of self-regeneration in floodplains, Mahoney and Rood (1998) developed the Recruitment Box Method (RBM), which helps to identify the zones in elevation and time in which riparian vegetation seedlings are likely to become successfully established if stream flow patterns are favourable. Figure 2-1 below shows the recruitment boxes (i.e. suitable time for recruitment) for both riparian cottonwoods and willows. As shown in Figure 2-1, sandbar willow recruitment box is offset from cottonwood recruitment box, and both willows and cottonwoods could be established during the same recruitment event (Amlin and Rood, 2002). Due to differences in the recruitment parameters of willows and cottonwoods, this method could be adjusted to encourage the

establishment of different species of both genera. It also demonstrates that ramping river stage by 2.5 cm/d at higher topographical locations will encourage cottonwood seedling establishment. In addition, if the river stage decays to 1 cm/d at lower topographical locations then it should encourage willow seedling establishment.

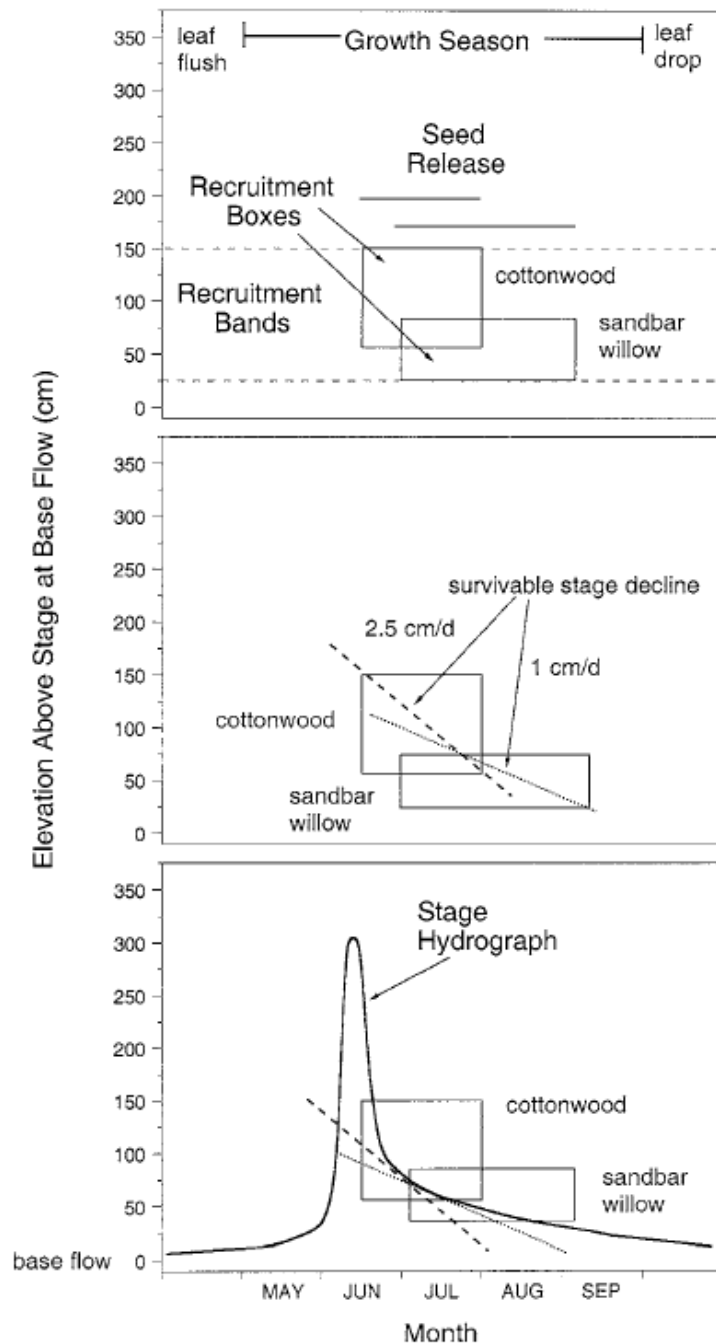


Figure 2-1 The 'Recruitment Boxes' for riparian cottonwoods and willows defined by the establishment elevation (Recruitment Band) and seed release periods for each genus (top), survivable rates of water-table decline (middle) and stage hydrograph requirements (bottom) for both genera. These figures are expanded from the cottonwood recruitment box model of Mahoney and Rood (1998).

Source: Amlin & Rood (2002).

Mahoney and Rood (1998) have characterised the Recruitment Box of several species (e.g. cottonwoods and willows) and the methodology has been successfully applied by Rood *et al.* (2003) to propose sequences of discharges (i.e. high spring flows and then gradual flow decline) for seedling survival.

2.3.2 Sum Exceedence Values (SEVs): grasslands

The Sum Exceedence Values (SEVs) is another method used to assess self-regeneration potential by relating water table to vegetation development but based on grassland communities. The SEVs (Gowing and Spoor, 1998) focuses on the assessment of the soil water regime in the area; it relies on the estimation of the aeration stress and the drying stress thresholds (Figure 2-2). In simple terms, the aeration stress is the point at which the plant cannot take oxygen from the soil due to excess in water (waterlogging) and the drying stress is the point at which the plant cannot extract water from the soil successfully (drought).

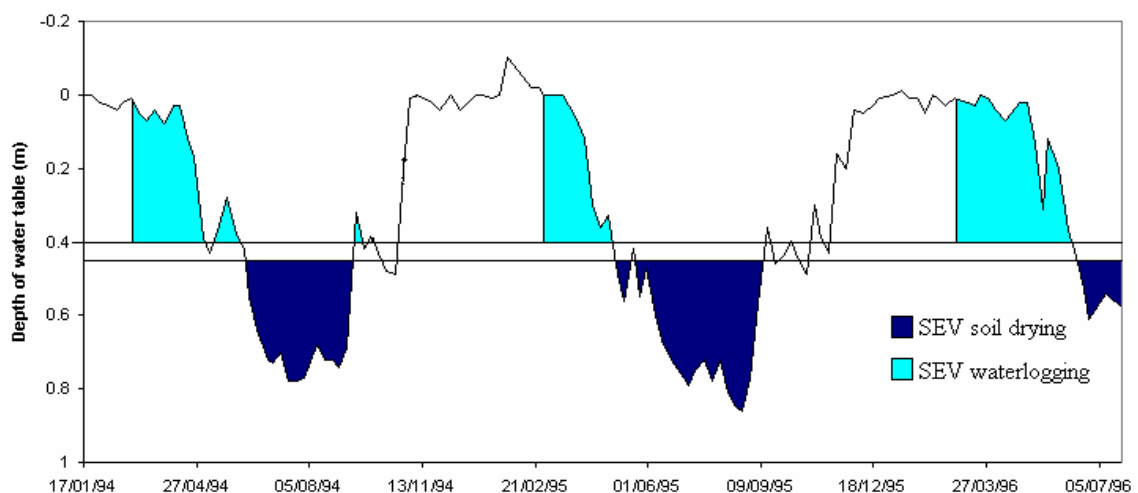


Figure 2-2 Sum Exceedence Value derivation from a hydrograph as generated by a hydrological model. The horizontal lines represent threshold depths for the particular soil type. The upper one the waterlogging threshold with the shaded area above it representing the SEV (waterlogging), the lower is the soil drying threshold and the shaded area below it represents the SEV (soil drying). Source: Gowing *et al.* (2002).

2.3.3 Recruitment Box Method (RBM) vs. Sum Exceedence Value (SEV)

Both methodologies study the water-table interaction with the growth of vegetation communities (i.e. relative water decline tolerance of cottonwoods and sandbar willow in the case of RBM and water table interaction with grasslands and reedbeds in the case of SEV). RBM defines a zone in elevation and time in which riparian cottonwood seedlings are likely to become successfully established if stream flow patterns are favourable (i.e. elevation and seed release periods for each genus according to stage hydrograph requirements). SEV displays the preferred tolerances to waterlogging (i.e. plant cannot take more oxygen) and drought (i.e. plant cannot take more water). The main difference between these techniques is that RBM has been applied to cottonwoods (*Populus sp.*) and Willows (*Salix sp.*) and SEV has been applied to a large number of grassland species (e.g. MG4-*Alopecurus pratensis*-*Sanguisorba officinalis* and S4-*Phragmites australis* in NVC). RBM identifies as key variables stage (i.e. stage hydrograph, favourable stream flow pattern), elevation, water-table decline rate and the time to when seedlings are likely to establish successfully. SEV uses soil water regime and estimates when the plant cannot take oxygen (i.e. waterlogged) and when plant cannot take water (i.e. drought); SEV mainly assesses the potential for self-regeneration by relating water table to grassland species growth. The SEV technique has identified the preferred and tolerable values of grassland species community for a limited period of a range of depths. Both techniques can be used as a reference for tree genus such as *Populus sp.*, *Salix sp.* and other grassland species that coexist in the floodplain forest by knowing the elevation, water table (i.e. soil wetness), stage of the River Great Ouse and time. These methodologies open the possibility of adding new species if their water table requirements are known.

2.3.4 National Vegetation Classification

One of the key common standards developed for the country nature conservation agencies aimed at classifying plant communities of Great Britain is

the National Vegetation Classification (NVC). British Plant Communities is the five-volume account of the National Vegetation Classification (NVC) published by Cambridge University Press. NVC is one of the key standards created for the British nature conservation agencies and aims to provide an extensive classification and description of the plant communities of Britain. In it, the classification and community descriptions are organised under major five headings: Woodlands and scrub (Rodwell 1991a), Mires and heaths (Rodwell 1991b), Grasslands and montane vegetation (Rodwell 1992), Aquatics, swamps and tall-herb fens (Rodwell 1995) and Maritime communities and vegetation of open habitats (Rodwell 2000). For the present research using the floodplain forest as a case study, it was expected that communities would be in the following categories: Woodlands and scrub, Grasslands and montane vegetation and Aquatics, swamps and tall-herb fens. Nevertheless, due to the early stage of vegetation development on the site, the classification and identification of these plant communities was regarded as difficult. NVC comprises 286 community types subdivided amongst 12 major types of vegetation.

Several authors have estimated the tolerances to waterlogging and drought of a large number of grassland species. For example, Gowing (2004) has identified water-table regime for MG4 in NVC (*Alopecurus pratensis*-*Sanguisorba officinalis*) mesotrophic grassland for a list of different hydrological scenarios under which MG4 can exist. Mountford (2004) has identified water regime variables for S4 (*Phragmites australis*) Reedbed, swamps and tall-herb fens in NVC. Both approaches show the range of depths that are “preferred” and “tolerable for limited periods” by the vegetation community.

2.4 Restoration appraisal: monitoring approaches

Restoration appraisal requires implementation of monitoring programmes that quantify the change of target variables over time. The design of monitoring programmes for river restoration at a reach-scale management can only have a relatively local effect (Hughes *et al.* 2008). Much effort has gone into developing methodologies that can guide the process. For example, the Practical River

Restoration Appraisal Guidance for Monitoring Options (PRAGMO) (River Restoration Centre, 2011) is a guidance document on suitable monitoring for river and floodplain restoration projects. It is divided in two parts; the first part provides a summary of the more detailed information of the main body of the guidelines and the second part allows the person involved in the monitoring to assess specific elements of the guidance such as: river restoration understanding, project limitations, robust project and monitoring objectives, making informed decisions, identifying different monitoring methods, the need to prioritise monitoring aspirations and case studies. This guidance also provides a summary of key processes and components for developing a monitoring and appraisal strategy for river restoration and its associated floodplain, suggesting what are the key aspects. Another good example for restoration appraisal is “The Flooded Forest: Guidance for policy makers and river managers in Europe on the restoration of floodplain forest” (Hughes, 2003). The document is presented in an accessible way to understand not only the key physical and biological processes involved in restoration projects but also the policy context in which restoration practitioners may proceed.

2.4.1 Adaptive Monitoring Framework-hypothesis for uncertainty

Lindenmayer and Likens (2009) classify monitoring programmes into three categories: (1) passive monitoring, which is devoid of specified questions or underlying study design and has limited rationale other than curiosity, (2) mandated monitoring where environmental data are gathered as a stipulated requirement of government legislation or a political directive and (3) question-driven monitoring which is guided by a conceptual model and by a rigorous design that will typically result in a priori predictions that can be tested. As the site conditions were in-progress for this case study (i.e. gravel extraction works), a question-driven monitoring was regarded as a suitable method.

Question-driven monitoring programmes can provide insights into the ecological processes giving rise to emergent environmental patterns. Kentula (2000) suggested that one way to deal with the uncertainty of the response of the ecosystem to a restoration scheme is to use scientific principles of hypothesis

testing and model building in an Adaptive Monitoring Framework (AMF). More information regarding AMF in the context of the PhD research is further developed in Chapter 3.

2.4.2 Long-term monitoring

Where restoration is planned on a large spatial scale, an “open-ended” approach to defining outcomes may be appropriate. Hughes *et al.* (2011) suggest in open-ended projects restoration goals should be framed in terms of promoting natural processes, mobile landscape mosaics and improved ecosystem services. In this project, it was proposed to employ a long-term monitoring approach that aimed to detect and evaluate changes of targeted variables in the floodplain ecosystem.

Long-term monitoring programmes are defined as “repeated field-based empirical measurements, collected continuously and then analysed for at least 10 years” (Lindenmayer and Likens, 2010a). Lindenmayer and Likens (2009) quote successful examples of long-term monitoring that have several features in common, such as well formulated questions that were posed at the outset of the work, an ongoing development of new questions as initial ones were answered, robust experiment design, high quality data collection and careful attention to field data and field sample storage and strong enduring leadership among others. These examples cited include the agricultural research and monitoring project at Rothamsted in the United Kingdom (Rothamsted Research, 2009) which has contributed to environmental, economic and social sustainability, the Hubbard Brook Experimental Forest (HBEF) in New Hampshire (USA) (Likens, 2004) which has pioneered the small watershed technique as a method of studying ecosystem processes and the Moreton Bay Waterways and Catchment Partnership in southeast Queensland, Australia (Ecosystem Health Monitoring Program, 2008, cited in Lindenmayer and Likens, 2009, p. 483) which is one of the most comprehensive freshwater, estuarine and marine monitoring programs in Australia. These examples describe successful long-term monitoring programmes and can be used as a reference for other restoration projects.

It is difficult, in contrast, to find failed monitoring programme examples in the literature because they are not published; failed or ineffective monitoring programme (i.e. due to lack of consideration at the funding stage) is not considered of interest to the reader, although it would be valuable to the scientific community. Setting goals and objectives at the beginning of the project, good questions, establishing fluent communication between any stakeholder partnerships, scientists, policy-makers and managers (i.e. organising periodic meetings), frequent use of data collected and budget estimations can help to achieve a successful and effective monitoring programme (Adapted from Lindenmayer and Likens, 2010a).

2.4.3 Successful long-term monitoring programmes

Existing methodologies are often site-specific and adjust to the spatio-temporal characteristics of the site and the type of restoration project carried out. Yet, Lindenmayer and Likens (2010a) identified some key features of successful monitoring programmes. These are: good and evolving questions, the use of a conceptual model, well-developed partnerships, strong and dedicated leadership, ongoing funding, frequent use of data, scientific productivity and maintenance of data integrity and calibration of field techniques.

Posing good questions lies at the heart of good science and effective long-term research and monitoring (Lindenmayer and Likens, 2009). The conceptual model needs to be developed at the beginning of a study, ensuring all the relevant components are captured in the project design (Lindenmayer and Likens, 2010b). It is well known that most successful monitoring programmes are built on partnerships between people from different backgrounds with complementary skills; they are important because they can facilitate the flow of information (Lindenmayer and Likens, 2010a). It is important to maintain on going funding and a strong and dedicated leadership, in order to avoid the work slowing down or stopping altogether. Lindenmayer and Likens (2010a) state that the frequent use of data may stimulate new research and management questions; they strongly believe that results of a monitoring programme must be published in peer-reviewed literature contributing to scientific productivity. For

this to be applicable they recommended employing state of the art field techniques and adopting up-to-date methodologies.

2.4.4 Long-term monitoring failure

Existing projects have mentioned stakeholder participation, stakeholder education and construction criteria as being important to the success of projects (O'Donnell and Galat, 2008). Lindenmayer & Likens (2010b) state that “with questions lacking it is not possible to diagnose the cause of a change, which in turn limits predictive capability through time or space to other restoration sites; a poor study design can lead to the results of work not being written up, or when it is, making it difficult for findings to be published in reputable outlets”. The so-called “laundry list” occurs when monitoring too many things poorly rather than fewer things well (Zeide, 1994).

Other problems are the failure to properly articulate what to monitor and why, it is important to monitor targeted entities and an inappropriate assumption that there is a single approach to monitoring that is uniformly applicable to all monitoring programs (Lindenmayer and Likens, 2009).

2.5 Determining spatially relevant changes of land use and vegetation

Anthropogenic activities cause modifications to land-purpose and vegetation community features on variable spatial and temporal scales. Landscape approaches have become an important tool to predict future scenarios after flood events and any land-use modification. It is often necessary for approaches to be both spatially and temporally explicit and to include managers' and ecologists' decision-making to capture the temporal dynamics of this complex managed ecosystems.

With the increase of GIS and statistical tools, the growth of predictive habitat mosaic distribution approaches has increased in ecological restoration. The option of an appraisal measure should be led mainly by the aims of the study.

Predictive maps or scenarios can potentially allow us to forecast of the effect of water table changes after flood events on habitat patterns and mosaics at diverse spatial scales. There are some constraints that can restrain the use of predictive scenarios in practical applications (i.e. lack of reliable data). By taking the baseline monitoring field data, the variables quantified for assessing the growth responses of typical trees associated with floodplain forests and consideration of the new topography and hydrology of the study site associated within this thesis, an overview of recent landscape ecology approaches and its applicability to a real case study was taken. There was particular interest in the use of predictive scenarios for the assessment of habitat outcomes. Specific background context and the applicability of the landscape ecology approach and predictive scenarios are included in chapter 6.

The literature presented here has provided context and concepts that have shaped the research during this PhD and highlighted the complexity of understanding the outcomes of the restoration activity at a site. The remainder of the thesis focuses on the specific research undertaken and its outcomes to determine the key elements associated with understanding the development of the floodplain forest at Ouse Valley Park.

3 Introduction to the field site

3.1 Floodplain forest site at Ouse Valley Park

3.1.1 Site History and background

The case study was a 50 ha newly created floodplain forest, known as Manor Farm, located within the River Great Ouse river valley in northern Milton Keynes, Bedfordshire (United Kingdom) (Figure 3-1). The River Great Ouse is a meandering lowland river with a mean annual discharge of $20 \text{ m}^3 \text{ s}^{-1}$ (range $5\text{-}150 \text{ m}^3 \text{ s}^{-1}$) (Hughes *et al.*, 2000). The connection between the River Great Ouse and its associated new created floodplain was central to the restoration project and represents the first area in the country to implement this National and local Habitat Action Plan target (Nature After Minerals, 2013).

The project began with the UK Government, Environment Agency (EA) and the landowner The Parks Trust (TPT) working together with Hanson Heidelberg Cement Group (Hanson) to encourage the re-establishment of natural or new created floodplains to enhance the landscape. Outputs of the research were aimed at providing an in depth analysis of environmental factors that could be applied to the development of management guidelines for floodplain forests based on the long-term, adaptive monitoring approach.

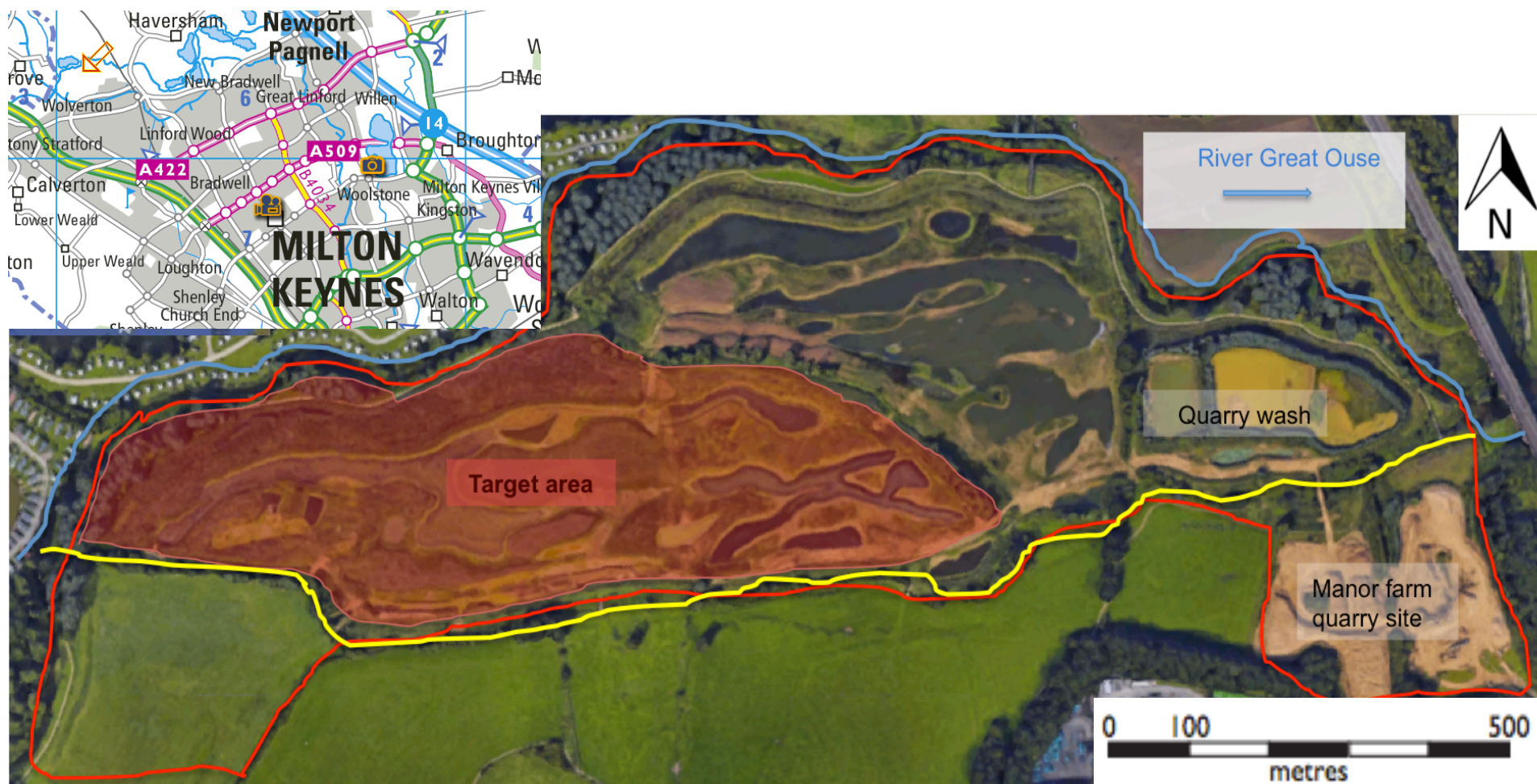


Figure 3-1. New created floodplain forest boundary at the Ouse Valley Park (red line). Blue line represents the 1 km reach of the River Great Ouse. Blue arrow shows the direction of the river. Yellow line displays the back brook channel. Red polygon shows the targeted area for the monitoring framework (i.e. further information regarding the target area in page 43-44). Source: Google Maps (2016).

The project to create the floodplain forest was planned and developed throughout the mineral extraction project, which began at the end of May 2007. Hanson removed the site's underlying sand and gravel deposits and the subsequent restoration was developed in five phases, which followed the phased gravel extraction from different areas of the site. Following removal of the sand and gravel a mosaic of new water channels, landforms, pools, marsh areas, water bodies, sand bars and small islands within the river floodplain were formed. This remodelled landscape was then handed back to The Parks Trust (TPT) to manage the site as a rich wildlife habitat. New landforms were created after each gravel extraction, and 35% woodland and other species were then planted (through direct planting and seeding). The final quarry works for the floodplain forest were completed by spring 2015. TPT had planned a statement about the tree planting as well as other habitat creation quarry works so the desired baseline state of the site was known.

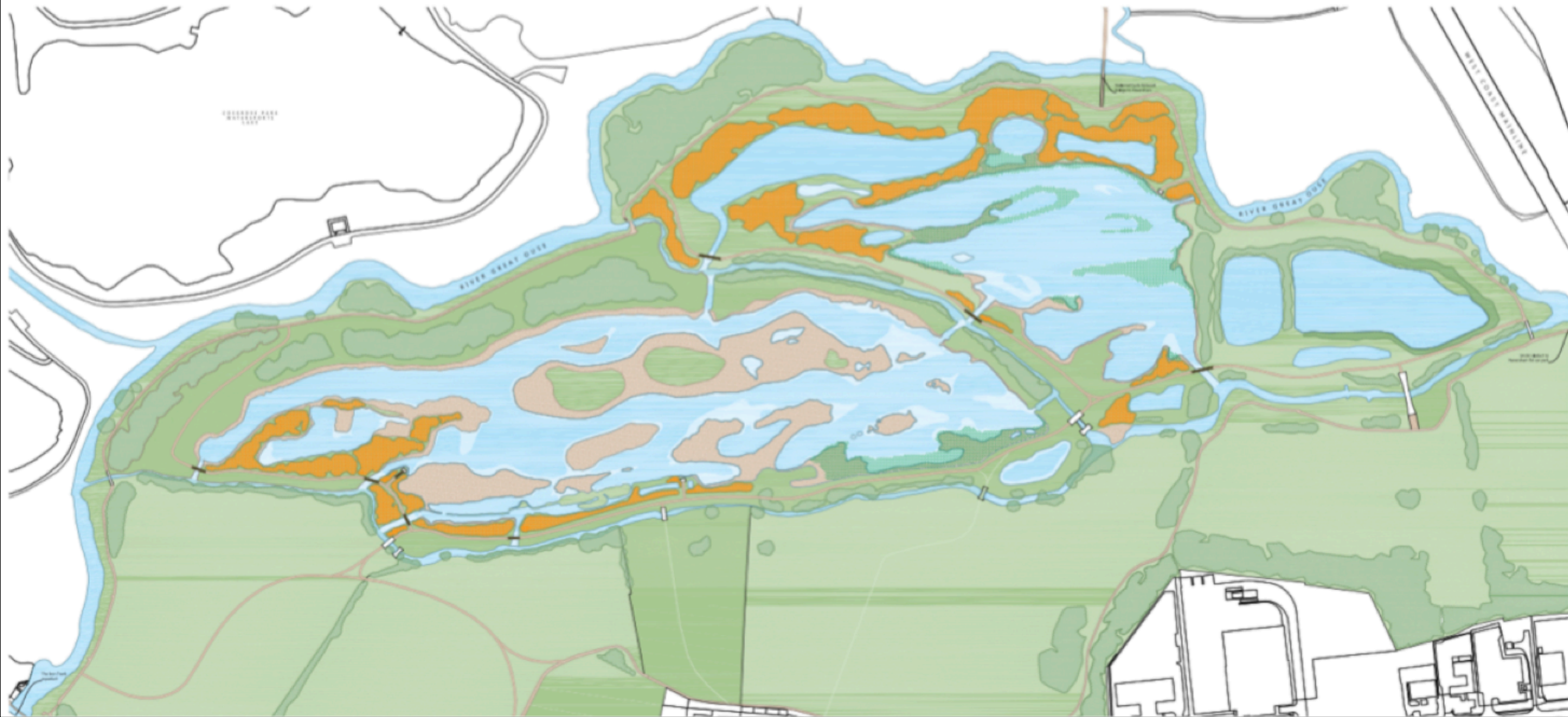
The yellow line in Figure 3-1 indicates a back brook channel at the south side of the site, which is currently disconnected from the floodplain forest. There were plans between Hanson and TPT to open it and connect it to the floodplain forest in the future. These further plans to open such channels and connect the River Great Ouse with the back brook passing through the floodplain forest were not included in this PhD research.

During the period between 2012-2015, there was only pioneer vegetation growing on site, with the exception of some mature trees that existed prior to its transformation (i.e. mature willow and poplar tree species). It will take time for vegetation (i.e. new grasses, reedbeds, plants and trees) to mature and establish across the floodplain forest. Once vegetation communities have begun to be established on site, it is expected that new habitats will emerge which will attract many bird and animal species.

It was planned during the habitat creation process to carry out weed control on site (i.e. approximately Spring/Summer 2015); this was to prepare the ground for seeding scheduled to commence in Autumn/Winter 2015. The planting proposed included a wet woodland mix, namely Black poplar (*Populus nigra*), Alder (*Alnus glutinosa*), Crack willow (*Salix fragilis*) and Downy birch (*Betula pubescens*). However, TPT planned to retain open ground to provide habitat for wading birds. It had been noted

that despite the quarry works, the site already provided habitat for many birds, which included those of conservation concern such as lapwing (*Vanellus vanellus*), common tern (*Sterna hirundo*) and redshank (*Tringa totanus*). TPT future plans are to provide lookouts for local users to watch the birds and wildlife.

TPT also wanted to encourage the natural establishment of willow on the small islands, formed within the largest water body created. In addition, they proposed to establish reedbeds and new planting throughout some of the new water bodies and existing trees, which are a familiar wetland site and again provide important habitat for birds (Phil Bowsher, The Parks Trust, personal communication). Further information on the planting areas scheme is displayed in Figure 3-2 below. In the future, TPT proposes plans for new footpaths, new boardwalk crossings, informal grass footpath and also spots for birds watching to encourage local community accessing the floodplain forest (Figure 3-3).



59

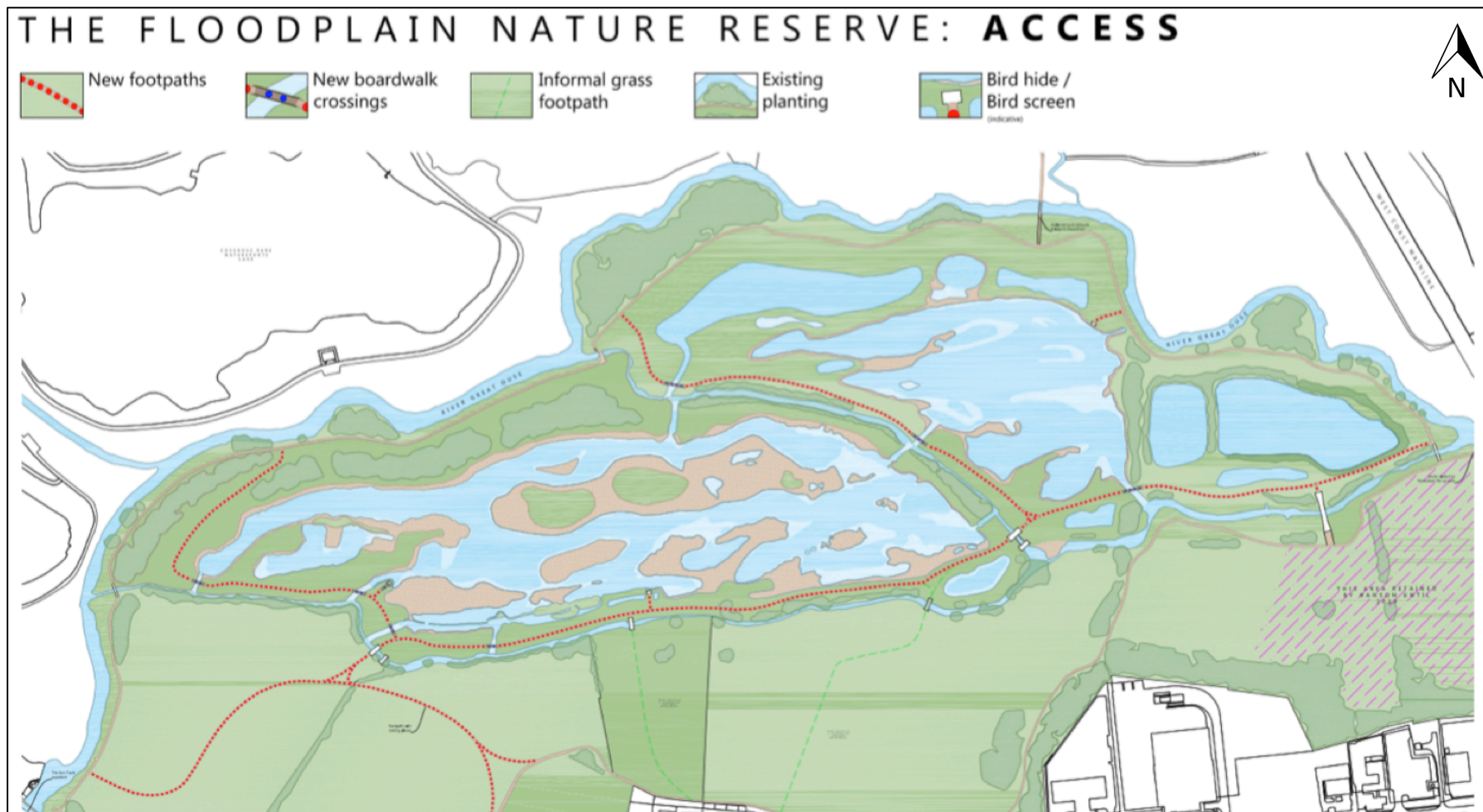


Figure 3-3 Proposed access routes for the floodplain forest. Source: TPT (2013).

3.1.2. Proposed Woodland mixes for the Floodplain forest at Ouse Valley Park

TPT were looking for woodland mixes for the site and planted areas of the 'dry woodland' mix on the higher embankments following the gravel works. However TPT were relying more on natural regeneration particularly of the wetland-type species like Willow (*Salix sp.*) and Poplar (*Populus sp.*) in the later restored and lower-lying zones with some supplementary planting of target species, primarily Black poplar (*Populus nigra*), which they obtained as locally sourced stock from the "Black Poplar Project" in Aylesbury. In the absence of a specific plan TPT did this random planting in terms of how they observed the levels at the time and the developing habitats in the site rather than following a reasoned plan as will be proposed in this project using topographical and hydrological levels across the site. They hoped that the developing natural regeneration would be a good indicator of where the different vegetation communities will develop, and they adapt their planting and management through time to what they observed at the site. The sites will likely change further as it develops and further planting will occur following the installation of paths and bird hides (from the end 2015-early 2016). Once the installations are finished they intend to complete planting around those areas. Table 3-1 below shows the habitat description, elevation levels and the species to be planted in the floodplain forest. These plantings were mainly in higher and drier areas and aimed to screen and buffer access routes and hides so as to reduce the potential impact on wildlife (mainly birds). TPT felt it was necessary to install the infrastructure in the best alignments and then plant around them rather than plant first and then try to fit the paths in. Hence the TPT could have benefited from a justified and focussed plan for where on the site particular species and species mixes might be expected to develop, which would need a monitoring programme in place.

The proposed communities for the site were woodland species that resemble NVC W8 semi-natural woodland ("Wet woodland" in Table 3-1). In addition to the woodland species, it was also proposed to encourage ground flora, particularly W8a *Primula vulgaris* and *Glechoma hederacea* sub-community with small areas of other types such as W22b *Viola riviniana* and *Veronica chamaedrys* sub-community (The Parks Trust, 2011). These communities were selected because they are prioritised

within the Biodiversity Action Plan (BAP) of The Parks Trust (The Parks Trust, 2011). As the development of the vegetation on site was closely linked to river water levels, ordnance datum (mAOD) was used as the reference point to calculate height above sea level in the UK.

Table 3-1 Proposed Habitat Woodland types of the floodplain forest.

Habitat	Elevation	Description	Species
"Dry" woodland	Above 61.75 mAOD - "On higher ground at margins of the floodplain"	Typical of NVC W8 ash/maple/oak woodland	<p>Mainly: Ash (<i>Fraxinus excelsior</i>) Field maple (<i>Acer Campestre</i>) Oak (<i>Quercus robur</i>)</p> <p>Minor component of: Aspen (<i>Populus tremula</i>) Small-leaved lime (<i>Tilia cordata</i>)</p> <p>Shrub layer of: Blackthorn (<i>Prunus spinosa</i>) Hawthorn (<i>Crateagus monogyna</i>) Hazel (<i>Corylus avellana</i>)</p>
"Damp" woodland	Between 61.0 and 61.74 mAOD- "on damper areas subject to more frequent flooding"	Typical of W7/W8 woodland, still predominantly ash/maple/oak but introducing small numbers of alder and downy birch, with scattered white willow, crack willow and black poplar.	<p>Mainly: Ash (<i>Fraxinus excelsior</i>) Field maple (<i>Acer Campestre</i>) Oak (<i>Quercus robur</i>)</p> <p>Minor component of: Alder (<i>Alnus glutinosa</i>) Downy birch (<i>Betula pubescens</i>)</p> <p>Scattered: Black poplar (<i>Populus nigra</i>) Crack willow (<i>Salix fragilis</i>) White willow (<i>Salix alba</i>)</p>
"Winter wet/summer dry" woodland	Between 60.5 and 61.0 mAOD	Small pockets typical of W6 alder woodland	<p>Mainly: Alder (<i>Alnus glutinosa</i>)</p> <p>With: Crack willow (<i>Salix fragilis</i>) White willow (<i>Salix alba</i>)</p> <p>Scattered: Ash (<i>Fraxinus excelsior</i>) Black poplar (<i>Populus nigra</i>) Downy birch (<i>Betula pueescens</i>) Grey poplar (<i>Populus alba</i>)</p> <p>And a few: Almond willow (<i>Salix triandra</i>)</p>
Wet woodland	Approx. 60.5 mAOD- frequently flooded wet ground alongside channels	Wet woodland dominated by native black poplar, with white, crack, almond and osier willows and willow.	<p>Mainly: Black poplar (<i>Populus nigra</i>)</p> <p>With: Almond willow (<i>Salix triandra</i>) Crack willow (<i>Salix fragilis</i>) Goat willow/sallow (<i>Salix caprea</i>) Osier willow (<i>Salix viminalis</i>) White willow (<i>Salix alba</i>)</p>

Source: The Parks Trust (2015)

Figure 3-4 displays the floodplain forest proposal proposed by Dave Southgate (Landscape architect at Hanson), which highlights the desired restored levels and the water bodies that were envisaged in the final ecosystem structure. The proposal highlights the need to take account of topography (i.e. restored levels), soil and water table levels, which were determined as the main aspects to be analysed as part of this project.

The floodplain forest landscape was designed to flood regularly when water levels in the river Great Ouse rise. This is beneficial to flood storage management due to the capacity of the floodplain water levels increasing. As the river level and water table rises, water can flow into the site via the 'back channels' that lead to the complex of low-lying landforms within the site, including gravel banks, sand bars, water bodies and small islands (Figure 3-4). It is expected that this varied floodplain habitat will mature into a diverse ecosystem supporting a wide range of plants and insects, amphibians, birds, fish and mammals such as otter and water vole.

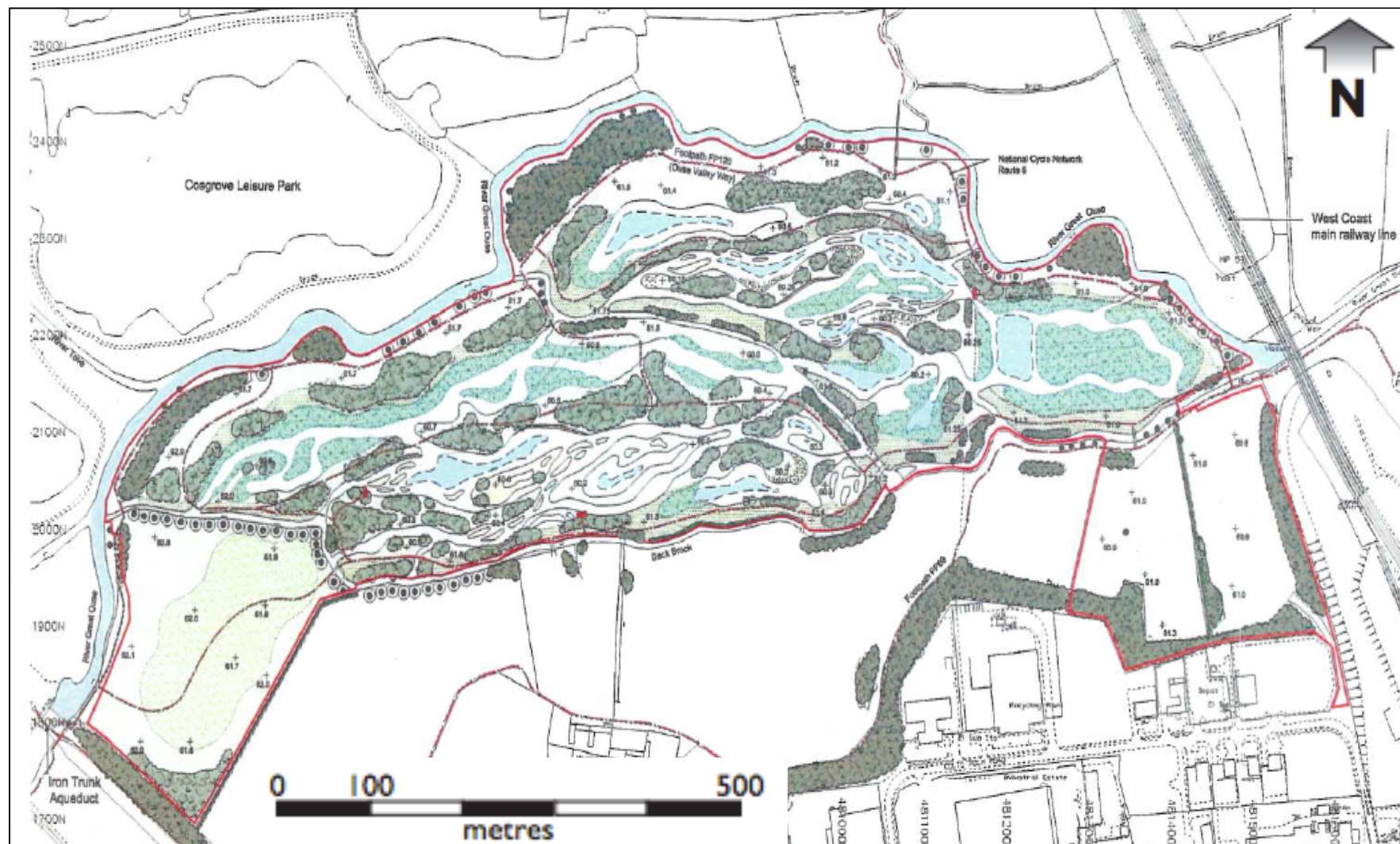


Figure 3-4 Floodplain forest proposal by Dave Southgate (Landscape architect). Source: Hanson Heidelberg Cement group (2002).

The income to TPT from the sale of the minerals from the site is held in a special fund for the creation of the floodplain forest habitats, the provision of public access facilities and the site's future care and maintenance.

Through discussions between Cranfield University (CU) and TPT, it was determined that owing to the novelty of the project and the need to learn from the project to inform future restoration projects, a research approach was appropriate in the form of a PhD study. The PhD started while the gravel extraction was on-going in January 2012 (i.e. the fifth year of gravel extraction); it meant that due to the changing nature of the project, during the PhD, the research plan had to be adapted to the changes that were occurring in an on-going project.

3.1.3. Existing data from within and in close proximity to the floodplain forest

An initial assessment of all environmental and biodiversity data existing associated with the floodplain forest site or in close proximity was undertaken at the beginning of the PhD (January 2012). A meta data sheet (i.e. The floodplain forest database in CD provided) was created including existing records collated from Cranfield University, The Parks Trust, The Royal Society for the Protection of Birds (RSPB), Hanson, Envireau water and Environment Agency databases. Table 3-2 summarises the number of points available within and in close proximity of the floodplain forest for each of the available databases. The list of datasets that are of relevance to the study is displayed in Appendix A. A map showing the location of the data is provided in Appendix B (scale on map displays the distance between sampled data).

Table 3-2 Number of records per database or studies within and in close proximity to the floodplain forest study area.

Available data	Data gathered	No of records gathered within the floodplain forest	No of records gathered in close proximity to the floodplain forest	Years available
Ecological status of water bodies data-Ecological Quality Ratio (EQR)	14 records	0	0	April 2007
Fish records-National Fish Population Data (NFPD) (species counts)	107 records of different fish species	1	1	May 2009
Water table data-Hanson loggers (water table below ground in cm)	2 loggers readings	2	0	July-September 2011
River geomorphology data-River Habitat Survey (RHS)	164 records	1	1	May 1994-September 2008
River invertebrate, plant and algae data-BIOSYS (Sample Physical Data Report)	4 records	0	3	Jan 1986- July 2012
Hydrological data obtained from ADCP or current meter-BIBER	7 records	0	0	From 1979 to current date
Hydrological data recorded by telemetry or data loggers-WISKI	3 records	0	0	From 1979 to current date
Hydrology and hydrogeology	1 study available	1	0	2002
Flood Risk Impact Assessment - Amec Environment & Infrastructures UK Ltd for Hanson	1 study available	1	0	2003

Available data	Data gathered	No of records gathered within the floodplain forest	No of records gathered in close proximity to the floodplain forest	Years available
Amphibians	1 study	0	0	May 2012
Birds	133 records	90	0	2007-2012
Soil data	51 records	51	0	2002
Geology data (Study by Ground Engineering)	40 records	40	0	1999
Geology data (Study by Hanson)	121 records	121	0	2004
Ecology: flora, fauna and habitats (study)	1 study	1	0	2002
Topography survey	45.103 elevation points	45.103 elevation points	0	December 2011

Within the floodplain forest there were information on fish records (NFPD), river geomorphology (RHS), as well as partial groundwater level records (Hanson). Further information included bird population densities, vegetation community estimates and a detailed topographical survey. For the planning application (Hanson, 2002) produced an environmental statement that included: ecological, soil, hydrology and hydrogeology and flood impact assessments.

A baseline survey was carried out within the environmental assessment for the planning application. This included flora, fauna and habitat records. Results showed that the predominant vegetation and habitat prior gravel extraction started were improved agricultural pasture under intensive management and grazing. The assessment also identified a few areas with semi-natural and amenity grassland, broad leaf plantations, swamp vegetation and pollarded trees. Overall the area was species poor.

Regarding faunal records, few species were identified around the channels (e.g. heron (*Ardea cinerea*), moorhen (*Gallinula chloropus*) and swan (*Cygnus atratus*)). Bats (*Pipistrellus pipistrellus*), barn owls (*Tyto alba*) and badgers (*Meles meles*) were the only protected species identified within the area. The wildlife interest of the site is mainly restricted to the channels within the floodplain forest. Finally, the habitats assessment identified no-UK Biodiversity Action Plan (UK-BAP) priority habitats or species are present within the site (except pipistrelle bat).

The geological studies carried out at Manor Farm focused mainly on the gravel deposits. They gave an indication about the tonnes of gravels available for extraction within the area as well as their sizes (Ground Engineering, 1999). The geology was terraced gravels overlaid by 0.3 m of topsoil, 0.3 m of made ground and varying thicknesses of alluvial clay. The gravel deposits were highly permeable (i.e. 10-50 m per day) forming an aquifer perched on low permeability clays (Hanson, 2002). The soil survey carried out by Hanson only identified one type of soil (i.e. Fladbury I Association) characterized by stoneless clay. For the assessment of the habitat outcomes of the floodplain forest restoration project further information on chemical and physical properties of the soil (specially the topsoil) was required. The land use before the extraction works started was agricultural pastureland with river-sides (public area access). The site was mainly rated Grade 3 on the Provisional Agricultural Land Classification (MAFF, 1968).

The hydrological study showed that the area receives 632 mm of rainfall per annum on average. From this, 480 mm is thought to be lost over grassland areas through evapotranspiration (Hanson, 2002). The average hydrologically effective rainfall was expected to be around 152 mm per annum (Hanson, 2002). The Environment Agency (EA) estimated that the 100-year flood level of the Great Ouse at Manor farm is 62.68 metres above ordnance datum (mAOD) at the western end and 61.79 mAOD at eastern end in 2002.

The topographical survey done in December 2011 demonstrated that the floodplain forest has a variation in elevation of approximately 8 m within the range 56.60 mAOD to 64.65 mAOD. During the survey carried out in 1999, groundwater level annual

mean was estimated to be approximately at 58.72 mAOD (Scott Wilson Resource Consultations, 1999).

Geomorphological information from a River Habitat Survey carried out in 2006 was also available within the floodplain forest (Appendix B). Unfortunately, some of the more informative quality scores (e.g. Habitat Quality Assessment (HQA) and Habitat Modification Score (HMS)) were missing from the survey. Yet, other records were available – e.g. number of trees, vegetation bars, bank vegetation, land uses and flow index among others. The survey indicated that there were a low number of trees counted on the right and left side of the 500 m reach surveyed; however, there was existing parkland or gardens closer to the sampling point and few amphibians, algae and emergent reeds were observed, which means the site had different features that compound the river geomorphology. The records for vegetation indicated that banks were vegetated along this part of the river thus preserving the river continuum theory. There were no major discontinuities observed on the banks due to erosion and anthropogenic impact along the sample reach. Note that the geomorphological condition of the site may have changed during the duration of the restoration.

The bird populations identified were typical of wetland areas and floodplains. A total of 90 species were observed and recorded in the floodplain forest from 2007 to 2012 (Appendix C). Changes in the hydrological dynamics of the floodplain may affect these populations and hence, great care must be taken when developing management guidelines for the hydrological regime of the site.

The fish species observed in 2004 along a reach of the Great Ouse falling within the floodplain forest are in Appendix C. There was not information about population structure. The survey was carried out 3 years prior the beginning of the gravel extraction works, so the species identified may not be very representative of the current situation.

In adjacent areas of the floodplain there were records of water quality (BIBER), macroinvertebrates (BIOSYS), discharge (WISKI) and amphibians. But they were considered not of high relevance for the project because they were distant to the restoration site.

After gravel extraction works in the floodplain forest there was a need for an updated baseline of the key variables which will then assist in the interpretation of existing site status and suggestion of how to go forward to look at the changes over appropriate time periods. The remainder of this chapter develops the case for specific site surveys to understand and potentially predict how changes may manifest themselves through the implementation of a robust monitoring framework of key variables, which can be applied at the site and potentially in future floodplain forest restoration projects,

Understanding what information was and was not available, provided the starting point of what key variables needed to be collected as part of the monitoring framework. Following the results from this initial assessment and analysis, the next step was to take informed decision with the stakeholders regarding the design of this monitoring framework and the key variables criteria selection.

3.2 Baseline data: key variables selection criteria

This section provides the rationale for all key variables selected as appropriate for the monitoring framework. The key variables criteria selection for the monitoring framework was based on the initial meta data and the existing data gathered of the floodplain forest prior to quarry works along with the subsequent discussion and agreement with the stakeholders. The set of key variables finally identified and agreed with the stakeholders fell within the following categories:

- Soil
- Water quality (main rivers and channels)
- Vegetation
- Hydrology (water table level)
- Topography

Soil is an essential source of nutrients for vegetation community development. The habitats (i.e. vegetation communities) will develop at different rates depending upon the nutrient availability. Measuring nutrient available in soil will therefore provide information regarding the development of specific habitat communities according to their nutrient demands.

The importance of water quality in the floodplain forest relates to its fundamental role in vegetation development directly and in the effect on the water bodies (i.e. eutrophication).

Vegetation type and distribution forms the basis of the habitats in the floodplain forest which is also linked to determinations the biodiversity, density and richness of the site (i.e. native species proliferation, natural succession, desired species).

It has been discussed in section 2.2.2 of Chapter 2 (“The link between hydrological processes and vegetation”) the existing relationship between plants and water table level interaction. Rood *et al.* (2003) stated it is the water table level rather than the flow that is relevant for most riparian processes such as seedling recruitment. Hence water table level is considered as a key variable due to the expected growth effect over vegetation communities in the floodplain forest.

Topography completes the key variable list, as it is a new created floodplain forest and there has been gravel extraction involved, it was necessary to study the evolution of the landscape over time after quarry works finish.

According to Vallauri *et al.* (2005a) each key variable should be SMRRT (Simple, Measurable, Reliable, Relevant, Timely) to be included in an effective monitoring framework. It is necessary at this stage to clarify the difference between monitoring and sampling.

Monitoring is “collecting information on an object through repeated or continuous observation in order to determine possible changes in the object”. “Sampling is used in the usual broad sense of selecting parts from a universe with the purpose of taking observations on them” (De Gruijter *et al.* 2006), where universe is defined as the natural variable that the sampling or monitoring are targeting. The understanding of both terms will be used all through this chapter and elsewhere in the thesis wherever referred to. The samples type specified here are inherent of any monitoring framework, as described in Table 3-3; this standardised approach is applied here for the specific case study of the floodplain forest at the Ouse Valley Park.

Table 3-3 Samples type inherent in any monitoring framework.

Sample type	Description
Sample	The collection of the selected parts
Sample unit	A single part that is or could be selected
Sample size	The number of sampling units in a sample
Sampling location	Position of a sampling unit in space
Sampling time	Position of a sampling unit in time (i.e. frequency)
Sampling pattern	The positions of all sampling units of a sample together from a pattern in space and/or time

Source: De Gruijter *et al.* (2006)

Dufour and Piégay (2005) suggested that a floodplain forest-monitoring framework should include a (pre- and post-) restoration survey of hydrological, geomorphic and biological characteristics. Ideally, the framework for monitoring should have been developed with an initial evaluation at the beginning of the project when gravel extraction starts and then be reappraised and be adapted over time.

3.3 Adaptive Monitoring Framework

One of the major objectives of the research (Section 1.2.2 in Chapter 1) was to design a robust adaptive monitoring framework that would be suitable for the assessment of the habitat outcomes of the floodplain forest restoration project. This section focuses on the most suitable monitoring framework approach to carry out in this case study by taking into account that floodplains are dynamic and complex systems with a number of inter-related processes (Marriott, 1998).

The term “adaptive management” was coined in 1978 by an interdisciplinary team of biologists and system analysts to describe a guiding principle for managing the interface between society and the biosphere (Gilmour, 2007a). The most suitable monitoring approach in those cases is an Adaptive Monitoring Framework (AMF) (Lindenmayer and Likens, 2010a) that enables questions driving the monitoring framework to be re-phrased as site conditions change (Figure 3-5); AMF is motivated by questions carefully posed at the outset. Lindenmayer and Likens (2010b) proposed that what makes an effective monitoring framework can only occur if it is based on suitable questions. The establishment of precise objectives and clear questions will assist in determining what to monitor because that will be founded on

the specific questions posed. Question setting, experimental design, data collection, data analysis and data interpretation are iterative steps in the AMF (Figure 3-5). It means that Adaptive Monitoring can incorporate new questions or new protocols (i.e. new technology, updated data etc.) while maintaining the integrity of the core measures (Lindenmayer and Likens, 2010a). Therefore AMF is deemed suitable for the current research, as there was on going gravel extraction and site landscaping in the floodplain forest.

The initial key steps were the development of critical questions and the design of a monitoring approach for the floodplain forest to answer the questions.

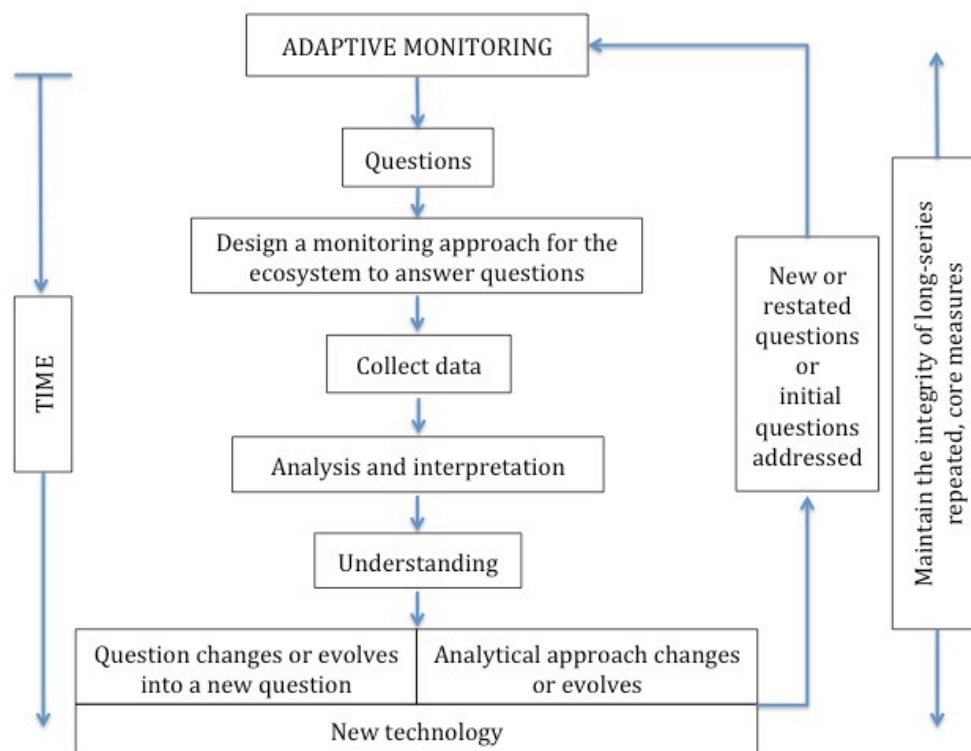


Figure 3-5 The Adaptive Monitoring Framework (redrawn from Lindenmayer and Likens, 2009, with permission from Elsevier). Source: Lindenmayer & Likens (2010a).

The indicative parameters per key variable to sample as part of an initial proposed monitoring framework plus methods are described in Table 3-4. This information was used to elaborate the justification of measurable parameters as part of the AMF

(Table 3-5) and build the baseline after gravel extraction to redefine/re-design the monitoring framework if necessary.

Table 3-4 Proposed parameters and methods. “K” stands for category.

K	Parameters	Methods
SOIL	Soil particle size distribution/Soil texture and structure	Samples analysed using a Standard Operating Procedure (SOP) based on British Standard BS 7755 Section 5.4:1998 <i>Determination of particle size distribution in mineral soil material – Method by sieving and sedimentation</i> which is identical to ISO 11277:1998.
	Total Organic Carbon (TOC)	Samples analysed using a SOP based on British Standard BS 7755 Section 3.8:1995 <i>Determination of organic and total carbon after dry combustion (elementary analysis)</i> which is identical to ISO 10694:1995.
	Water content and dry matter content	Samples analysed using SOP based on the British Standard BS 7755: Section 3.1:1994 <i>Determination of dry matter and water content on a mass basis by a gravimetric method</i> which is identical to ISO 11465:1993.
	Total Nitrogen of soil /plant material	Samples analysed using a SOP based on British Standard BS EN 13654-2:2001 <i>Soil improvers and growing media-Determination of nitrogen- part 2: Dumas method</i> .
	Phosphorus	This SOP was based on British Standard BS 7755: Section 3.6:1995 <i>Determination of phosphorus- Spectrometric determination of phosphorus soluble in sodium hydrogen carbonate solution, which is identical to ISO 11263:1994</i> .
	Potassium and Magnesium	This SOP was based on annexes D, E and G of British Standard 3882:1994 <i>Specification for Topsoil</i> .
WATER (freshwater)	pH & Conductivity	Probe and meter (more accurate), litmus paper, and a field kit. Indicator paper and electronic determination.
	Phosphorus	Total phosphorus in water by persulphate digestion, based on a method by W. A. House, F.H. Denison, modified by T. Butler & P. Haygarth 3/99. Reference: Eiseneich, S.J., Bannermen, R.T., Armstrong, D.E. (1975). <i>A simplified phosphorus technique</i> . Environ. Lett. 9, 45-53.
	Phosphate-P	Method supplied by Burkard SFA-2000 auto analyser. The method used is “Automated Ascorbic Acid Reduction Method”, p 4-114, Standard Methods for the Examination of Water and Wastewater, 19 th Edition, 1995.
WATER (freshwater)	Ammonium	Method supplied by Burkard SFA-2000 auto analyser. The method used is “Automated Phenated Method Method”, p 4-81, Standard Methods for the Examination of Water and Wastewater, 19 th Edition, 1995.

K	Parameters	Methods
WATER (freshwater)	Total Oxides of Nitrogen (TON)	Method supplied by Burkard Scientific. "Automated Hydrazine Reduction Method", p 4-90, Standard Methods for the Examination of Water and Wastewater, 19 th Edition, 1995. Samples have been analysed using the Burkard SFA-2000 auto analyser.
	Total Suspended Solids (TSS)	"Automated Phenated Method", p 4-81, Standard Methods for the Examination of Water and Wastewater, 19 th Edition, 1995. Using the Burkard SFA-2000 autoanalyser.
WATER TABLE	Water table level	Data loggers and barologger if available. Manual water table level dipper.
VEGETATION	Density	Measured by counting the number of individuals of each species within the quadrat (Bullock, 2006). Bullock (2006) states that for sessile plants density is a straightforward measure in comparison with that for some animals, which can move in and out of the area during the census period.
	Frequency	Can be measured in two ways. One is to use the quadrat as a sampling unit. A large number of quadrats are placed in the study area and the proportion of quadrats containing species is counted. A more local measure of frequency can be derived if the quadrat is subdivided into a grid and the percentage of grids squares containing the species is calculated (Bullock, 2006).
	Cover	Can be measured by estimating visually the proportion of the quadrat occupied by each species (Bullock, 2006).
	Dead/alive individual per target species	Measured by counting the number of dead/alive species within the quadrat.
TOPOGRAPHY	Elevation patterns	Aerial photography by using Unmanned Aerial Vehicle (UAV).

For the monitoring framework, justification of parameters measured for the floodplain forest case study in the context of the AMF are summarised in **Table 3-5**. It is important that the integrity of long-term data record is not corrupted and that some questions cannot be posed with a long term dataset, so a new investigation may need to be carried out (Lindenmayer and Likens, 2010b). It means that due to the dynamic nature of the project, parameters may be incorporated in the long-term basis.

Table 3-5 Justification per measurable parameters as part of the monitoring framework designed in context of the Adaptive Monitoring Framework. “K” stands for category.

K	Parameter	Justification
Soil	Soil particle size distribution/Soil texture and structure	To determine the grain (granular) size distribution of soil samples. Texture gives a first indication of what to expect from other properties (e.g. SOC and nutrient status).
	Total Organic Carbon (TOC)	It relates to the amount of organic matter that is available for plants. It depends on soil texture, climate, vegetation and land use/management.
	Water content and dry matter content	Quantification of water content in soil samples.
	Total nitrogen/plant material	Important nutrient for plant development. The vegetation will develop at different rates depending upon the nutrient availability.
	Phosphorus	Important nutrient for plant development. The vegetation will develop at different rates depending upon the nutrient availability.
	Potassium & Magnesium	
Hydrology	Water table level	Rood <i>et al.</i> (2003) stated it is the water level rather than the flow that is relevant for most riparian processes such as seedling recruitment.

Vegetation	Density	Density is the standard count of the number of organisms in a prescribed area (Bullock, 2006). It informs on how many plants are present within the sample area. The higher the density the less likely the area is to suffer erosion.
	Frequency	Bullock (2006) suggests it is measured to know the chance of finding an individual of a species in the sample area. The higher the frequency the higher the presence of the specie within the area is.
	Cover	To know the size-based measure of the area covered by the aboveground parts of plants of a species when viewed from above (Bullock, 2006). This could be an indication of erosion likelihood.
	Dead/alive individual per target species	To know the standard count of the number of dead/alive plants in a prescribed area. This informs on the success of the re-vegetation.
Water quality	pH & Conductivity	The pH value of a stream may affect organisms living in the water or changes in pH in a stream can be an indicator of increasing pollution or some other environmental factor. It is useful to know the pH present in this water in order to assess if the water is suitable for the desired species. Conductivity measures the water's ability to conduct electricity, which provides a measure of what is dissolved in water. Higher pH indicates alkaline water. Lower pH indicates acidity. Vegetation communities, each being adapted to a variety of conditions, have certain preferences in pH for rainfall and soil conditions. One common effect of a high pH, or of a high soil pH, is chlorosis, more commonly observed as the yellowing of the leaves whereas leaf veins remain green.
	Phosphorus	Important for plant growth. Control eutrophication. Eutrophication means the water becomes rich in nutrients; plants and organism grow in abundance. The problem is when this plants and organisms die, they rot and the water quality drop. It reduces the dissolved oxygen present in water due to the proliferation of algae. Water may become no longer suitable for living organisms and as a consequence the ecosystem may be seriously affected.
	Phosphate-P	
	Ammonium	Ammonium is a good indicator of the presence of microbial putrefaction in plants and animals. Ammonium ions are main form available for uptake by plants and are a proxy variable for vegetation development.

Water quality	Total Oxides of Nitrogen (TON)	An excessive quantity may produce eutrophication. As an essential component of life, nitrogen is recycled continually by plants and animals, and is found in the cells of all living things. Affected by agricultural run-off.
	Total Suspended Solids (TSS)	Provides an actual weight of the particulate material present in the water sample. It is important in aquatic systems because it reduces the penetration depth of surface light, thereby photosynthesis as well as the visual range of aquatic animals (Jones <i>et al.</i> 2006).
Topography	Elevation patterns	As it is a new created floodplain forest an there has been gravel extraction involved, it is necessary how the landscape has changed after quarry works finish.

Gilmour (2007a) stated it is better to think of the adaptive management process as a series of action learning loops rather than a straight line from planning to the achievement of planned outcomes. **Figure 3-6** shows an overview of the proposed measurable parameters per key variable.

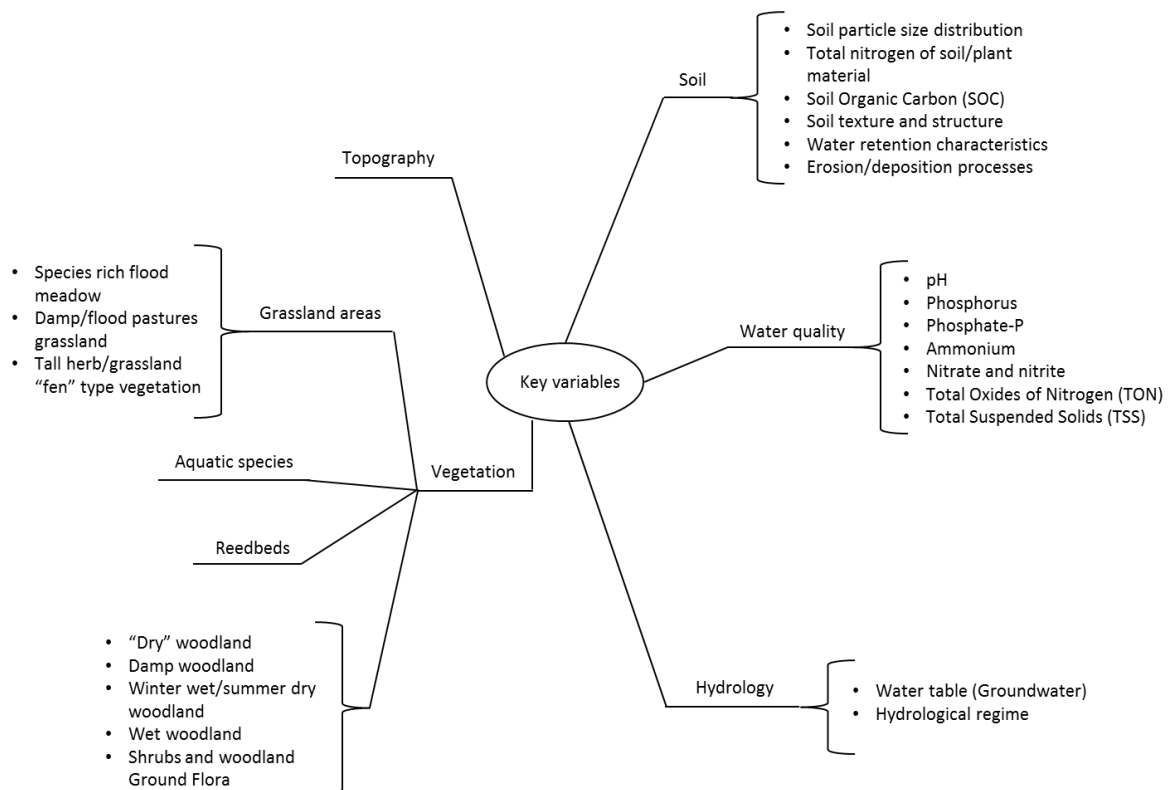


Figure 3-6 Proposed diagram showing the key variables and an indicative list of measurable parameters as part of the AMF.

The aim of the monitoring framework here defined is to provide an overall appraisal and guidance of the restoration project. This was required when considering the final success (or not) of the restoration when assessing habitat outcomes. It is important to note that the definition of success in restoration is site dependent because of (i) the high spatio-temporal variability in freshwater ecosystems, (ii) the large number of restoration techniques available and (iii) the response of the ecosystem to a particular restoration scheme does not allow for the prescription of general indicators of success. A common method to assess success may be through comparing the stages of evolution of a restored site with a control or reference site (i.e. a good

analog of the site to be restored) (White and Walker, 1997). Reference landscapes provide information about composition, ecological processes and functioning, and, crucially but often the most difficult to pinpoint, cyclical changes over time (Dudley, 2005). Ruiz-Jaen and Mitchell Aide (2005) stated that including reference sites will increase restoration costs, but recognised that they are essential for evaluating restoration success. The research here provided much of the necessary data and a robust monitoring framework with which to determine the stages that the restored floodplain forest would go through. Sayer (2005) states that broadly shared understanding and acceptance by all stakeholders is fundamental to the success of any restoration project. Five to ten years is the minimum period needed to assess questions like natural dynamics, nursery and plantation techniques for native species (Oviedo, 2005). For the case study, the concept of reference site was discounted, as no reference values from other floodplain forest restoration projects of similar characteristics were available and due to the short period that a PhD research lasts. It was decided to build a baseline reference level to quantify the spatio-temporal changes in measurable parameters of the key variables that occur at the site.

Pastorok *et al.* (1997) proposed an ecological planning framework where one of the primary steps is to develop a restoration hypothesis regarding responses to specific habitat manipulations or transplant efforts. Due to the novelty of the project, and the uncertainty of how habitats will develop in a future, a research hypothesis was proposed to complement the AMF.

For the scope of this project such a framework was named “Hypothesis driven Adaptive Monitoring Framework”. The research hypothesis for the case study of the new created floodplain forest was used to define the expected habitat outcomes of the restoration if the system were to evolve under a set of new topographical and hydrological target conditions (i.e. the assumption was made that after gravel extractions, a new topographical profile and water table level would be apparent in the floodplain forest). Background information was accessible, however most of the data fell over adjacent areas. Based on Chapter 2 and the assessment of any existing data within and in close proximity of the floodplain forest, a hypothesis was posed. The hypothesis was developed based on the author’s current understanding of the floodplain forest system in the context of the review of the literature review.

The hypothesis to be incorporated into the AMF was as follows:

The ratio of wet/dry vegetation within the floodplain forest is determined by the site topography and water table level.

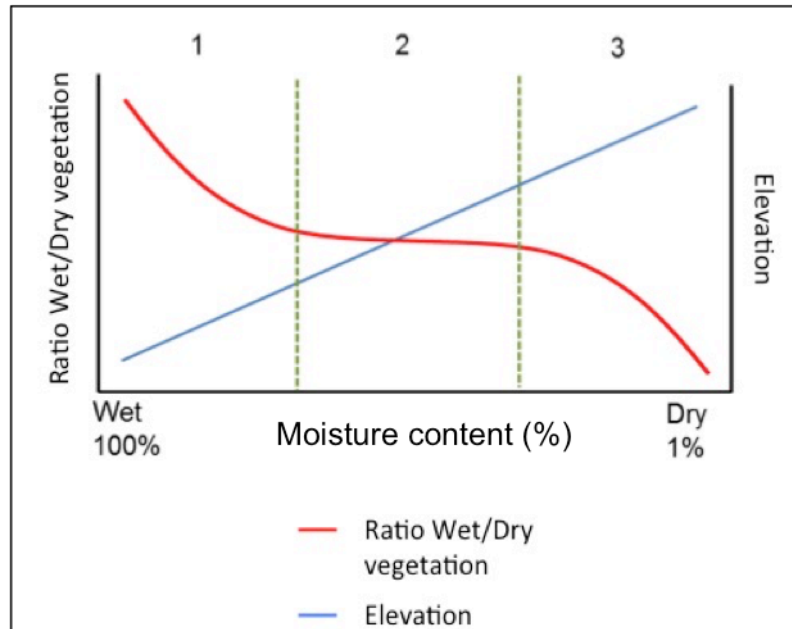


Figure 3-7 The hypothesised relationship between wet/dry vegetation versus elevation and water table level. The x-axis represents the moisture content (%) (i.e. water table). Dash green lines split the floodplain into 3 (relative) strata based on the preferences of vegetation communities to elevation range (i.e. topography) and water table demands.

Figure 3-7 shows the basic expected relationship between elevation versus water table level and its effect on wet/dry vegetation in the floodplain forest site. The blue line represents the range of elevation from wet to dry vegetation. The red line represents the ratio between wet/dry (i.e. aquatic/terrestrial) vegetation. The plot has been divided in three strata based on the assumption that distinct types of communities are expected to develop in the new created floodplain forest based on their water demands and their elevation above the water table. The rationale behind these strata boundaries choice and its numerical quantification are further explained in the next section (*Strata numerical quantification*, page 95).

It is expected that there would be species that could tolerate wetness (100% in stratum 1), species that could tolerate dryness (stratum 3) and species that preferred

an intermediate position between wet-dry extremes (stratum 2). Wet vegetation in stratum 1 encompasses species such as Reeds (*Phragmites australis*), White lily (*Nymphaea alba*) and Gipsywort (*Lycopus europaeus*) in lower areas whereas dry vegetation in stratum 3 includes Common sallow (*Salix cinerea*), Blackthorn (*Prunus spinosa*) and Hawthorn (*Crataegus monogyna*) among others in higher areas. Stratum 2 is the area where the ratio of wet/dry vegetation is more balanced. It is the point at which vegetation starts changing from wet to dry communities. The principle behind the hypothesis is that each vegetation community, both wet (aquatic) and dry (terrestrial), will fit somewhere in the graph (Figure 3-7) according to elevation and water table level within the floodplain forest.

Gowing (2004) developed a study demonstrating that specific lowland wet grassland communities are more adapted to different water-table depth zones. This study supports the above general relationship (Figure 3-7) holding for grassland communities. However, it was unknown whether the hypothesis holds true for the floodplain forest species and in particular, for the case study area. Therefore, part of the proposed monitoring framework aimed at testing the hypothesis.

3.3.1 Proposed survey design

Determining the relationship between dry to wet vegetation ratio and elevation and water table level was necessary to understand the effect that a change on key variables will have in the floodplain forest over time. This required spatially located data therefore, at each sampling point all the parameters per key variable needed to be sampled at one time. This requirement translated into the selection of priority variables that drive the design of the proposed monitoring framework by defining the location and number of samples. Prior to any fieldwork the basic monitoring framework was designed and, vegetation was deemed the key variable. Ruiz-Jaen and Mitchell Aide (2005) suggest parameters associated with vegetation structure to be the driver of restoration appraisals because they are easy and rapid to measure and usually present little seasonal variation. Moreover, vegetation patterns could be directly associated to habitat mosaics and would fit with the main aim of the research (i.e. assessing habitat outcomes). The sampling of the remaining key variables (i.e.

soil, water table level etc.) had to conform to the sampling pattern specified for the priority variable.

Despite vegetation being chosen initially as the principal proxy variable of the monitoring framework, vegetation development was scarce after the recent gravel extraction on site. It became clear that the floodplain forest would need more time for species communities to establish and develop. Due to the lack of vegetation, the option of using it as a proxy was discarded.

As a new proxy variable, elevation was then chosen to be the focus of the monitoring framework. At this stage of the research (2012), topography data collected by Hanson in December 2011 were used for making subsequent analysis (Digital Elevation Model, Kriging etc.) and integrated results in the design of this monitoring framework. It was expected that due to quarry works and on progress gravel extraction within the floodplain forest, access to some parts of the site would be denied due to Health & Safety reasons. Extreme weather conditions (i.e. cold, flooding, mud etc.) and waterlogged areas also were significant reasons for Hanson and TPT to overrule any fieldwork in the floodplain forest.

Elevation was used as a proxy to identify vegetation patterns and mosaics. According to the hypothesis it was assumed that vegetation communities will develop according to different elevation strata and different water table demands. High points in elevation within the floodplain would be associated with less water table dependent vegetation communities such as woodland areas with Aspen (*Populus tremula*) and Small-leaved lime (*Tilia cordata*), whereas lower areas in elevation would be expected to represent highly water table dependent vegetation communities such as White willow (*Salix fragilis*) and some aquatic species (Yellow iris (*Iris pseudacorus*), Watercress (*Rorippa nasturtium-aquaticum*)) (Street, 2002). It is expected that species-rich mosaic would develop in situations where topography is varied and provide a great variety of water levels in a wetland habitat. The idea was to use elevation to maximise the diversity of vegetation communities (i.e. habitats) captured with the sampling strategy; the larger the topographical variability, the larger the habitat diversity represented. For this purpose, through the PhD research a Digital Elevation Model (DEM) was constructed of the floodplain forest and by

using interpolation techniques with inputs of the topography data of 2011. As DEM outputs are quite sensitive to the interpolation technique selected, two different interpolation methods were used: Inverse Distance Weighted (IDW) and Kriging. Results for the kriged surface and the associated errors are displayed in Figure 3-8 and Figure 3-9 respectively.

IDW uses weighted values measured in a local neighbourhood to estimate the value of a target variable at a non-measured location whereas kriging takes into account the way that the property varies in space. Webster and Lark (2013) state that it is an effective procedure to calculate local weighted averages using a window which can be moved over the region of interest to create as many local predictions as desired. Kriging is based on the assumption that points that are close to one another are more alike than those that are farther apart. Mueller *et al.* (2004) state that IDW procedure is simple and quick, whereas Kriging provides a best linear unbiased estimate of an unmeasured value calculated from weighted values measured in a local neighbourhood. The advantage of Kriging over IDW is that Kriging provides an estimation of the prediction error; this is why Kriging was used to generate the DEM in the floodplain forest.

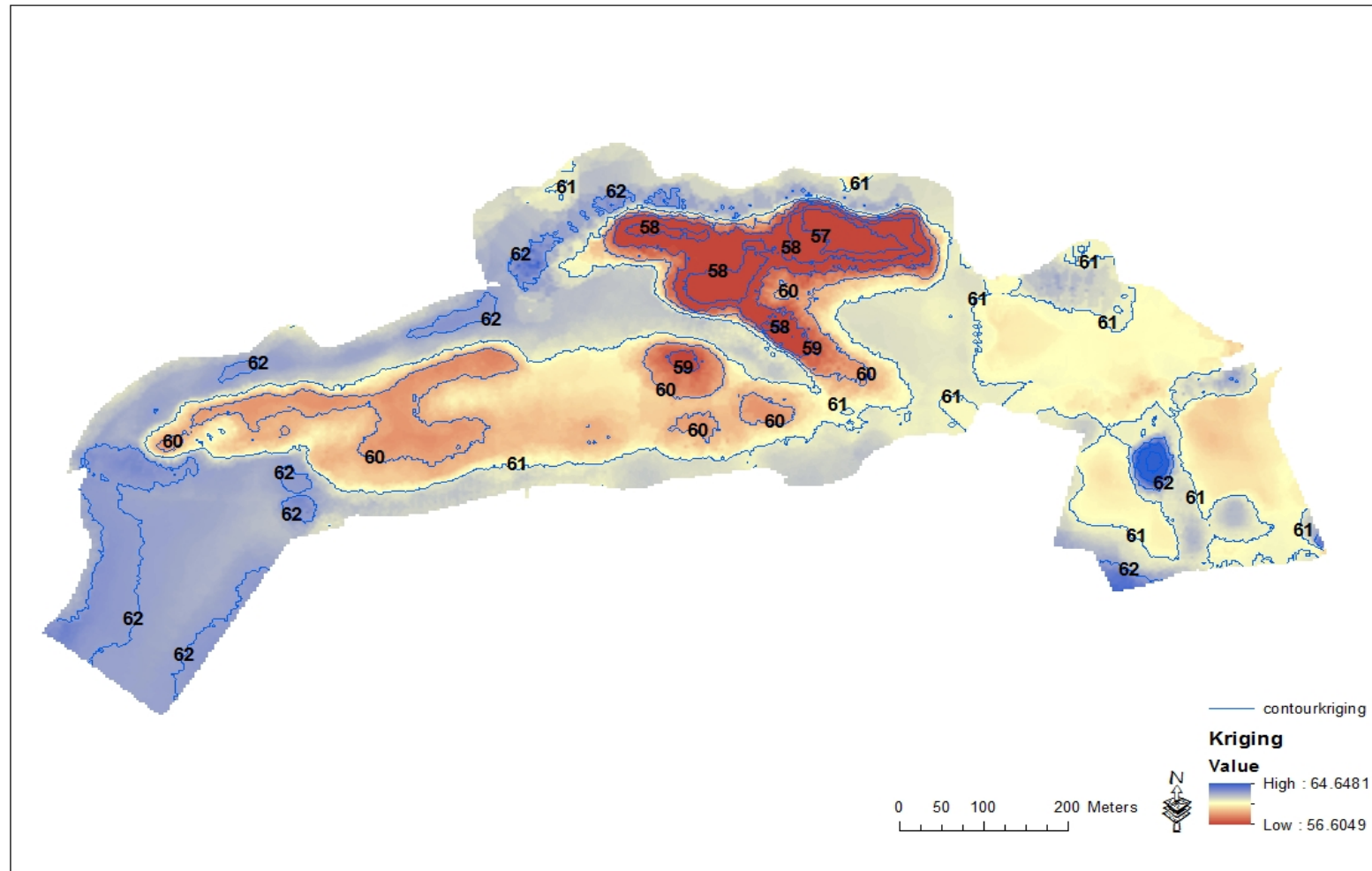


Figure 3-8 Digital Elevation Model (DEM) in mAOD for the floodplain forest obtained through Kriging interpolation technique.

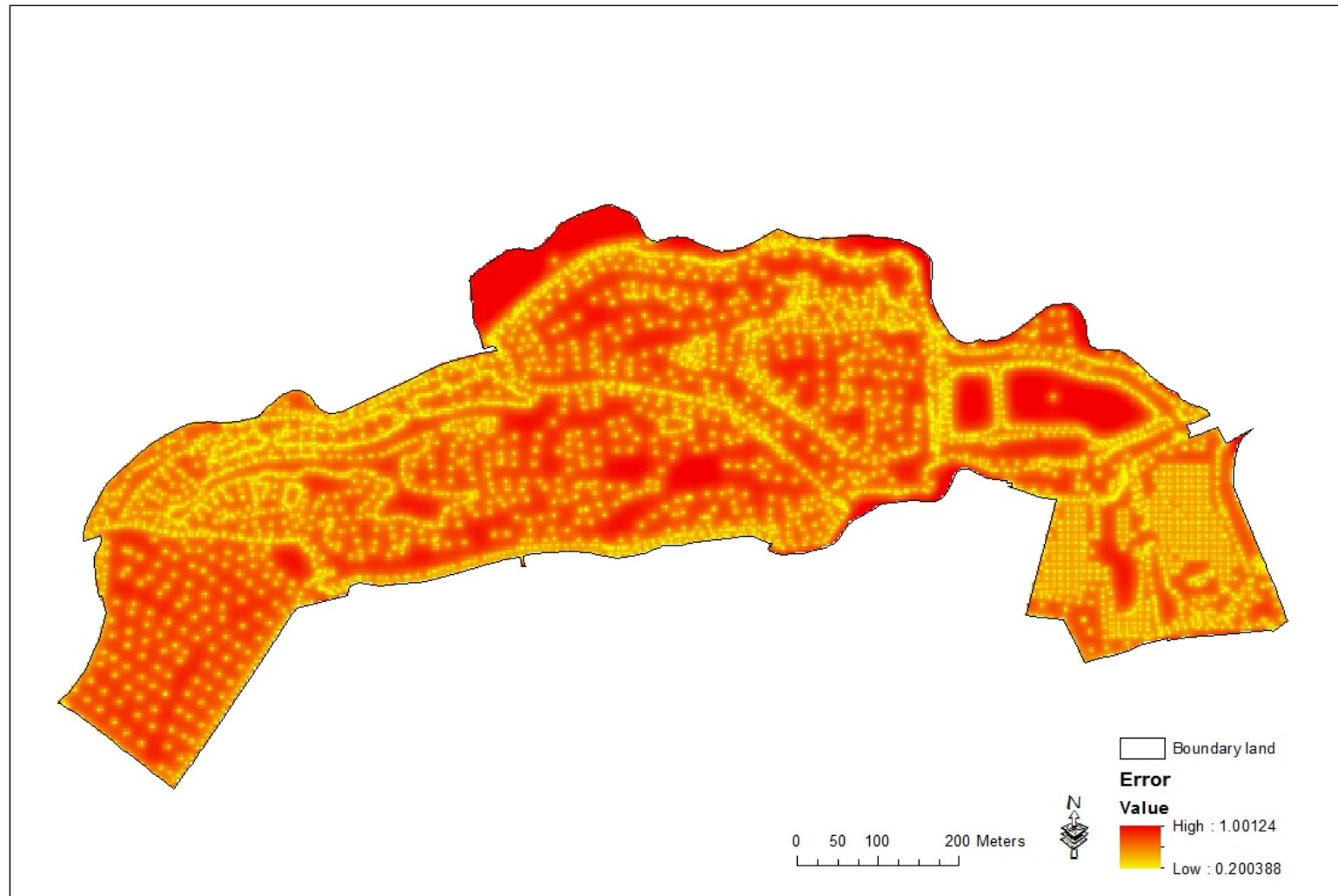


Figure 3-9 Maps of errors in mAOD derived from the interpolated surface shown in Figure 3-8 by using kriging technique.

A total of 40 transects were drawn along the interpolated surface in a first attempt to quantify the variability in elevation. Transects were used because they conform to the way that vegetation is generally sampled. For instance, Bullock (2006) states that “transects are commonly used to survey changes in vegetation along an environmental gradient or through differing habitats”. To cover an area properly, a number of independent transects should be walked (Greenwood and Robinson, 2006). The idea for these transects was to capture as many different habitat features as possible (e.g. low land points, high land points, water, vegetation etc.), ensuring that they would be representative of all the habitats present. However, one single transect along the floodplain would only provide an imprecise estimate for the whole area and it is very likely not be representative of the vegetation communities found in the floodplain forest. Greenwood and Robinson (2006) suggest that to increase precision and representativeness, it needs more than one sampling unit. For coverage of the site, a set of 20 transects lines from west to east (Figure 3-10) and a set of 20 transects lines from north to south were applied (Figure 3-11).

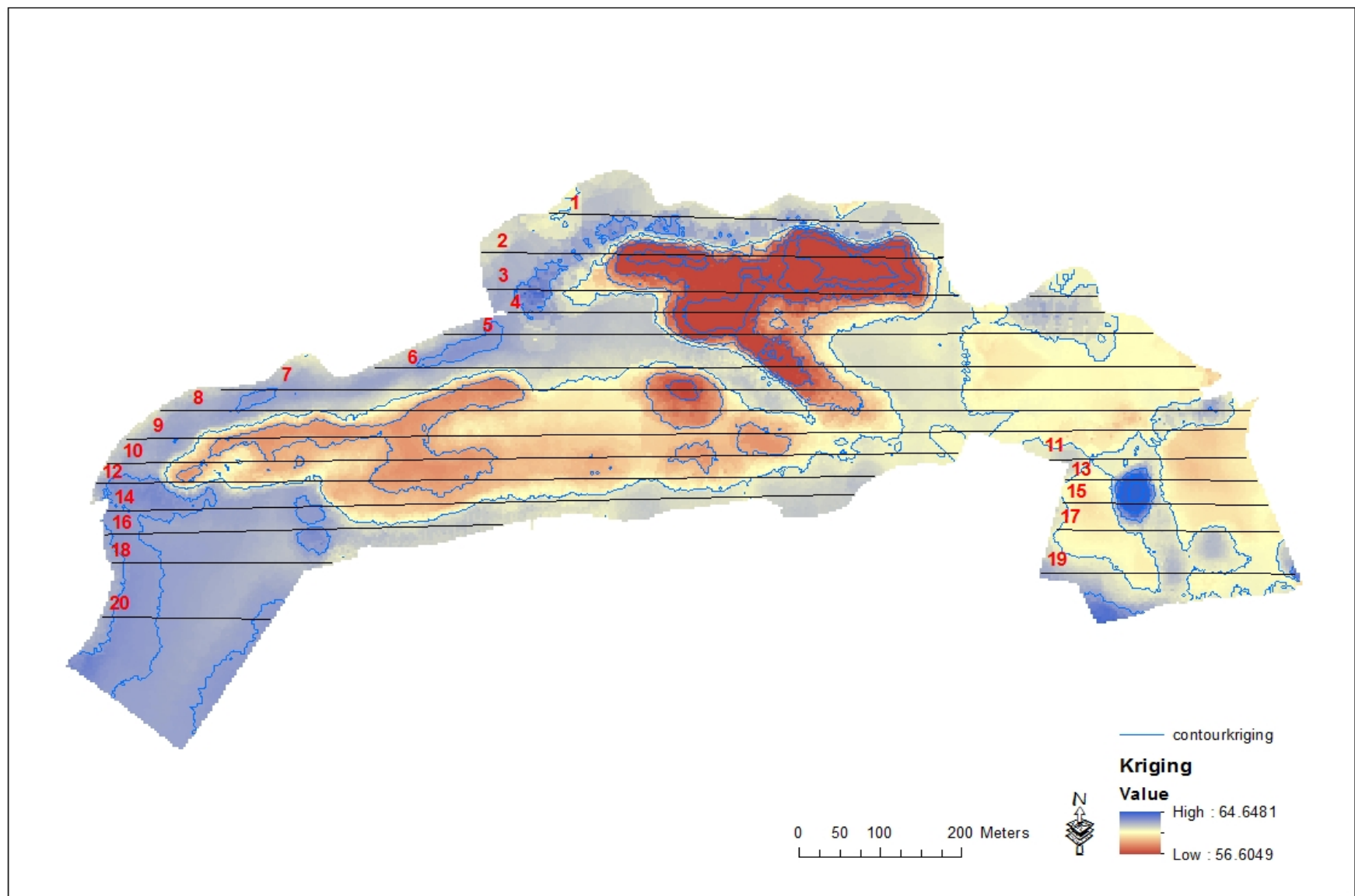


Figure 3-10 Set of 20 transects lines from west to east along the floodplain forest (in mAOD).

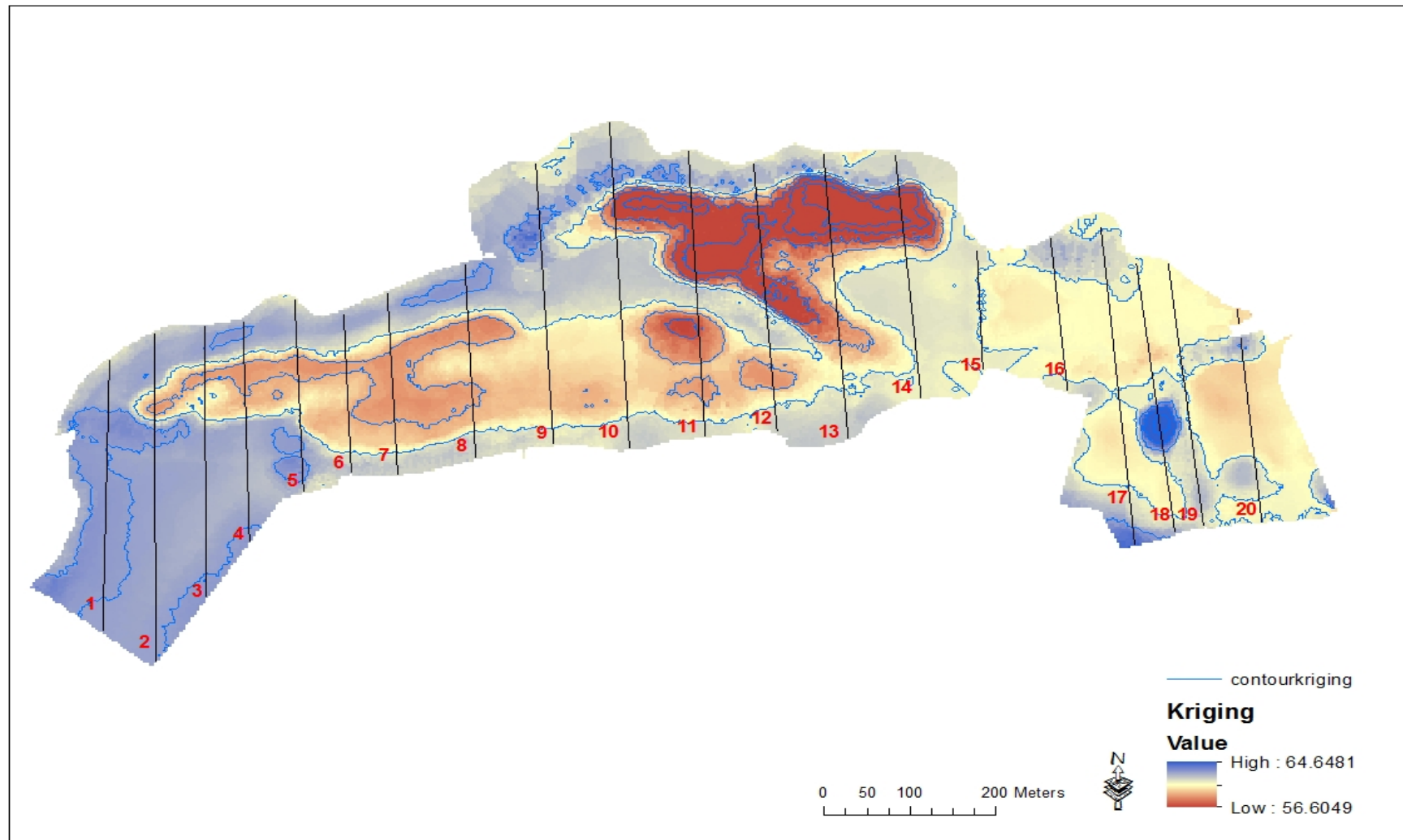


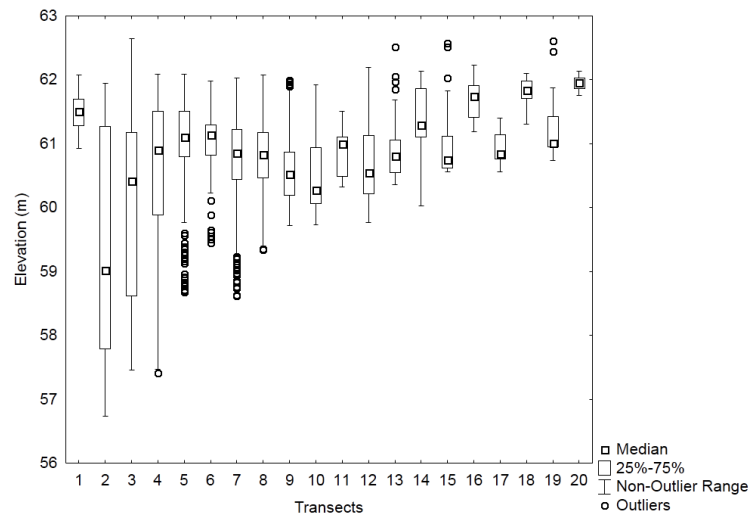
Figure 3-11 Set of transects lines from north to south along the floodplain forest (in mAOD).

Transects were drawn from west to east at intervals between 50-24 m and from north to south at intervals between 38-96 m. Transects were distributed evenly over as much area of the floodplain as possible. Cross sections corresponding to each transect lines both west to east and north to south show the topographic variability in Appendix D and Appendix E respectively.

A box plot showing the elevation (m) ranges for a sub-set of transects running from west to east and from north to south along the floodplain was generated, Figure 3-12 (a) and Figure 3-12 (b) respectively. Intervals on the right (1, 2 and 3) along with the red dash lines represent the three strata associated with assumed vegetation communities in the floodplain forest specific to the topography and the water table level (water tolerant species, wet-dry species and dry tolerant species based on the hypothesis in Figure 3-7 in page 83). The topography data collected in December 2011 were used to defining the elevation range (lowest topographical point was found at 56.60 mAOD and the highest topographical point was found at 64.65 mAOD) for doing the statistical analysis in Figure 3-12.

Figure 3-12 (a) shows that transects 2, 3 and 4 (west to east) had high variability in elevation, whereas transects 18 and 19 showed low variability. Figure 3-12 (b) compares north to south transects, with transects 11 and 12 having the largest variability and transects 1, 2 and 15 the lowest variability. It is clear from Figure 3-12 that selection of equally spaced/regular grid transects may not be the best way to sample the landscape to determine the vegetation development distribution over the site. This is because some of the transects do not capture the full topographical variation (i.e. linked to the potential range of habitats that could develop) over the floodplain forest site. For example, if transect 18 is selected from Figure 3-12 (a) vegetation communities that may develop in the wet areas would be missed. Yet, if transects with higher variability were to be selected (e.g. transect 2 in Figure 3-12 (a)) a large number of elevation points will be required given that these are the longest transects. It is necessary therefore to ensure all the habitats (i.e. vegetation communities) within the floodplain forest are sampled.

a)



b)

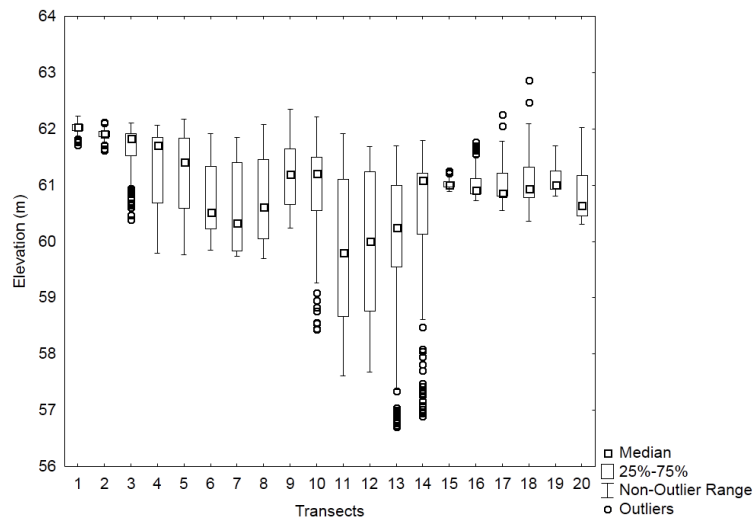


Figure 3-12 (a) Box plot showing the elevation (m) ranges for the set of selected transects running from west to east. (b) Box plot showing the elevation (m) ranges running from north to south along the floodplain. Elevation is reported in metres above ordnance datum (mAOD).

In terms of typical floodplain forest species, no studies on growth of the native species relevant to the floodplain case study were available. The author based her understanding of how woodlands species are affected by elevation patterns and water table changes by using other countries examples. Hence, the reference to successful seedling growth of a close taxonomic relative the cottonwoods (*Populus deltoides*) that have been shown to establish at elevations from about 0.6 m to 1.5 m above the base flow (Mahoney and Rood, 1998) has been used. The same value for

this case study has been assumed. Cottonwoods (*P. deltoides* and *P. Fremontii*) are susceptible when the water table drops below their rooting zone and this cause seedling death where water levels can drop faster than roots can grow (Oregon State University, 2002). It was expected due to the water table variation that Poplars (*Populus sp.*) found in the British floodplain forest would be responsive to flood and drought periods as cottonwood are. Both species come from the same genera and they are both susceptible to flooded or drought conditions with the exception of different water table levels ranges, but the rationale of being affected by hydrological changes on their rooting zone was considered comparable.

Poplars in United Kingdom (UK) typically grow in or on the border of alluvial, riparian and wetland habitats and are well adapted to seasonal flooding; they can tolerate temporary anoxic conditions while the moist and evaporation of surface water provides an ideal environment for seeds germination. When soil moisture remains high enough for roots to grow down in the soil at the same level that the saturated waterfronts diminish, and then the regeneration is considered successful (Isebrands and Richardson, 2014).

Sandbar willow (*Salix interior*) in America is native along riverbanks and is found along streambeds. It does well in moist sites, surviving severe flooding but it is not drought tolerant (from <https://www.ag.ndsu.edu/trees/handbook/th-3-65.pdf>). Willows in UK need plenty of moisture during seed germination and seedling establishment. However, after that stage, constant soil moisture is not as important to the survival of many willow species (Skvortsow, 1968, 1999, Argus, 1986). Willows colonise water margins, wet zones and open habitats that are favourable for seed germination. Due to its adaptation to withstand root exposure, heavy sediment deposition and wind erosion, willow can survive in the constantly dynamic floodplains forests (Isebrands and Richardson, 2014).

Both Poplars and Willows depend on river flow and stream size and nature. This assumption would be consistent with the knowledge that large rivers considered for the RBM are under more gradual stage changes as they have tributaries to produce the overall river flow.

Strata numerical quantification

As part of the hypothesis (Figure 3-7), the floodplain forest was divided into three indicative strata that were used to assess how the monitoring approach represented the habitats progression (i.e. vegetation communities) according to their water preferences and elevation pattern.

These three strata (Table 3-6) were defined based on:

- Topography data gathered in 2011 (lowest level at 56.60 mAOD and highest at 64.65 mAOD).
- The groundwater level reported in 1999 (58.72 mAOD).
- The Recruitment Box Model reference value assumption (as explained in Chapter 2 “2.3.2. Recruitment box method for woodlands: cottonwoods and willows”) for cottonwoods (*Populus angustifolia* and *Populus balsamifera*) and sandbar willow (*Salix exigua* and *Salix drummondiana*) (Amlin and Rood, 2002). According to Mahoney and Rood (1998) the base flow associated with the river usually represents the typical low stream stage during the late summer or autumn seasons. Mahoney and Rood (1998) stated that 0.60-1.5 m above the base flow was generally the right conditions for poplar roots to grow in North America (the higher value relating to sites with fine-texture substrates; as has the floodplain forest site). It is the base flow that defines the groundwater zone when assuming the river is horizontally connected with the water table. Hence, the assumption made was that the base flow and low stream stage (i.e. groundwater) were at the same level in the floodplain forest. Therefore, the recruitment box extended up to 60.22 mAOD (58.72 mAOD + 1.5 mAOD above base flow = 60.22 mAOD).

Elevation points (n=45103) of a topographical survey in 2011 were distributed according to the three strata defined above (Figure 3-13). By knowing these ranges and the total area of the floodplain (50 ha), surface (ha) per stratum and % of the floodplain were also calculated. Note that most of the elevation points fell in stratum 3 (Table 3-6).

Table 3-6 Information per stratum in the floodplain forest in 2012.

Stratum	Surface per stratum (ha)	Elevation range (mAOD)	No of elevation points	% of the floodplain
1	2.71	56.60-58.72	2447	5.43
2	6.74	58.72-60.22	6076	13.47
3	40.55	60.22-64.65	36580	81.10
Total	50		45103	100

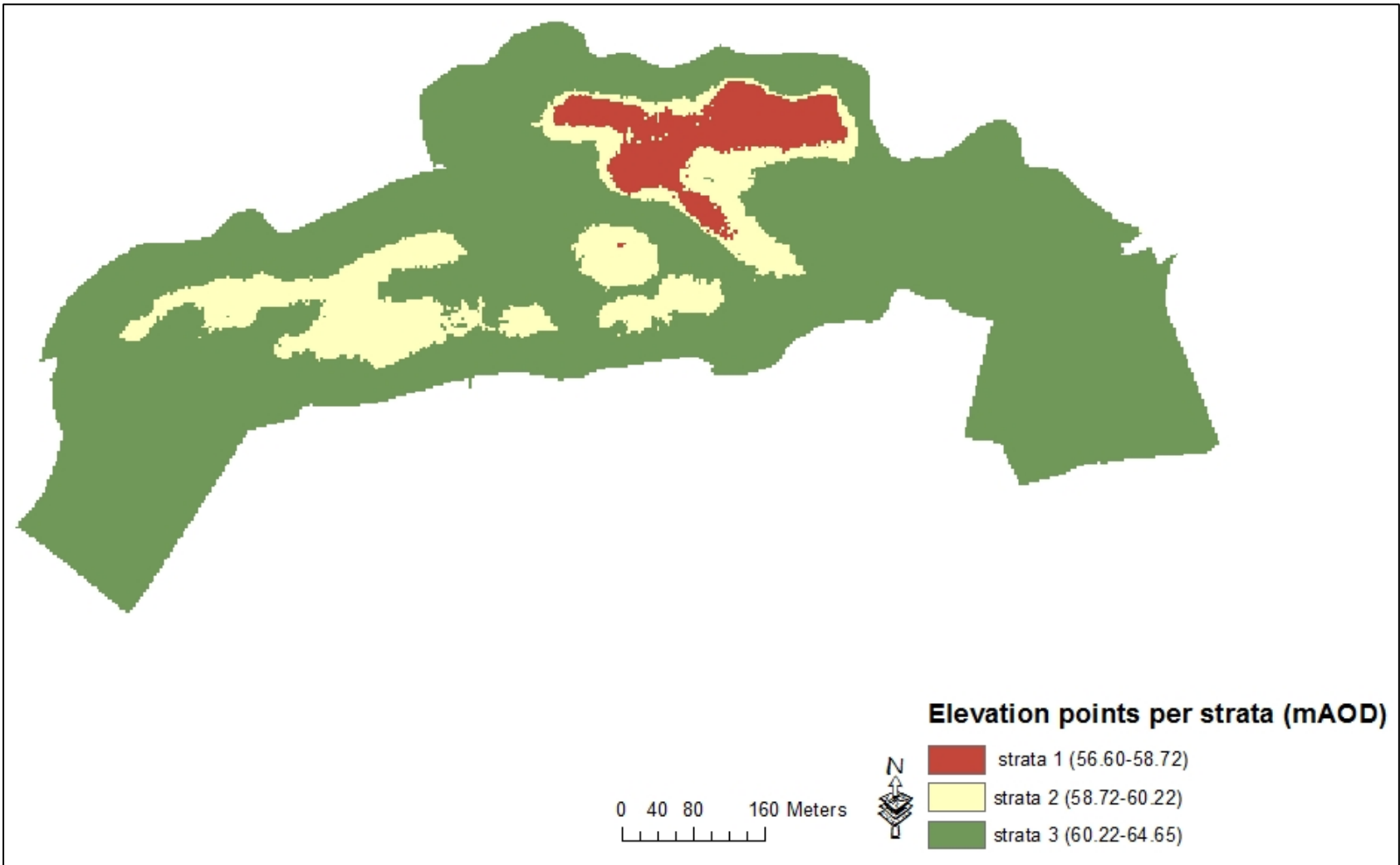


Figure 3-13 Elevations points' distributed per strata.

The first stratum corresponded to the area between the lowest elevation point and the estimated, average groundwater level. The second stratum corresponded to the area between the average groundwater level and the maximum level at which seedlings of a Poplar species (i.e. cottonwood) are expected to be able to develop. The level at which sandbar willows seedlings establish is below the one defined for cottonwood (according to characteristics of species explained in page 94). Finally, the third stratum corresponded to the area between the maximum level at which seedlings of a Poplar species are expected to be able to establish and the highest elevation point. Those points falling within the first strata were expected to be waterlogged whereas those above the recruitment box threshold were expected to be dry for the majority of time.

A single box plot (Figure 3-14 (a)) shows the 45103 elevation points derived from the kriged surface generated (Figure 3-8) using a regular grid of 3 m x 3 m. Haag and Tonn (1998) state that “if the ecologist has prior knowledge of differences within the study area (e.g. low, wet areas vs. dry upland sites) it might be better to sample each area separately”. There is an existing capillary fringe over the groundwater and it is often 0.3 to 0.4 mAOD in elevation (Mahoney and Rood, 1998); the capillary fringe was estimated at the case study site as 59.12 mAOD (i.e. 58.72 mAOD + 0.4 mAOD) and is part of the recruitment zone where the water is drawn up. The recruitment zone is typically over 0.6-2 mAOD above the base flow (i.e. groundwater; Mahoney and Rood, 1998)). The Recruitment zone was defined at 60.72 mAOD (58.72 mAOD + 2mAOD) for the current case study.

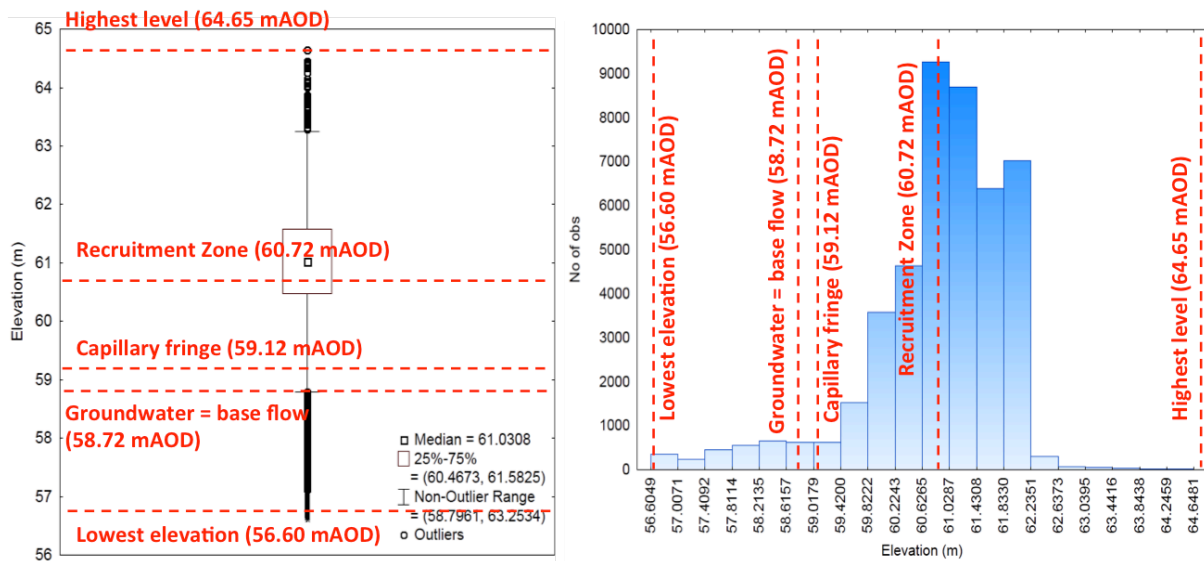


Figure 3-14 (a) Box plot representing elevation in the floodplain. (b) Histogram representing elevation points versus number of observations in the floodplain. Red dash lines indicate the division of highest elevation, recruitment zone, capillary fringe, groundwater and lowest elevation. All levels are reported in metres above ordnance datum (mAOD).

Figure 3-14 (a) displays the box plot representing elevation in the floodplain forest. Figure 3-14 (b) shows the histogram of elevation (mAOD) in the floodplain forest. Threshold for defining the strata were determined based on the information available at that stage of the research (i.e. 2012-2013 PhD year).

Owing to the range of field methods available that could be applied to monitor vegetation it was important to select methods that would collect data at appropriate scales. For a project such as the floodplain forest using a combination of remote sensing techniques, mapping and quadrats is suggested. The combination of these three methods is considered the most appropriate when gathering data across the relevant spatial and temporal scales for the floodplain forest.

Remote sensing techniques are applied to understand how the overall landscape changes over time (i.e. new major features such as habitats, erosion and deposition patterns). Kennedy *et al.* (2009) stated that remote sensing provides a broad view of landscapes and can be consistent through time, making it an important tool for monitoring and managing protected areas. Frohn (1998) introduced metrics for

landscape ecology analysis of remote sensing images; these quantitative measurements of landscape pattern, often called metrics or indicators, have been used to link ecological and environmental processes with patterns found in the landscape. Mapping is at a fine scale to identify habitat features such as flooded or dry areas. It will inform for instance stakeholders and managers where to build a bird's observatory or a public footpath. In the fieldwork, quadrats provide a more specific vegetation inventory; however some information may be missed between quadrats. A survey of the literature revealed a variety of remote sensing strategies applied to habitat mapping projects spanning a wide range of spatial scales (i.e. habitat type, habitat use, habitat preferences etc.) (McDermid *et al.* 2005). Remote sensing is used fundamentally as a complement to field studies (i.e. quadrats, local inventories, habitat surveys etc.), however the labour intensive kind of such manual methods tend to restrict the scope of the studies conducted. According to McDermid *et al.* (2005), nowadays researchers faced with larger study areas have turned to digital processing satellite imagery use. A combination of these three techniques is appropriate to gather all information needed in order to have the best understanding of the floodplain forest dynamic.

3.3.2 Proposed sampling locations and frequency of sampling

A regular grid approach was proposed to distribute the points within the target area as it has been proved to maximise spatial coverage (Webster and Lark, 2013). The total number of samples was estimated based on sampling densities suggested by several authors in other studies. For example, Cass (2012) stated, "for sites with smaller plots the required sampling density is approximately one 1 m x 1 m fixed quadrat per 10 m² to facilitate comparisons between data from the wide range of experimental sites". Other authors such as Higgins *et al.* (2012) have stated less common species require a larger number of samples than do the more common ones.

For the monitoring of vegetation using remotely sensed data, the author proposed the use of an Unmanned Aerial Vehicle (UAV). This device can overfly the landscape to map vegetation communities. An UAV is a remotely controlled model helicopter with an attached camera to get accurate real time data. The resolution depends on

the camera attached to the device (2-4 cm approximately pixels camera resolution). UAVs obtain more accurate aerial images under stable weather conditions: clear days, with no wind and no rain and early morning to avoid disturbance (i.e. people curiosity, walking dogs, kids playing etc.). It operates better when following straight lines; therefore the suggestion to overfly the floodplain following transects ensuring that the locations where the fixed quadrats are placed were covered. This would enable comparison of different techniques for vegetation sampling (i.e. fixed quadrats vs. remote sensing techniques). Table 3-7 below shows the proposed number of sampling points per stratum in the floodplain forest and frequency (i.e. sampling time). More information regarding frequency is further explained in the next section.

Table 3-7 Proposed number of sample size per stratum and frequency (sampling time) per key variables in the monitoring framework proposed for the 50 ha. I, II & III refer to the three strata in Figure 3-13.

Key variables	Sample size per stratum				Frequency (Sampling time)
	I	II	III	Total	
Soil	3	8	39	50	Every 4-6 months
Vegetation	3	8	39	50	Remote-sensing techniques: on annual basis for the duration of the project and then every five years (≥ 5 years). Random quadrats: every 3 months
Water table	-	5	6	11*	Monthly
Water quality (river and channels)	-	-	-	7	Monthly
Topography	-	-	-	-	Yearly

*Subject to availability

For a monitoring framework with the requirement for spatially collocated measurements of soil, water table, water quality and vegetation, the records may be compromised for some of the variables due to weather conditions and due to the dynamism of the project itself (i.e. quarry works on-going). For example, as was encountered in the present project there can be areas in the floodplain forest that

could be waterlogged at some points in the year or could be under maintenance works and therefore, they will not be accessible to collect information at every sampling point suggested within the monitoring framework.

3.3.3 Final Survey Design

Owing to circumstances outside of our control occurring at the site, Health & Safety reasons associated with on going quarry works over most of the floodplain forest (32 ha) and the 3-year time frame of the PhD, monitoring of vegetation development across the site was not possible.

The collection of baseline data on soil, water quality, vegetation, hydrology (water table level) and topography characteristics described earlier in this chapter was determined to be the focus for the assessment of the habitats outcomes in future in those areas of the floodplain forest where the gravel works were finished (i.e. in 18 ha of the former 50 ha). The 18 ha were defined as the target area (Red polygon in Figure 3-1) of the monitoring framework. Sampling points for key variables were randomly assigned within a limited area to the west of the 18 ha target area owing to inaccessible waterlogged areas or parts of the site considered out of bounds for health and safety reasons under TPT and Hanson responsibilities.

Therefore, the adaptive monitoring framework designed in 2012 was tailored to the new conditions taking into account the site constraints described above and some of the key variables were sampled but in selected areas of the floodplain forest. A summary of the new key variables sampling points, locations and frequency is displayed in Table 3-8.

Table 3-8 Sampling points sampled in some areas (*) of the floodplain forest (i.e. target area, Figure 3-1 in page 56) and frequency (sampling time) per key variables in the monitoring framework after site constraints.

Key variables	Sampling points	Area of the floodplain sampled (*)	Frequency (Sampling time)	Observations
Soil	11	18 ha target area	April 2013	Target area is displayed in Figure 3-1
Vegetation	-	18 ha target area	June 2013	One inventory carried out
Water table	11	18 ha target area/ upstream and downstream of the River Great Ouse	Loggers (June 2013-October 2014) Manual (June 2013- September 2014) Loggers and Manual for upstream and downstream loggers: October 2013- September 2014)	9 loggers were installed in total. Seven the target area, and 1 logger upstream and 1 logger downstream. Loggers collect data every 15 minutes.
Water quality	7	50 ha (in rivers and channels)	April, May and June 2013	
Topography	-	50 ha	December 2011 (topographical survey) December 2013 (UAV survey)	-

3.3.4 Field methods and baseline results for selected key variables

This section summarises the field methods used and baseline results obtained for the key variables selected for restoration appraisal as the initial part of the proposed monitoring framework. The field methods used were subjected to variability depending on external conditions (i.e. material available, equipment, budget, weather conditions).

Figure 3-15 displays the location of the environmental monitoring sampling points. Soil sampling and vegetation were entirely carried out within the target area, whereas water quality, water table and topography were sampled within the target area plus in the remaining floodplain forest area (50 ha) to provide baseline monitoring points for future use.



Figure 3-15 Ortho-rectified aerial photo taken by UAV in 2013 and final environmental monitoring sampling points. Red polygon represents the target area (18 ha). Grey dots are the 11 soil samples points (identified as 0 to 10). Upstream and downstream loggers in river Great Ouse are shown in orange.

The blue shaded area in Figure 3-15 represents indicative areas of water body formation and habitat features according to the original Master Plan of TPT and Hanson before any gravel extraction started. Some of the water level loggers (upstream and downstream of the River Great Ouse in orange) and water quality sampling points were taken outside the target area but within the floodplain forest boundaries.

The information collected as part of the proposed monitoring framework provides a useful as part of the baseline after gravel extraction is finished in areas of the floodplain forest. The proposed monitoring framework will also be useful for further measurements taken in the floodplain forest to compare how key variables change over time once gravel extraction fully finish.

Soil

Hanson cement group extracted sand and gravel in the floodplain forest, they washed the sand and gravels at the quarry in Manor farm and weighed them on site prior to sale. The soil used for the new landform created at the restoration site was the same soil, which was stored and until the quarrying and land movement was finished. Hence, they were typical of pre-quarrying situation.

Soil parameters measurement was proposed for the current research in order to know the soil properties in the floodplain forest after gravel extraction (i.e. land movement). Soil samples were taken in the target area in those areas that were not waterlogged at the same time (dealt with on page 102-site section 3.3.3).

A total of 11 soil samples (0-10 in Figure 3-15 above) were gathered in the target area in April 2013. A composite sample of soil was taken at each target location (field access depending) using a trowel. Soil was sampled from the surface layers at the soil-sampling points within the target areas. Samples taken were labelled in separate bags. To avoid contamination between soil samples, the trowel was cleaned between samplings. Soil particle distribution, Soil texture and structure, Soil Organic Carbon, dry matter and water content, and nutrients available for plants (Total Nitrogen, Magnesium, Potassium and Phosphorus)

were analysed. Soil characteristics were also analysed by sample site using soil texture triangle (Appendix F). Justification regarding why these soil parameters were measured is found in Table 3-5, page 78.

Total Organic Carbon (%)

Figure 3-16(a) indicates Total Organic Carbon content in soil. The values varied between 6.6% and 3.7%.

Total Nitrogen (%)

Figure 3-16(b) indicates Total Nitrogen content in soil with the values varying between 0.7% and 0.4%. According to Sparling *et al.* (2003) cited in Environment Agency (2006) (p.113), total nitrogen values between 0.20% and 0.60% are considered adequate and values between 0.60% and 0.7% are considered large trigger values for soil indicators for forestry. Therefore, total nitrogen values collected were considered ample and depleted for the floodplain forest. Parameters measured vary across the site. For example, TOC is understood to vary similar to total nitrogen in Figure 3-16(a) and Figure 3-16(b) respectively.

Dry matter content in soil on a Mass Basis (%)

Figure 3-16(c) indicates dry matter content in soil. The values varied between 69.6% and 56.6% but overall they were relatively constant (Figure 3-16(c)).

Water content in soil on a Mass Basis (%)

Figure 3-16(d) indicates water content in soil. There was a slight increase in water content from sampling point 1 to sampling point 11. The water content varied but was within a range of 76.8% to 43.4%.

Phosphorus soluble in sodium hydrogen carbonate solution ($\mu\text{g P}$)

Figure 3-16(e) indicates Phosphorus content in soil. The values varied between 13.1 $\mu\text{g P}$ and 64.3 $\mu\text{g P}$. All sampling points were lower than 30 $\mu\text{g P}$ with the exception of sampling point 2, which was more than 60 $\mu\text{g P}$.

Potassium

Figure 3-16(f) indicates Potassium content in soil. The values varied between 218.4 mg/kg and 128.8 mg/kg.

Magnesium

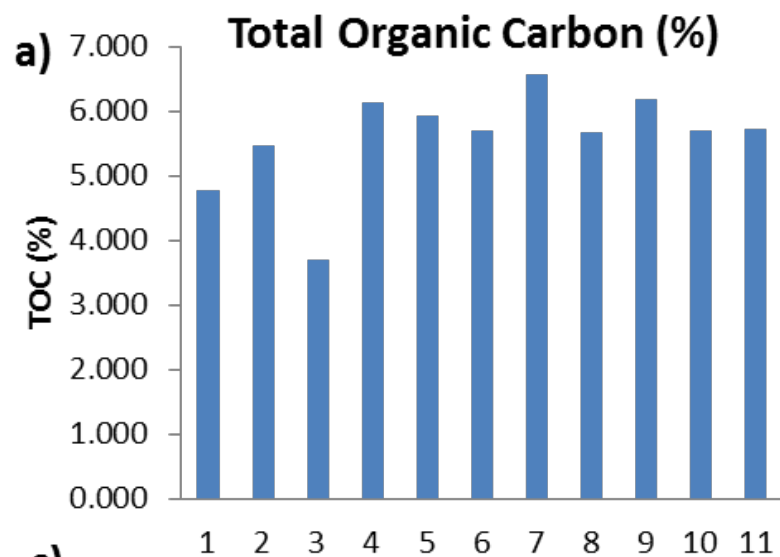
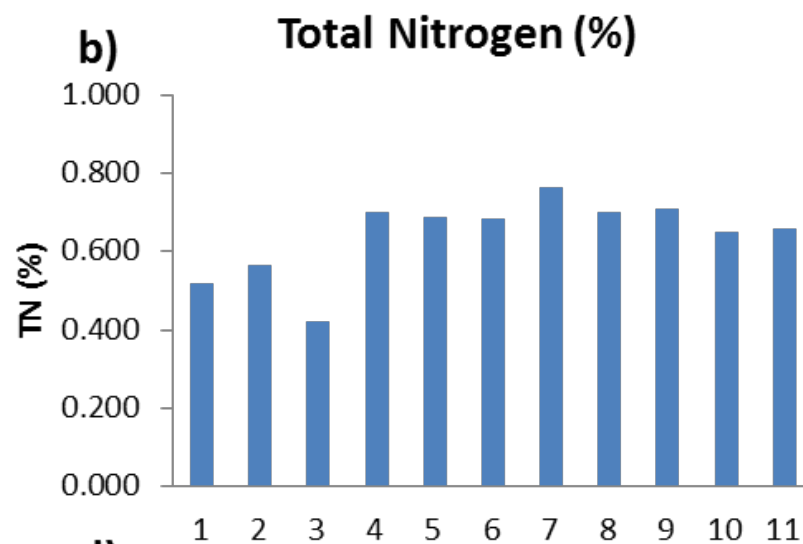
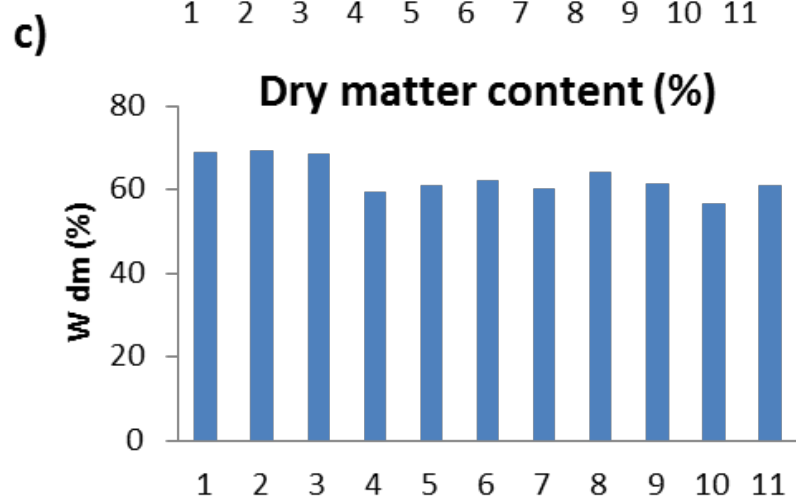
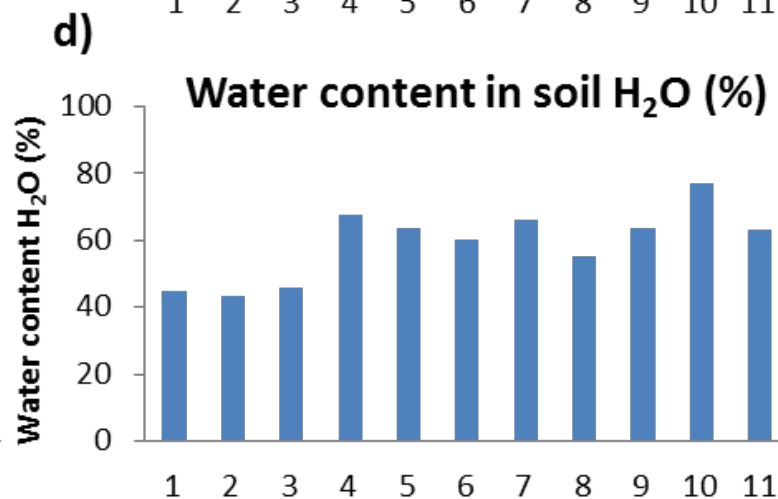
Figure 3-16(g) indicates Magnesium content in soil. The values varied between 377.3 mg/kg and 185.5 mg/kg.

Particle size distribution (%)

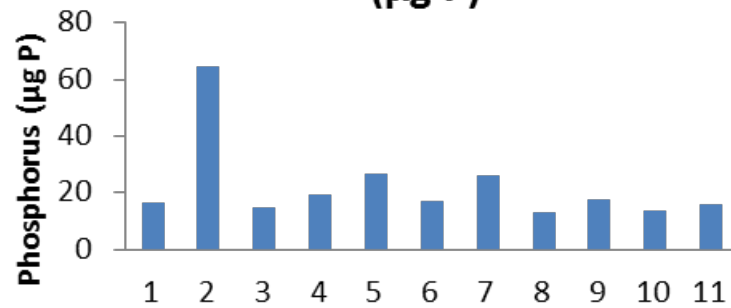
Figure 3-16(h) indicates Particle size distribution (PSD) in soil. Soil classification was divided in %sand (red bars), %silts (green bars) and %clay (blue bars) as shown Figure 3-16(h). **Table 3-9** below displays all values per sampling points. Overall all sampling points display %sand, %silt and %clay content, but %clay content was predominant in all soil samples (Figure 3-16(h)). Soil composition that includes static properties shows little change over time in mineralogy and PSD. On the other hand, soils including dynamic properties still are subject to change over relatively short time periods and respond to change in management (i.e. quarry works that involve gravel extraction).

Table 3-9 Particle Size Distribution (%) values per sampling point in April 2013.

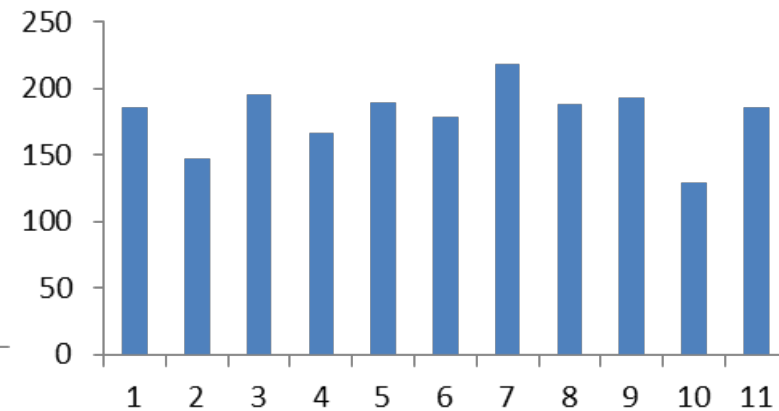
Sampling points	% sand (0.063 - 2 mm)	% silt (0.002 - 0.063 mm)	% clay (< 0.002 mm)
1	19.80	21.61	58.59
2	31.41	23.90	44.69
3	17.82	17.08	65.10
4	9.73	18.76	71.51
5	14.01	19.33	66.66
6	14.15	15.83	70.02
7	12.85	17.11	70.04
8	8.01	16.93	75.06
9	9.05	17.70	73.25
10	13.08	33.25	53.67
11	7.34	19.37	73.29



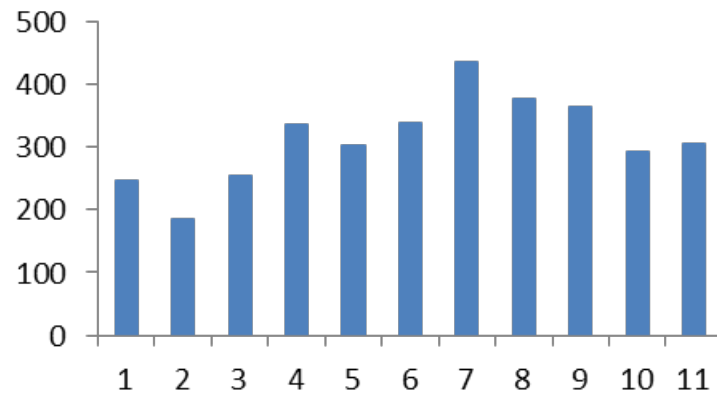
e) Phosphorus soluble in sodium hydrogen carbonate solution ($\mu\text{g P}$)



f) mg/kg of Potassium extractable



g) mg/kg of Magnesium extractable



h) Particle size distribution

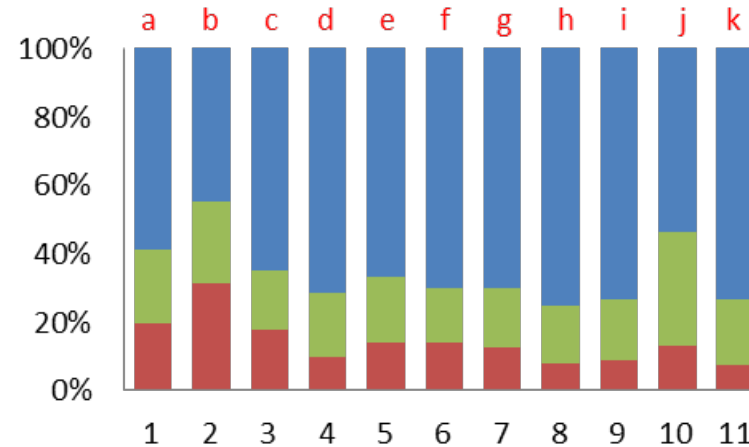


Figure 3-16 (a) Total Organic Carbon (TOC) (%). (b) Total Nitrogen (TN) (%). (c) Dry matter content (%). (d) Water content in soil (%). (e) Phosphorus soluble in sodium hydrogen carbonate solution (µP). (f) mg/kg Potassium extractable. (g) mg/kg of Magnesium extractable. (h) Particle size distribution (%) (Blue bars indicate % clay content (<0.002 mm), green bars indicate % silt content (0.002 mm-0.063 mm) and red bars indicate % sand content (0.063 mm-2 mm)).

The soil texture triangle in Appendix F shows the distribution of soil content according to %sand, %silt and %clay content per sampling point. All samples fell in the clay threshold.

Vegetation

An inventory of main species (Table 3-10) found in the target area of the floodplain forest was undertaken the 17th of June 2013 in collaboration with Graham Bellamy (experienced botanist with Bedfordshire, Northamptonshire and Cambridgeshire Wildlife Trust). The inventory identified the existing species during on-going restoration quarry works in the remaining area of the floodplain forest. An invasive species marked as red (Alert) in Table 3-10 was also found in a water edge near one of the imported slabs of reedbeds (Figure 3-17) that TPT planted (TPT was notified). This information was very helpful, as no flora data were collected in the target area since quarry works started. Most of the species found in the target area of the floodplain forest were thistle and other weeds. The edges of water had species expected in a floodplain forest such as Water mint (*Mentha aquatica*), Gipsywort (*Lycopus europaeus*), Greater pond sedge (*Carex riparia*), Greater water dock (*Rumex hydrolapathum*), Water plantain (*Alisma plantago-aquatica*), Great hairy willowherb (*Epilobium hirsutum*), Meadow buttercup (*Ranunculus acris*), Sedge (*Carex sp.*), Cut-leaved Cranesbill (*Geranium dissectum*), Cock's-foot or orchard grass (*Dasctylis glomerata*) and Tufted Hair-grass or Tussock grass (*Deschampsia cespitosa*). Vegetation species expected in the floodplain forest (Street, 2002) are displayed in Appendix G.

Table 3-10 Inventory of species identified 17th of June 2013.

Common name	Scientific name
Common groundsel	<i>Senecio vulgaris</i>
Carlina Thistle	<i>Carlina vulgaris</i>
Sheperds's Purse	<i>Capsella bursa-pastoris</i>
Spear-leaved Orache	<i>Atriplex prostate</i>
Cut-leaved Cranesbill	<i>Geranium dissectum</i>
Bristly ox-tongue	<i>Picris echioides</i>
Cleavers	<i>Gallium aparine</i>
Plantago major	<i>Plantago major</i>
Willowherb	<i>Epilobium sp.</i>
Sedge	<i>Carex sp.</i>
Meadow buttercup was creeping buttercup	<i>Ranunculus acris</i>
Garlic mustard	<i>Alliaria petiolata</i>
Creeping cinquefoil	<i>Potentilla reptans</i>
Bistort was redleg	<i>Persicaria bistorta</i>
Meadow foxtail	<i>Alopecurus pratensis</i>
Cock's-foot or orchard grass	<i>Dasctylis glomerata</i>
Bent or bentgrass	<i>Agrostis</i>
Cow parsley	<i>Anthriscus sylvestris</i>
Goatsbeard	<i>Tragopogon pratensis</i>
Tufted Hair-grass or Tussock grass	<i>Deschampsia cespitosa</i>
Redshank	<i>Persicaria maculosa</i>
Thyme-leaved Speedwell, bird's eye,	<i>Veronica sepyllifolia</i>
Nettle	<i>Urtica dioica</i>
Docks and sorrels	<i>Rumex</i>
Swamp stonecrop or New Zealand pigmyweed	<i>Crassula helmsii</i>
Water Mint	<i>Mentha aquatica</i>
Reedbeds	<i>Phragmites australis</i>
Water-plantains	<i>Alisma</i>
Hedge mustard	<i>Sisymbrium officinale</i>
Wild cabbage	<i>Brassica oleracea</i>
Wild turnip	<i>Brassica rapa L.</i>
Burdock	<i>Arctium</i>
Squarestem spikerush and four-angled spikerush	<i>Eleocharis quadrangulata</i>
Great hairy willowherb	<i>Epilobium hirsutum</i>
Gipsywort	<i>Lycopus europaeus</i>
Creeping Yellowcress	<i>Rorippa sylvestris</i>

Common name	Scientific name
Hogweed	<i>Heracleum</i>
Common Silverweed, Silverweed Cinquefoil	<i>Argentina anserina</i>
Coltsfoot	<i>Tussilago farfara</i>
Dandelion	<i>Taraxacum</i>
Fuller's teasel and wild teasel	<i>Dipsacus fullonum</i>
Greater water dock	<i>Rumex hydrolapathum</i>
Common Cleavers	<i>Galium aparine</i>



Figure 3-17 Invasive species Swamp stonecrop or New Zealand pigmyweed (*Crassula helmsii*). On the right side is the imported slab of reedbed vegetation that may have introduced the invasive species.

Much of the vegetation away from the water appeared rich, growing large stands of thistle (*Carduus spp.*), nettle (*Urtica dioica*) and dock (*Rumex sp.*).

The main purpose was to identify the habitat/vegetation communities present in the floodplain forest and their interaction with the water table level of the floodplain forest (hypothesis).

Water quality

Mining activity has a great effect on the hydrogeology of an area, and it also interferes with the natural surface water hydrology (Henton, 1981). Some of these effects are the result of hydrological changes, such as diversion flow or

draining of floodplains. A different range of natural and human influences modifies water quality. Examples of natural influences can be hydrological and geological. Erosion, especially at banks in river and water bodies, can cause turbidity in water. Quarrying can modify the routing of recharge and water quality may be degraded (Gunn and Hobbs, 1999). Other amounts of silt and other disposal elements from quarries (waste, fuel, oil) may pollute rivers as well as groundwater water bodies within and far beyond the boundaries of the floodplain forest.

Water quality was sampled in both the river and adjacent channels (Figure 3-15). The Environment Agency collects one sample point every 5 km of river (General Quality Assessment (GQA)) (Cranfield University, 2011), hence these provided the nearest reference points relating to the river bringing water to the floodplain forest.

Within the floodplain forest seven sampling points were located upstream and downstream of the reach of the Great Ouse falling within the target area, as well as at the beginning and the end of every sub-channel within the floodplain. Data were collected monthly during the main growing period (from April to June 2013) to provide an indicative baseline (Figure 3-15). Water quality was sampled manually in both the river and adjacent channels (i.e. River Great Ouse, in-channels and in the back brook located in the south side of the floodplain, Figure 3-1). Freshwater samples were focussed in those areas where the river changed or splits (Figure 3-15). Water was analysed for Total Oxides of Nitrogen (TON) (mg/l of suspended material), Conductivity (μ S), pH, Phosphorus (μ g/l), Total Suspended Solids (TSS) mg/l of suspended material, Phosphate-P (mg P/l) and Ammonium (mg N/l). Justification regarding why these parameters were measured is found in Table 3-5, page 79.

Total Oxides of Nitrogen (TON) (mg/l of suspended material)

Data collected monthly per sampling point are displayed in Table 3-11 below. All values varied between 7.7 mg/l and 0.01 mg/l (Figure 3-18(a)). According to Nitrogen (mg/l) classification in Environment Agency Water Quality (2014),

Nitrogen values are in Grade 1/2 and very low/low respectively in water concentration. Samples collected in April (blue line) range between 7.7 mg/l and 4.4 mg/l. Samples collected in May (red line) vary between 5.9 mg/l and 1.3 mg/l. Samples collected in June (green line) vary between 6.7 mg/l and 0.01 mg/l. Values in April (blue line) and May (red line) indicate a similar pattern for all sampling points. Values have decreased from April to May in all sampling points. Data collected in June shows similar pattern than April and May from sampling point 3 to 7. Figure 3-18(a) shows the mean values $\pm$ standard deviation for TON.

Table 3-11 TON (mg/l of suspended material) per sampling point and date.

Date	Sampling points						
	1	2	3	4	5	6	7
11/04/2013	6.1	4.4	7.4	6.9	7.3	7.7	7.6
10/05/2013	3.1	1.3	5.9	5.6	5.2	5.9	5.8
10/06/2013	0.01	6.2	6.4	6.6	5.9	6.4	6.7

Conductivity (μ S)

Conductivity values varied between 695 μ S and 440 μ S. Samples collected in April (blue line) vary between 609 μ S and 658 μ S. Samples collected in May (red line) range between 440 μ S and 572 μ S. Samples collected in June (green line) vary between 484 μ S and 695 μ S. Conductivity in April was relatively constant. May and June show a similar pattern with a drop in the first sampling point. Overall sampling points from 2-7 show a similar pattern. Data collected monthly per sampling point are displayed in Table 3-12 below. Figure 3-18(b) shows the mean values $\pm$ standard deviation for Conductivity.

Table 3-12 Conductivity (μ S) values per sampling point and date.

Date	Sampling points						
	1	2	3	4	5	6	7
11/04/2013	609	657	640	645	643	650	658
10/05/2013	440	572	526	549	534	560	548
10/06/2013	484	691	680	695	674	685	690

pH

Data collected monthly per sampling point are displayed in Table 3-13 below. All pH values varied between 8.5 and 7.6. According to River Ecosystem (RE) Classification, pH values oscillating between 6 and 9 are considered water of good quality and suitable for coarse fish populations (Environment Agency Water Quality, 2014). Samples collected in April (blue line) range between 8.4 and 7.7. Samples collected in May (red line) vary between 8.5 and 7.6. Samples collected in June (green line) vary between 8.2 and 7.7. Values in April (blue line) and May (red line) indicate a similar pattern. Values in June show a different pattern than April and May from sampling points 1-3. Figure 3-18(c) shows the mean values $\pm$ standard deviation for pH.

Table 3-13 pH values per sampling point and date.

Date	Sampling points						
	1	2	3	4	5	6	7
11/04/2013	8.2	7.7	8.4	8.3	8.3	8.3	8.3
10/05/2013	8.1	7.6	8.4	8.3	8.3	8.4	8.5
10/06/2013	7.7	8.1	8.2	8.2	8.2	8.2	8.2

Phosphorus ($\mu\text{g/l}$)

Data collected monthly per sampling point are displayed in Table 3-14 below. All values varied between 1537.6 $\mu\text{g/l}$ and 40.5 $\mu\text{g/l}$ (Figure 3-18(d)). Samples collected in April (blue line) ranged between 40.5 $\mu\text{g/l}$ and 60.9 $\mu\text{g/l}$. Samples collected in May (red line) vary between 277.1 $\mu\text{g/l}$ and 91.9 $0\mu\text{g/l}$. Samples collected in June (green line) varied between 58.6 $\mu\text{g/l}$ and 1537.6 $\mu\text{g/l}$. Graph in Figure 3-18(d) shows phosphorus values have increased monthly. Similar pattern was observed for sampling points from 3-7 in all values. Overall all values have similar distribution with the exception of a peak observed in sampling point 2 in June (green line). Notes were taken for this value in fieldwork indicating that eutrophication process was present. For instance, eutrophication was visible in sampling point 7 (Figure 3-15), which displays 40.5

µg/l of phosphorus during April 2013. Figure 3-18(d) shows the mean values ± standard deviation for Phosphorus.

Table 3-14 Phosphorus (µg/l) per sampling point and date.

Date	Sampling points						
	1	2	3	4	5	6	7
11/04/2013	43.3	60.9	46.2	51.4	64.3	50.5	40.5
10/05/2013	91.9	118.6	277.1	122.4	99.1	117.6	114.3
10/06/2013	58.6	1537.6	220.5	221.4	225.7	206.2	211.9

Total Suspended Solids (TSS) (mg/l of suspended material)

Data collected monthly per sampling point are shown in Table 3-15. All values vary between 9.2 mg/l and 0 mg/l (Figure 3-18(e)). Samples collected in April (blue line) range between 6 mg/l and 3.6 mg/l. Samples collected in May (red line) vary between 4.8 mg/l and 0.8 mg/l. Samples collected in June (green line) vary between 9.2 mg/l and 0 mg/l. Values in April (blue line) indicates a more linear distribution. Values in May (red line) indicate a similar pattern than April (blue line) but lower values for all sampling points except the sampling point 2, which is the same level. Values in June represent an irregular distribution, with three peaks observed in sampling point 3, 5 and 7. Figure 3-18(e) shows the mean values ± standard deviation for TSS.

Table 3-15 TSS (mg/l of suspended material) per sampling point and date.

Date	Sampling points						
	1	2	3	4	5	6	7
11/04/2013	4.8	4.8	6	4.4	4.8	5.2	3.6
10/05/2013	3.2	4.8	1.2	1.6	1.6	0.8	0.8
10/06/2013	3.2	0	9.2	3.2	8.4	5.2	7.2

Phosphate-P (mg P/l)

Data collected monthly per sampling point are displayed in Table 3-16. All values vary between 0.047 mg P/l and 0 mg P/l. According to Phosphate (mg P/l) classification in Environment Agency Water Quality (2014), Phosphate values are in Grade 2 and low in water concentration. Samples collected in April

(blue line) range between 0.020 mg P/l and 0 mg P/l. Samples collected in May (red line) vary between 0.063 mg P/l and 0.010 mg P/l. Samples collected in June (green line) vary between 0.147 mg P/l and 0 mg P/l. Values in May (red line) and June (green line) indicate a similar pattern from 3-7 sampling points (Figure 3-15). Values increased monthly in all sampling points, except sampling point one, which indicates less change over that time between an upper and lower level. No information was collected in sampling point 2 during April, as the access was not advisable. Figure 3-18(f) shows the mean values $\pm$ standard deviation for Phosphate increased over the three months period sampled. Average values of Phosphorus ($\mu\text{g/l}$) and Phosphate-P (mg P/l) present similarities because Phosphates-P contains phosphorus in a different chemical arrangement.

Table 3-16 Phosphate-P (mg P/l) values per sampling point and date.

Date	Sampling points						
	1	2	3	4	5	6	7
11/04/2013	0.003	-	0.010	0.010	0.020	0.010	0.010
10/05/2013	0.013	0.010	0.053	0.063	0.040	0.050	0.043
10/06/2013	0.000	0.083	0.147	0.130	0.103	0.130	0.133

Ammonium (mg N/l)

All ammonium values (Figure 3-18(g)) varied between 0.983mg N/l and 0 mg N/l. Data collected monthly per sampling point are displayed in Table 3-17 Ammonium (mg N/l) values per sampling point and date below. Samples collected in April (blue line) range between 0 mg N/l and 0.067 mg N/l. Samples collected in May (red line) vary between 0.098 mg N/l and 0.117 mg N/l. Samples collected in June (green line) vary between 0.047 mg N/l and 0 mg N/l. According to River Ecosystem (RE) Classification (Norwich Northern distributor route, 2005), Ammonium values between 0.25 and 2.5 mg N/l are included in the range water of good quality and suitable for all fish species (Grade A-D, good/fair water quality). Ammonium in April and June represents a more linear distribution and similar values. May (red line) shows higher values and a peak (0.098 mg N/l) in the sampling point 2. Overall sampling points from 3-7 show a

similar pattern. Note some information was not collected at sampling point 5 (April and June) and sampling point 7 (June). Figure 3-18(g) shows the mean values $\pm$ standard deviation for Ammonium.

Table 3-17 Ammonium (mg N/l) values per sampling point and date.

Date	Sampling points						
	1	2	3	4	5	6	7
11/04/2013	0.010	0.067	0.010	0.007	0.000	0.010	0.013
10/05/2013	0.223	0.983	0.117	0.163	0.170	0.180	0.130
10/06/2013	0.037	0.037	0.047	0.017	0.000	0.007	0.000

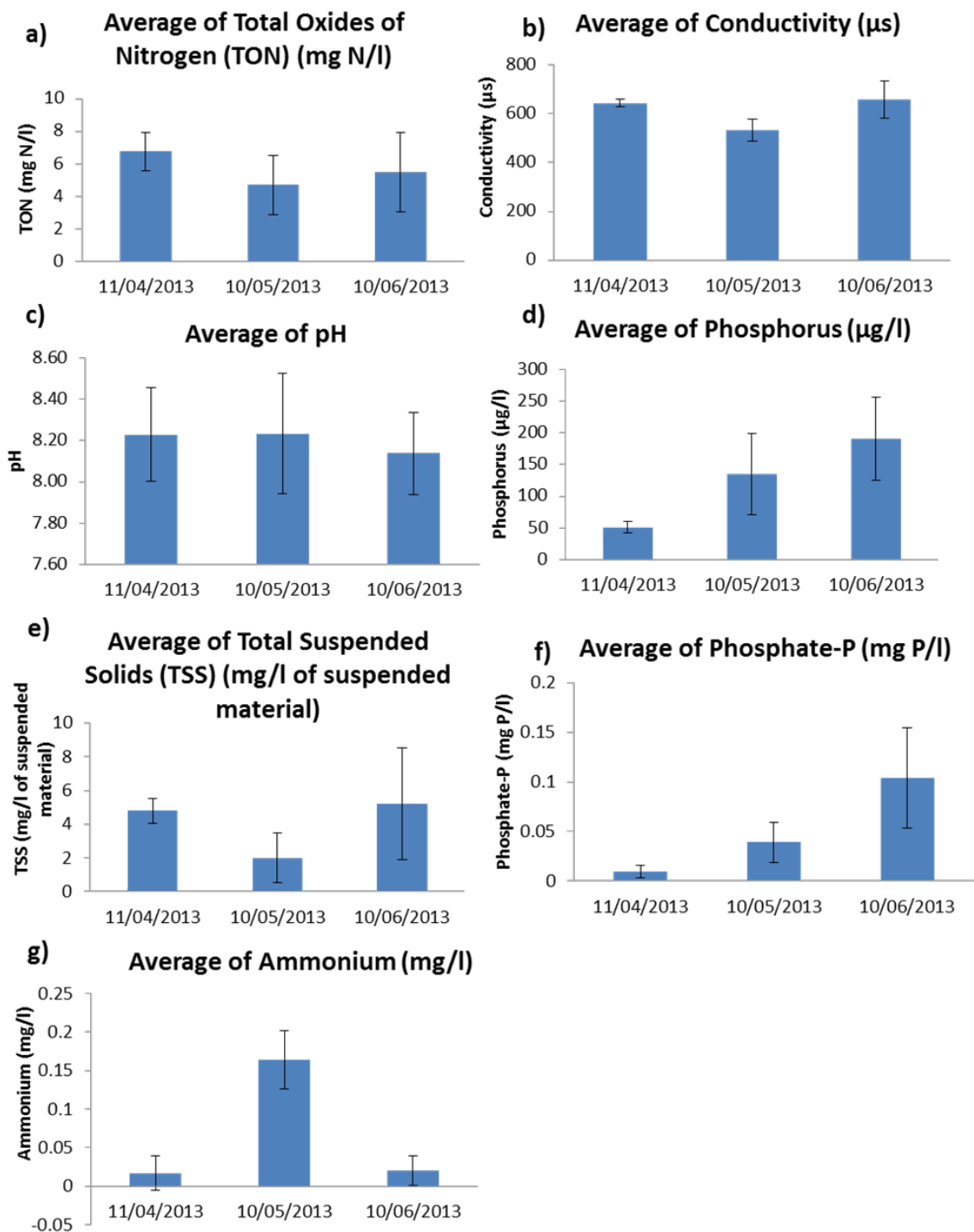


Figure 3-18 Averaged monthly values of: Total Oxides of Nitrogen (TON) (mg N/l). (b) Conductivity (μ S). (c) pH. (d) Phosphorus (μ g/l). (e) Total Suspended Solids (TSS) mg/l of suspended material. (f) Phosphate-P (mg P/l). (g) Ammonium (mg N/l). Blue bars show the mean values $\pm$ standard deviation per month and per parameter measured.

Water table level

Water table level sampling points were sampled with available data loggers in 9 locations (7 in the target area plus one upstream and one downstream within the floodplain forest boundaries) (Figure 3-15). Water table level variability was analysed monthly by sample site. Water table level and field methods are specifically addressed in the next chapter.

Topography

Initially, to provide the rationale behind the strata boundaries at the initial stage of the research, topography data from December 2011 were used. However, during the progress of the PhD, an up-to-date elevation set of data of the floodplain forest site was surveyed by an UAV in December 2013 (i.e. ortho-photo displayed in Figure 3-15). A team specialising in aerial mapping in GIS data management mapped and surveyed the site utilising a Quest Unmanned Aerial Vehicles (Figure 3-19). Updated elevation was used to test the hypothesis along with water table outputs in Chapter 6. The UAV survey covered the whole area (approximately 50 ha). QuestUAV used high accuracy GPS to add control points on the ground to create accuracies on all data to < 10 cm. The constant height at which the UAV flew the proposed area was 120 m. The 3D image and contour line map of the floodplain forest was produced (Appendix H and Appendix I respectively).



Figure 3-19 Operator launching the UAV in December 2013.

3.4 Discussion

This chapter summarises the field site characteristics (i.e. baseline) and the proposed adaptive monitoring framework along with restoration appraisal to be implemented at the floodplain forest restoration project. It is also understood that it is an iterative monitoring and it could be modified and adapted to other ecosystem with similar characteristics.

Owing to constraints in sampling area and timescale, a total of 18 ha (target area section 3.3.3) within the floodplain forest were monitored at small scale for soil, vegetation, water quality and water table. UAV data (Topography) in addition to some water quality and water table sampling points were collected for the whole 50 ha site. Key variables were collected as part of the baseline of the floodplain forest.

Based on the relationship between topography and water table level (Table 3-6), 5.43% of the floodplain forest was directly fed by aquifer replenishment whereas 81.10% of the area was expected to be mostly dry during the year. The lowest areas within the floodplain are located on the east side of the floodplain, with few spots on the west (Figure 3-13). This configuration was expected to have an impact on the development of the vegetation communities present in the area. Note that these were initial estimates based on the topographical survey done in 2011; it was suggested that an updated study was required to fully understand the hydrological dynamics of the floodplain forest after gravel extraction works.

Little was known about the vegetation within the floodplain forest after quarry works started in 2007. It is expected that new vegetation communities will grow in the floodplain as a consequence of the new topography. For the management of the site a tool for predicting habitat types could be used to help deciding where monitoring for particular vegetation with traits linked to the wetness and elevation should take place.

Despite the fact of lack of vegetation quadrat locations would have presented much better baseline for further monitoring. The total number of vegetation samples proposed in the designed AMF was an initial estimation and therefore, adjustments to the number of samples may have to be made in the future once more detailed information about the site to monitor are available. For this purpose, an Ecological Habitat Survey (EHS) would be appropriate to be carried out to (i) identify which habitats are present, (ii) determine what species are per habitat type, (iii) identify the National Vegetation Communities (NVC) and vegetation assemblages distributed within the floodplain and (iv) adjust the proposed sampling strategy so that the diversity and structure of the vegetation communities identified is captured. The vegetation inventory which identified existing species during the ongoing restoration works showed there were not yet habitats communities well defined, presumably as it was a newly created floodplain forest (i.e. disturbed area). Management interventions may be needed, they will need to be justified and also be aware of requirements for other desirable species such as nesting and breeding birds.

Water quality was measured at 7 points within the River Great Ouse and adjacent channels for three months from April-June 2013 (Figure 3-15). Soil was sampled once at 11 points (Figure 3-15). An initial vegetation inventory survey was completed along with experienced botanist help. Water table level was sampled at 9 points (7 points in the target area plus one upstream and one downstream within the floodplain forest boundaries). Topography data were gathered from the UAV survey outputs. These variables were measured as part of the adaptive monitoring framework to build the baseline after gravel works in the floodplain forest. One aspect of the baseline study was that the design could be used in the future for further comparison between variables to check how they progress over time and it is suitable for continued sampling in the future.

Regarding water analysis in the floodplain forest, nitrogen values in the floodplain forest (between 7.7 mg/l and 0.01 mg/l) were in Grade 1/2 and very low/low respectively in water concentration (Environment Agency Water Quality, 2014). According to River Ecosystem (RE) Classification, pH values ranging

between 6 and 9 were considered water of good quality and suitable for coarse fish populations (Environment Agency Water Quality, 2014). pH values in the floodplain forest varied between 8.5 and 7.6. Eutrophication was present during fieldwork (April-June 2013) in some of the sampling points. For instance, eutrophication was visible in sampling point 7 (Figure 3-15) which displayed 40.5 µg/l of phosphorus during April 2013 fieldwork. According to Phosphate (mg P/l) classification in Environment Agency Water Quality (2014), Phosphate values (between 0.047 mg P/l and 0 mg P/l) were in Grade 2 and low in water concentration. Ammonium values (between 0.983mg N/l and 0 mg N/l) varied between 0.25 and 2.5 mg N/l and were classified in the range of water of good quality and suitable for all fish species (Grade A-D, good/fair water quality in River Ecosystem Classification) (Norwich Northern distributor route, 2005).

Total nitrogen values in soil were considered adequate trigger values for soil indicators in forestry. Parameters measured varied across the site. For example, TOC was understood to vary similar to total nitrogen in Figure 3-16 (a) and Figure 3-16 (b) respectively. Most of the sampling points for Phosphorus were lower than 30 µg P. The soil texture triangle (Appendix F) showed that the soil content was distributed mainly in the % clay. There was some variation in the clay context with some sites slightly more sandy (i.e. nearer to the middle of the triangle). Overall, %clay content was predominant in all soil samples (Figure 3-16(h)) in the floodplain forest. Clay was clearly distributed in the floodplain forest whereas other parameters such as magnesium (mg/kg) and potassium (mg/kg) still vary in the floodplain forest according to Figure 3-16(f) and Figure 3-16 (g) respectively.

Some of the Phosphorus value observed (i.e. sampling point 7 in Figure 3-15) was lower in comparison with other values gathered. Phosphorus supports the growth of algae and aquatic plants in water bodies, which may be beneficial for other species (i.e. food and habitat provision), therefore a lower value may affect the growth of algae or any other aquatic plant affecting other species. However, when phosphorus values are very high, water can be polluted. Too much phosphorus in the water can cause eutrophication, which can reduce or

eliminate oxygen levels in the water. The ortho-rectified aerial photo of 2013 provided the most up-to-date vision of the floodplain forest after gravel extraction. It displayed the created water bodies and topographical features and new habitat mosaics distribution in the floodplain forest.

Objectives for restoration projects should be defined as “motion pictures” rather than “snapshots” (Dunwiddie, 1992, cited in Sayer, 2005, p.102). For the present research aims and objectives were clearly defined in Chapter 1. Changes may arise in this type of re-creation project and therefore it may require adaptation to the needs of understanding the outcome of restoration. Hence, the monitoring framework was designed to be adaptive based on the data collection and to fit with determining the changes that would occur on the site as restoration progressed. Therefore, the monitoring framework presented in this research fits with the restoration principle defined by Dunwiddie (1992), which objectives support the dynamic nature of restoration projects and they require time to get conclusions over time. Adjustments can be done depending on the variables selected for the type of ecosystem considered (i.e. water table, soil, topography etc.). The current research has provided a baseline of site characteristics, which is essential for understanding how the site might change through time using the AMF, if further data are collected in the future.

A diagram summarising the research associated with developing the baseline as part of the monitoring framework is shown below (Figure 3-20). The diagram is an indicative outline for the current research. It contributes to understanding and interpreting changes in key variables that will occur at the site. It describes all the key targeted variables that were part of the baseline, parameters analysed and methods implemented in the project. In Figure 3-20 the clear blue box comprises the baseline (soil, vegetation, water quality, water table level and topography). The core boxes in dark blue in the centre of the diagram represent the selected key variables. Orange boxes represent methodology implemented for each parameter measured. Green boxes display the parameters analysed per key variable.

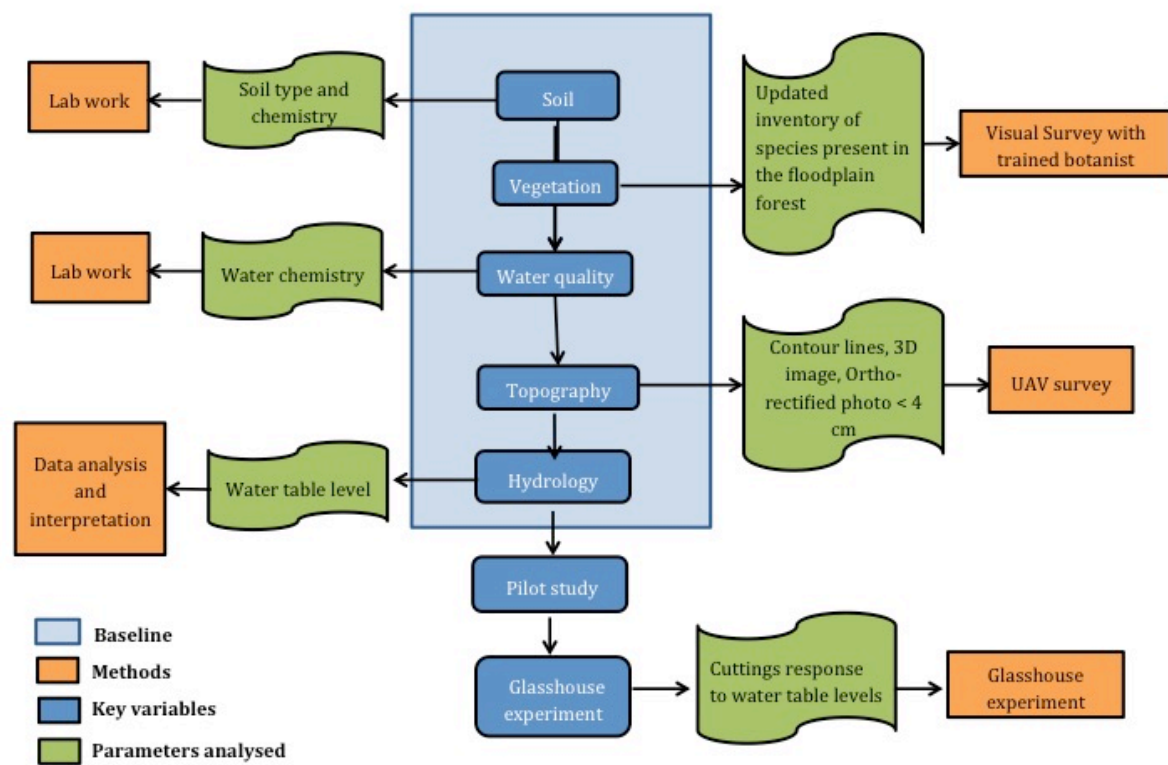


Figure 3-20 Diagram showing the research components carried out in the floodplain forest case study and associated research.

4 Hydrological dynamics in the floodplain forest

4.1 Introduction

Water table level plays an important role in the ratio of wet/dry vegetation community growth. The water table level was identified as one of the key variables in the initial monitoring programme proposed in Chapter 3 as part of the hydrology category. Junk *et al.* (1989) state the shape of a hydrograph depends on discharge characteristics, valley slope, floodplain size and vegetation. Gathering data about the hydrology of the newly created floodplain forest is aimed at understanding, in part, the dynamics of water table variations at a site of these characteristics. Pfeiffer *et al.* (2006) presented a detailed characterization of groundwater flowpaths and groundwater/surface water interactions in a forested floodplain wetland. They concluded the topographic features (i.e. bluffs, terraces, oxbow lake, and ridges and swales) are all important for creating a flow system with shallow, intermediate, and deep flowpaths. It is expected that at Ouse Valley Park species-rich habitats would develop in locations of the floodplain forest where topography is diverse and therefore provides a wide range of rooting depth to reach the water table. It matches with the hypothesis driven Adaptive Monitoring Framework as suggested in Chapter 3 that the vegetation communities are specific to the topography (i.e. elevation) and the associated depth of soil to reach the water levels. Also, by optimizing water depth for focal species, it will increase habitat quality and the probability that the restoration is successful (Nadeau & Conway, 2015).

As explained in Chapter 3, elevation was used as a proxy variable to identify vegetation patterns; the remaining key variables such as determining the local water table level also have to fit in the sampling pattern. This means that all sampling points of the remaining key variables should be located as near as possible together. More detailed data collected of a known sampling location point (i.e. existing vegetation communities, water table depth, soil composition etc.), will highlight restoration site dynamics at that specific point over time. The composition and structure of floodplain forests has been shown to vary in

response to very small differences in elevation (and therefore flooding), with pioneer stands of species of the Genera *Populus* and *Salix* on recent deposited sand, *Alnus glutinosa* dominated mixtures in peaty depressions, mixed broadleaved forests growing on well drained mineral soil, and *Quercus-Carpinus-Tilia* woodland on the floodplain margins (Peterken and Hughes, 1995). Elevation controlled the duration of flooding, and the flooding caused repeated initiation of succession on ground made available by channel movement (Adapted from Peterken and Hughes, 1995). Attributes of temperate floodplain forests can be identified from historical sources and surviving near-natural forests in eastern North America and continental Europe (Petts, 1990). Giles (1992b) states that the process of ecological succession can be halted at given stages by active habitat management to produce a complex mosaic of open water, submerged weed beds, reedbeds, willow/alder scrub and wet woodland. Hence, by knowing how the hydrological features at the floodplain forest vary over time, management decisions (i.e. water table regulation) to work towards a successful habitat succession can be taken. For instance, the influence of water table on riparian vegetation largely reflects the supply of moisture, which ultimately makes vegetation less dependent on precipitation (Stromberg *et al.*, 1996). The idea is to understand hydrological data to assess the diversity of vegetation communities (i.e. habitats) captured with the sampling strategy.

4.1.1 Response of floodplain forest tree species to different water table regimes examples

Water levels changes in the groundwater, like river stage, rise and fall (Naiman *et al.* 2005). As a consequence, soil aeration is promoted, creating favourable growing conditions (Egger *et al.*, 2013, cited in Maddock *et al.*, 2013, p.410). Some authors have run experiments in glasshouses or in a field site to determine the response of tree species to different water table regimes (as listed in 2.2.2 The link between hydrological processes and vegetation).

Low flows also affect riparian biocoenosis, low water conditions and receding groundwater levels that dry the soil, leading, ultimately, to desiccation and the

exclusion of vegetation (Egger *et al.*, 2013, cited in Maddock *et al.*, 2013, p. 409). In light of this evidence, areas in the floodplain forest suitable for species that prefer long-term dry conditions (i.e. Stratum 3 in Figure 3-13) would be associated with low water levels over time and areas with species tolerant of long-term waterlogged soils (i.e. Stratum 1 in Figure 3-13) would be associated with high water levels over time. The remaining areas were regarded as transitional wet to dry communities (i.e. Stratum 2 in Figure 3-13). In conclusion, the dynamic aspect of the main hydrological inputs in the floodplain forest, such as discharge of the adjacent River Great Ouse and rainfall data, needed to be considered in relation to their effect on the water table level as part of the hydrological variability of a river-floodplain system.

The importance of the water table in floodplains for the survival of vegetation habitats is well known. There are different techniques to raise the water level. For instance, Dufour and Piégay (2005) describe two existing techniques to raise groundwater level namely favouring more flow in the floodplain's former channel or artificial groundwater input from a reservoir; they described the re-injection of water into the aquifer by reconnecting a side channel from which water can infiltrate and raise the groundwater table by half a metre in the Rhone River (France) on the site of la Platière. Nadeau and Conway (2015) stated that implementing the optimal water depth for wetland-dependent wildlife to increase restoration success, water efficiency and water security in wetlands, diminishes water use while simultaneously increases habitat suitability for the focal species.

What is important is to gain a temporal sequence of water table level data on which to understand the wet and dry relationship across a site taking into account the principle water sources (i.e. rainfall events and their influence on water table recharge) and how it varies. This was the focus of the research in this chapter.

4.2 Methods: gathering hydrological data in the floodplain forest

Automatic logging of water table levels was originally planned to be combined with manual logging but issues with the loggers limited their use to supplementary. Hence, the water table level at the floodplain forest restoration site was assessed primarily through the manual recording supplemented with automatic data logger records for relative change assessment. Manual readings were taken with a dipper (In-Situ Rugged Water Level TAPE 100-50 m) on a monthly basis for the duration of the project (approximately during 1.5 years). A Leica total station was used to get the automatic and manual readings coordinates of the sampling points. Manual water table data measurements were gathered from the boreholes at each dipwell tube where loggers were dived (Figure 4-1). The loggers measured the total pressure acting on a transducer at their zero point/sensor. The total pressure is caused by the column of water lying above the logger pressure sensor and the barometric (atmospheric) pressure acting above surface (Solinst, 2012). Barologger data are used to compensate for barometric pressure fluctuations and get true height of water column measurements. Loggers could be adjusted in settings to gather data every 15, 30 or 60 minutes respectively. They were adjusted to record data every 15 minutes, as it was regarded as preferable and representative to have detailed information about water table variations in shorter periods of time. Data were downloaded every three months approximately. For verifying the logger's readings, the manual water table readings were used. These manual readings correspond in date and time with the actual logger recording to adjust all readings in the logger file (Solinst, 2012). Ten loggers were arranged below ground level in within the floodplain forest during the research (1-8 in the target area and 2 arranged immediately upstream and downstream of the River Great Ouse, Figure 4-1). Every logger is represented by a serial number. A single barologger (point 0 in Figure 4-1) was installed above ground for further calculations when downloading the water table readings from the loggers. The single barologger was used to compensate all data loggers on site within a 20-mile/30 km radius and with every 1000-ft/300 m in elevation (Solinst, 2012).

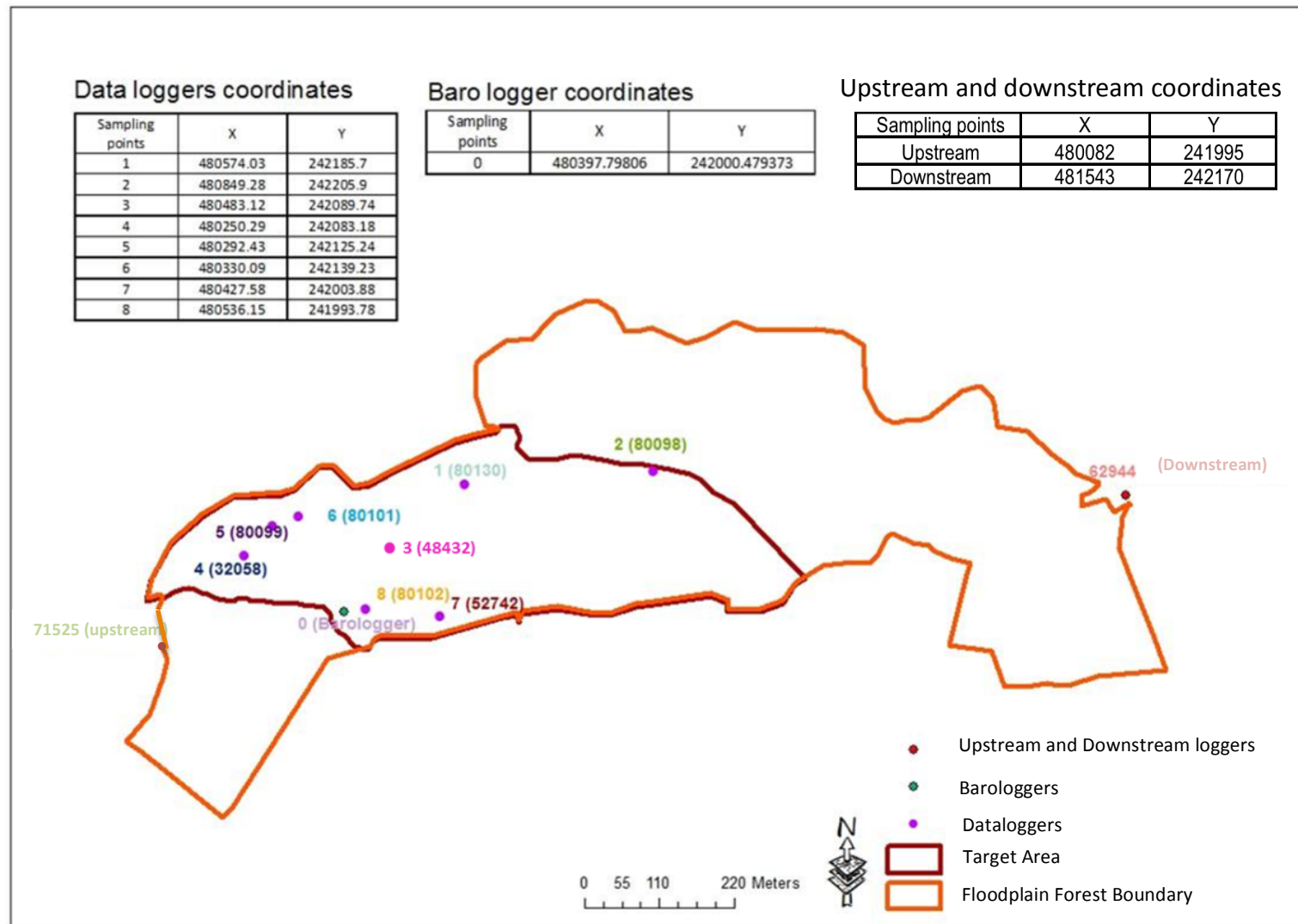


Figure 4-1 Manual and automatic water table and barologger locations and coordinates.

Installation of the loggers required a borehole of 1.5-2 m to be dug with a Dutch auger with extensions for the placement of the dipwells. Each dipwell tube had approximately 20 holes (1 cm diameter) drilled (Figure 4-2) and was installed at a different elevation range in the floodplain forest as the topography was not homogeneous and fluctuated from 56.60 mAOD to 64.65 mAOD. Calculations to adjust all water table-sampling locations up to the same ground level were made when downloading the data. Information regarding the heights from the ground to the top of the tube per logger and manual and automatic water table level measurements gathered are included in the CD of supplementary data.

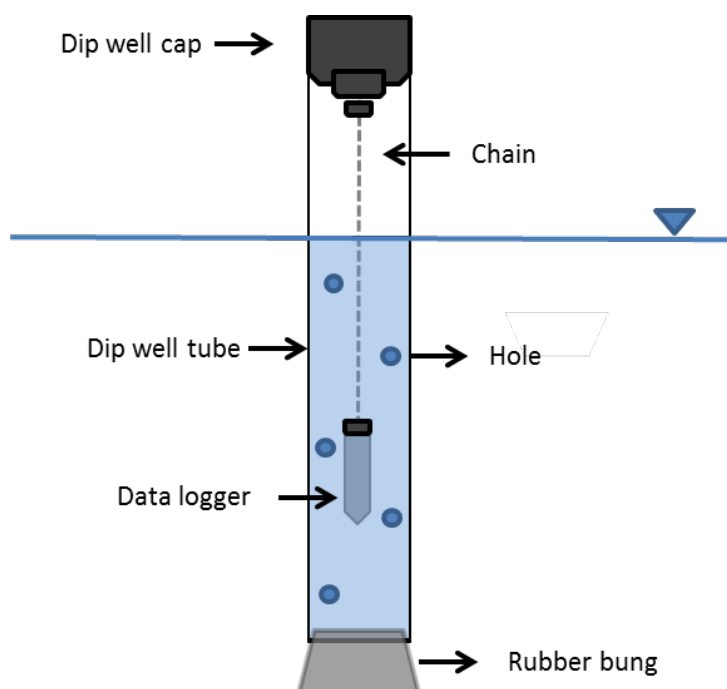


Figure 4-2 Data logger and dipwell tube.

Dipwell tubes were 1.5 m depth, 55 mm inner diameter and 70 mm outer diameter. Rubber bungs were placed at the bottom to stop the end of the dipwell tubes (Figure 4-2). In order to avoid soil going into the holes, dipwell tubes with rubber bungs already placed were covered with a nylon sock with one of its extremes tied tightly with a knot. Table 4-1 describes the types of data loggers used, owner, name, serial number, sampling points and battery (%). Some of the loggers were removed during the fieldwork due to malfunctioning or access restrictions (Logger 3 (48432) and logger 7 (52742) in Figure 4-1).

Table 4-1 Data loggers and barologger characteristics.

Owner	Name	Serial number	Sampling point	Battery %
Cranfield	DIVER	80130	1	99
Cranfield	DIVER	52742 (removed)	7	99
Cranfield	Solinst Barologger	62958	0	97
EA	DIVER	80098	2	99
EA	DIVER	80101	6	99
EA	DIVER	80102	8	99
Cranfield	Eijkelpark	32058	4	99
Cranfield	Solinst Model 3001	71525	Upstream	100
Cranfield	Solinst Model 3001	62944	Downstream	98
EA	DIVER	80099	5	99
EA	DIVER	48432 (removed)	3	99

Figure 4-3 below shows a Levellogger model 3001 installed in the floodplain forest. Solinst Version 3.1.1 software was used to programme loggers before going on site and to download the data records afterwards. A clear and systematic labelling system for the loggers was used when downloading data. Loggers were linked strongly and safely to the chain and were attached to a security cap that locked the dipwell tube at the top. Most of the loggers were installed in the target area, which was not open to public access; however, logger's upstream and downstream were in both sides of public footpath and could gain the attention of park users. The fieldwork equipment and material inventory needed for sampling water table and installing the loggers is listed in Appendix J.



Figure 4-3 Levellogger model 3001. Source: Geotechnical (2016).

Discharge values of the River Great Ouse were requested from the closest gauging station (i.e. 33037 gauging station at Newport Pagnell, Buckinghamshire). The averaged discharge regime data for 42 years of the River Great Ouse was calculated with the data available. Although the location of the gauging station was approximately 8 miles away down stream of the floodplain forest, the data were suitable as an indicator of River Great Ouse discharge fluctuations. A closer stage/discharge measurement point collection would have been preferred. Rainfall data from the nearest main weather recording extension in Northamptonshire (20 km away) were used for analysis.

According to Chapter 3, groundwater level average was estimated to be approximately at 58.72 mAOD, as stated in when listing the existing data in the floodplain forest; however, this represents the water level of the River Great Ouse at the site during the survey in 1999 before any of the planned works start. The gravel extraction works started in 2007 and finished in 2014, hence updated groundwater data were required.

There was a report available from Envireau Water commissioned by Hanson where they installed two loggers upstream and downstream of the River Great Ouse to measure water table level for two months (July 2011-September 2011). Outcomes of this report are displayed in results section, however the water table data were collected for only a small period of time and consequently had a high level of uncertainty, it could be used as a limited reference for further measurements taken in the floodplain forest.

4.3 Results

This section contains the hydrological data gathered within and in close proximity of the floodplain forest. These were the averaged discharge data of the River Great Ouse at Newport Pagnell gauging station, manual water table level direct measurements, relative water table data variations recorded by loggers, rainfall data and the final conclusions gathered from Envireau water report (i.e. drainage level assessment results for wetland restoration scheme).

4.3.1 Discharge values at the River Great Ouse

Figure 4-4 shows the averaged discharge regime for 42 years of the River Great Ouse. The blue line summarises the averaged discharge for each month. The dashed lines show the 95% Confidence Interval for a given month. A raise on average discharge values of the River Great Ouse were observed during autumn/winter months (from October to March) whereas decreased values were registered from spring/summer months (from April to September).

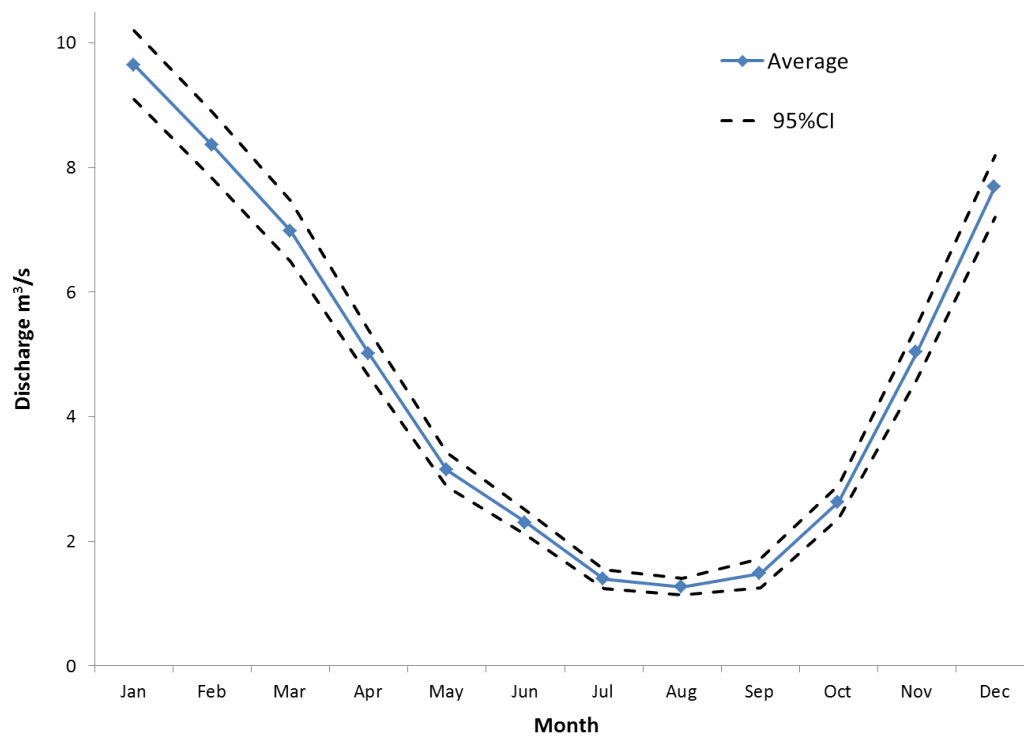


Figure 4-4 Averaged discharge regime for 42 years (1969-2011) of the River Great Ouse at Newport Pagnell.

4.3.2 Manual water table readings

Figure 4-5 below shows the manual water table readings gathered from June 2013 to October 2014. Each symbol represents the manual water table reading and matches the loggers sampling location (Figure 4-1). Manual water table readings were gathered during some of the periods when the automatic water table level sampled (orange boxes in Figure 4-6). Some measures were missed due to the inaccessibility of the area (i.e. waterlogged areas or quarry works taking place). Water table values varied between 10 cm and 200 cm below ground surface. All results relevant to water table are included in CD attached as a Microsoft excel data table.

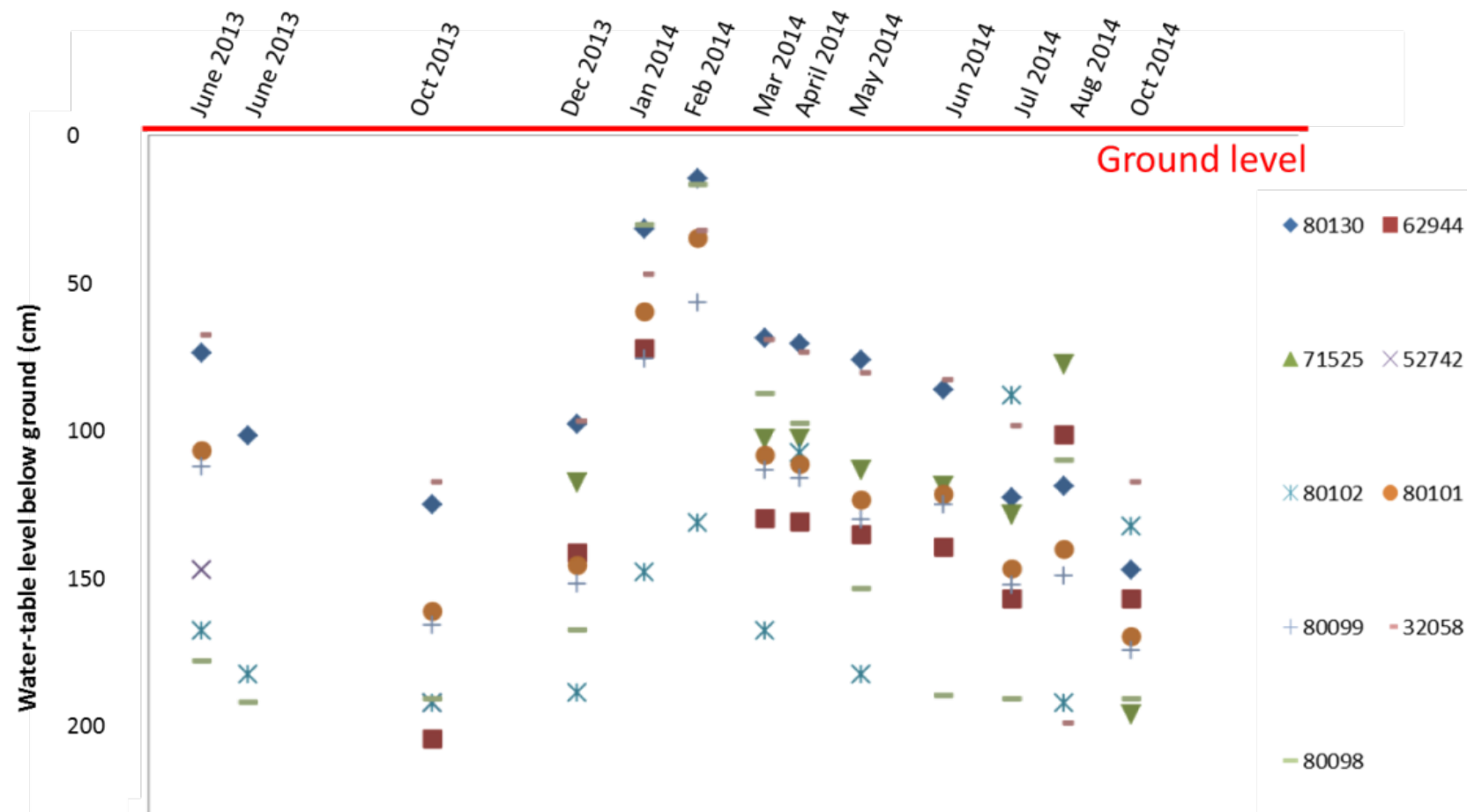


Figure 4-5 Manual water table readings gathered in 9 locations (i.e. from loggers' dipwells) the floodplain forest from June 2013 to October 2014. Logger 71525 was located upstream whereas logger 62944 was located downstream. Ground level was adjusted after measurements taken to 56.6 mAOD.

4.3.3 Automatic loggers

Each coloured line in Figure 4-6 below displays the automatic relative water table recording of the loggers at each dipwell tube. All loggers plus barologger were installed the 3rd of June 2013 with the exception of downstream logger 62944 and upstream logger 71525 that were installed the 1st of October 2013 (Figure 4-1). Logger 48432 (sampling point 3 in Figure 4-1) was removed at the beginning, as it was faulty. Partial measurements were gathered from logger 52742 (sampling point 7 in Figure 4-1). To sum up, a total of 9 loggers and 1 barologger were included in results (Figure 4-1). Barologger is represented in Figure 4-1 as sampling point 0 and it was located over ground.

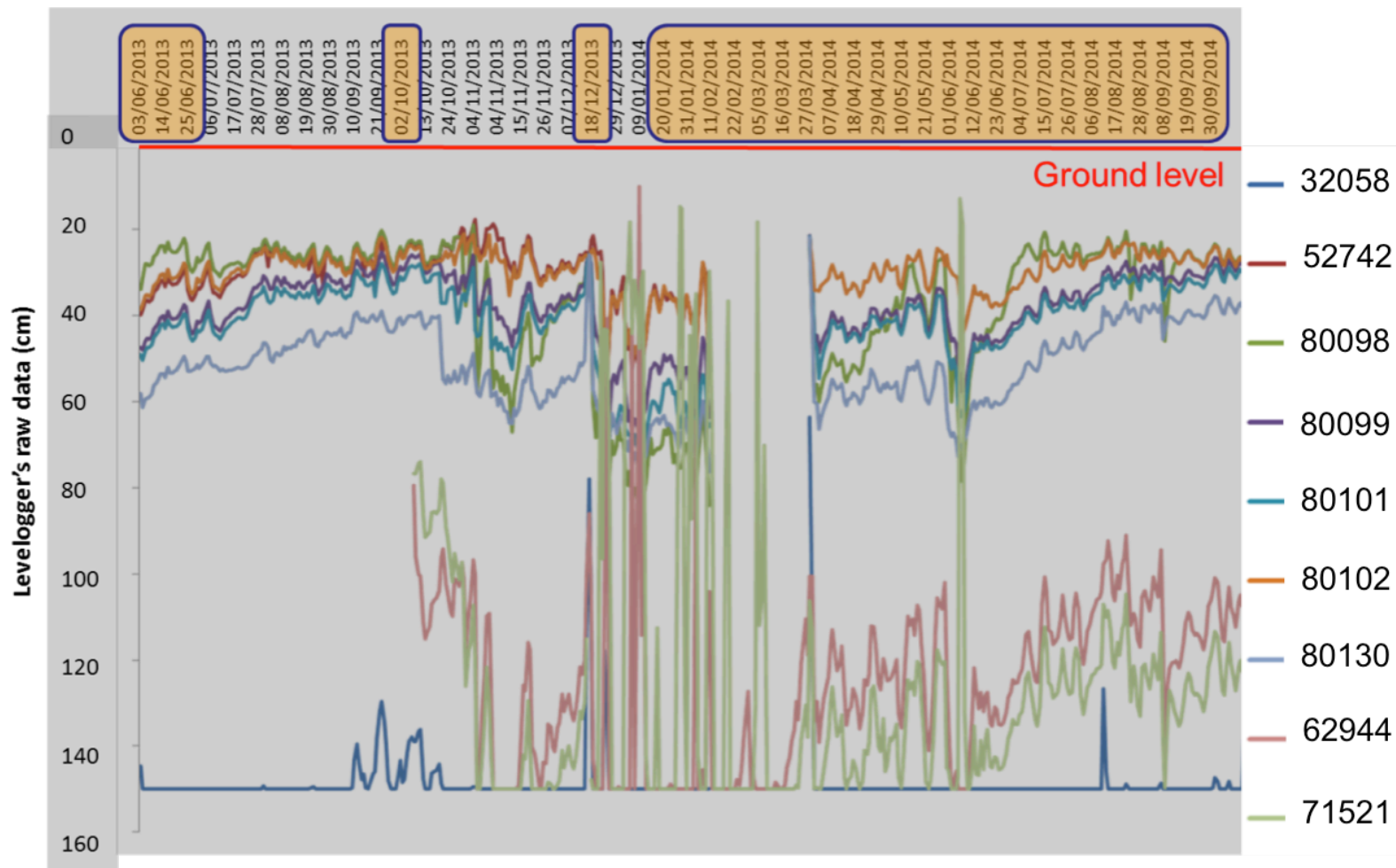


Figure 4-6 Relative water table values obtained automatically from 9 loggers. Orange boxes show the dates for which manual measurements were gathered. Ground level was adjusted for all loggers up to 56.60 mAOD.

4.3.4 Rainfall data at Ouse Valley Park

Blue bars in Figure 4-7 display the average monthly precipitation data in mm from June 2013 to October 2014. Red line represents water table depth averages for the period of manual measurements (i.e. January 2014 to October 2014) overlained over the rainfall bars. Highest average rainfall values were observed during October 2013, January 2014, May 2014 and August 2014 whereas the lowest rainfall values were observed in June 2013, March 2014, June 2014 and September 2014.

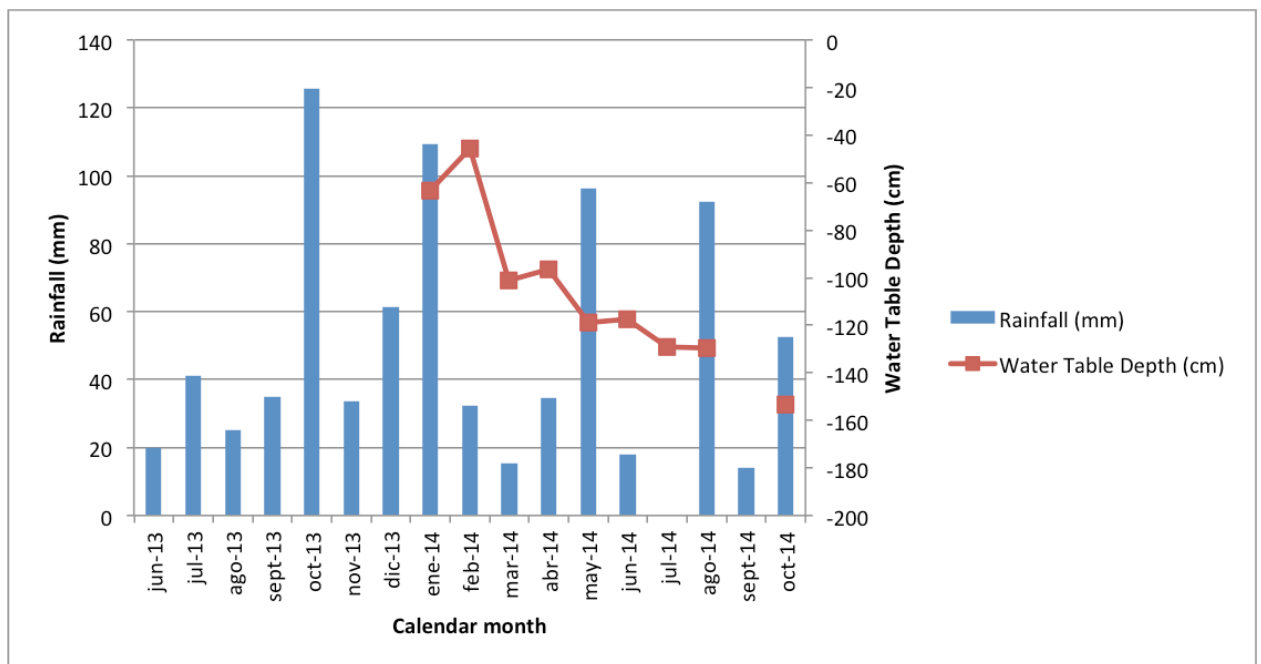


Figure 4-7 Rainfall data (mm) vs. Water Table Depth (cm). Source: Northampton weather recording station (2016)

4.3.5 Drainage level assessment

Envireau water report aimed to provide drainage levels for control structures that allow river water to enter into the restored floodplain. They identified two channels that flow into the floodplain during times of high flows (i.e. upstream, at the beginning of the back brock channel and a mid-channel that cross the floodplain in halves, Figure 3-1 in page 56). They combined two resulting logger's data with the data from the EA River gauging stations at Newport

Pagnell, Thornborough and Cappenham. The main conclusion was that statistically, for 18 days of the year the river levels of the River Great Ouse would be above the drainage levels calculated allowing river water to flow into the restoration area (Envireau water, 2012).

4.4 Discussion

Hydrological data gathered here provide evidence of the variability across the floodplain forest to provide explicit water table recommendations for future floodplain restoration efforts. These outputs help to understand how changes during the seasonal cycle will be an important baseline data when consider the type of vegetation community that will likely develop. The hydrology is a critical part of the habitats present in the floodplain forest for many water table-dependent species. The water table level does not have just an effect on tree species; birds (i.e. wading birds) are also affected by water table variations. Any change in water table level may have a direct effect on wading birds' response. Street (1986) observed that wading birds are attracted by the signs of a falling water level and consequently waders increased during periods of receding water.

Averaged discharge values were lower during July and September ($2.3 \text{ m}^3\text{s}^{-1}$ in July and $1.5 \text{ m}^3\text{s}^{-1}$ in September respectively). Highest discharge values were observed during winter months $5 \text{ m}^3\text{s}^{-1}$ in November and $7 \text{ m}^3\text{s}^{-1}$ in March. January averaged discharge values were $9.6 \text{ m}^3\text{s}^{-1}$ and $8.4 \text{ m}^3\text{s}^{-1}$ respectively. The remaining averaged discharge values were: April ($5 \text{ m}^3\text{s}^{-1}$), May ($3.1 \text{ m}^3\text{s}^{-1}$), June ($2.3 \text{ m}^3\text{s}^{-1}$), August ($1.3 \text{ m}^3\text{s}^{-1}$) and December ($7.7 \text{ m}^3\text{s}^{-1}$).

As deployment depth of the loggers contained in the dipwell tube was 1.5 m (i.e. length of the chain attached from the cap to the loggers), it meant that loggers did not collect any readings over 1.5 m. As an example, logger 32058 (sampling point 4 in Figure 4-6) does not show readings collected over 1.5 m depth; however, there are some fluctuations between September 2013 and October 2013 observed in the graph for this logger that shows the variability of water table observed for that period of time. Loggers 62944 (downstream) and 71525

(upstream) also do not display readings gathered below 1.5 m below ground from December 2013 to March 2014 (Figure 4-6). From 11th of February 2014 to the 27th of March 2014 data were not recorded by some of the loggers (i.e. with the exception of 62944 and 71525), as storage capacity was full. As upstream (71525) and downstream (62944) loggers were installed later than the remaining loggers, they did not present any storage problem. According to Figure 4-6 water table was below a meter in October 2013 and December 2013 for all loggers. From January 2014 to February 2014, logger 80130 (sampling point 1 in Figure 4-1) reached 30 cm below ground in January 2014 and 14 cm below ground in February 2014. There was an increase in water table for most of the loggers in January 2014 and February 2014 and logger 80102 (sampling point 8 in Figure 4-1) showed values below a meter (141 cm and 125 cm below ground) during the same period of time. There was a similar decreasing pattern in water table readings from March 2014 to June 2014 (i.e. between 181 cm and 65.5 cm below ground). There was an interesting pattern observed in all loggers in July 2014, August 2014 and October 2014 when heavy rain periods were registered. In July 2014, all loggers showed the same pattern as previous months with the exception of logger 80102 (sampling point 8 in Figure 4-1) that was 174 cm below ground in May 2014 and 84 cm below ground; it also decreased on August 2014 to 183 cm below ground and increased again to 126 cm below ground in October 2014. Loggers' levels dropped down again in October 2014. The deepest areas within the floodplain were located on the northeast side of the floodplain, with few smaller areas to the east (Figure 3-13 in page 97). It was expected for these areas to have higher water table values and be waterlogged the majority of the year. The variability of the water table level and the temporal wetness were expected to have an impact on the development of the vegetation communities present in the area. Automatic loggers' results indicated relative changes across the sites and how dynamic the water table in the floodplain forest was in a calendar year. Despite some loggers being found faulty and readings were not completed, the relative data still provided insight into the water level variation through time and this was

matched with the manual readings to show that the fluctuations were real. The water table variability displayed in figure 4-5 and Figure 4-6 suggests that future floodplain restorations should include dynamic hydrology variability.

Relative values gathered from the loggers and manual readings for the same period of time showed variability depending on the location considered (i.e. higher or lower areas, close to the River Great Ouse etc.) and seasonality (i.e. heavy rain or drought periods). Manual water table levels in Figure 4-5 increased during the same months as averaged discharge values in Figure 4-4 (i.e. January and February). Manual water table (Figure 4-5) and averaged discharge values (Figure 4-4) decreased during October. Both graphs outline the existing relationship between manual water table and averaged discharge values. Discharge and water table are interlinked in floodplain forest-rivers systems. At a given rate of discharge increase, the water level rises more slowly as the floodplain begins to fill (Junk *et al.* 1989). Both parameters have a strong influence in habitats development, soil and nutrients availability. According to Egger *et al.* (2013) flow regime is characterized by hydrological variability, which controls physical habitat, riparian characteristics, groundwater level, soil moisture, nutrient supply and disturbance regime. All these parameters have a direct effect on the establishment of floodplain vegetation, especially water table level. Amlin and Rood (2002) stated that gradual water-decline tended to promote shoot and especially root growth, whereas abrupt water decline reduced growth and ultimately induced mortality. An understanding of the relationship between water table declines and plant response may enable land and water managers to avoid activities that are likely to stress desirable riparian vegetation (Shafroth *et al.* 2000). It is important to carry out an effective management practice planning for the maintenance of the floodplain forest based on the understanding of the hydrology of the site and so saving in restoration costs and guaranteeing a successful management of the habitats created. This could be summed up in terms of planting, where it is strongly encouraged to survey the area to be planted first to assess the state of natural regeneration. Blackham *et al.* (2014) state blanket planting of large areas with a

low diversity of expensive saplings makes no ecological sense and planting should focus on suitable areas that need planting.

Manual water table readings were gathered twice in June and displayed high variability of the manual water table depending on seasonal conditions in a short period of time (i.e. water table at late June was lower than at the beginning in Figure 4-5). These readings were used to assess the stability of water levels especially in response to periods of high evaporative demand and heavy rain. It is evident that the rainfall has an effect over the water table replenishment and as a consequence and effect on the floodplain forest vegetation. Prax (1991) studied the changes in the hydrophysical properties of the soil (i.e. water table level) of a forest ecosystem and discussed the importance of rainfall to floodplain vegetation. The drop in water level (red line in Figure 4-7) appears to be at a slower rate if there was higher rainfall in or just prior to the month when the water level data were collected. So there is a response but on a monthly basis with periods of high rainfall slowing the rate of water table depth drop in the summer to autumn months. After a heavy rain event, it was expected a water table recharge, and as a consequence water table levels would raise. There were plans from Hanson and TPT to design a sluice as an option to divert water from the target area to the remaining floodplain forest. Hydrological data presented in this chapter may help with this design; however this option was not taken on board of this PhD. Envireau water correlated data for 2 months only, so there was a significant level of uncertainty that should be taken into account when designing engineering structures. By knowing in which period of time the River Great Ouse discharge is going to rise, it will help to regulate the open/closure of the sluice system to regulate water table levels. Adjusting the water level via a sluice system potentially gives some benefits such as raised water levels which can be used to flood water meadows in winter, isolated nesting islands in spring/summer from foxes, fill scrapes and pools adjacent to lakes and re-fill drawn down lakes (Giles, 1992a). Although this report was not considered reliable as water table data were collected for only a small period of time and consequently had a high level of uncertainty, it

could be used as a limited reference for further measurements taken in the floodplain forest.

To sum up, floods are needed to recharge the water table level, however flooding can be a problem if it occurs during the growing season; conversely, less effect will occur during the non-growing season because of a reduced demand for oxygen by roots and microorganisms (Egger *et al.*, 2013, cited in Maddock *et al.*, 2013, p. 410). Results in this chapter demonstrate the effect of seasonality (i.e. months) over the recharge rate of water table in the floodplain forest (i.e. it was observed an increase in water table readings on different season periods). The recharge rate will however depend on site characteristics. For example, the topography of the site, soil characteristics (e.g. if it is clay soil or sandy soil), vegetation present and any structures will influence the recharge rate which is why these are key variables to consider.

This chapter provides the insight of hydrology and its influence at this site. Topography was varied and soils were very homogenous across the floodplain. It claims the importance of key variables to measure and according to the outputs of this chapter it would appear that hydrology is regarded as the most influential on the resultant vegetation growing in the floodplain forest. The more information gathered regarding soil, topography, flow and water table of a specific site to be integrated in the AMF, the easier it will be for stakeholders to take management decisions by interpreting the results collected and to understand the specific characteristics that the floodplain forest habitats needs to succeed.

5 Glasshouse experiment

5.1 Introduction to the experiment: water level and plant response

The experimental studies focussed on water table variation stated in section 2.2.2 in chapter 2 clearly show the importance of understanding the relationship between vegetation development and water table depth, which is the focus of this chapter.

A glasshouse experiment to specifically test the main hypothesis stated in Chapter 3 (*The ratio of wet/dry vegetation within the floodplain forest is determined by the site topography and water table level*) was done. Whilst elevation was considered part of the main thesis hypothesis posed, due to glasshouse limitations, it couldn't be addressed in the experiment. The window of opportunity of the experiment settings in terms of timing and season of eligible species was limited. Decision was made to choose *P. trichocarpa x deltoides* (*P. x generosa*) (Generous poplar) and *S. viminalis* (Common osier) clones cuttings from Bowhayes tree nursery (Devon, United Kingdom) as both species can coexist within a floodplain forest, were considered by TPT of interest to study and cuttings were available at that specific time of the research. Hence the study specifically focussed on hybrid *Populus trichocarpa x deltoides* (*P. x generosa*) and *Salix viminalis* responses to water table variations.

Conducting experimental work on plant-water relationship in the laboratory requires an ability to simulate field conditions as closely as possible without losing experimental control (Araya *et al.* 2010). In the cited example in 2.2.2 (page 38), Araya *et al.* (2010) looked at plants that had different characteristics that related to the amount of water available through the year, however for the present study conducted over a limited time of several weeks, the interest was mainly in understanding the main effect of different water levels on selected floodplain forest species. The purpose was to establish which water-soil wetness levels promote growth characteristics and rates following cutting

establishment and link outputs obtained with fieldwork conditions if possible. Species from wetter habitats (at lower elevations or in the open water) tend to germinate better under flooded conditions compared with species from drier habitats (Kellogg *et al.* 2003). The outputs of the glasshouse experiment would then be interpreted in relation to the prediction that species tolerant to waterlogged conditions would occur in lower topographical areas and species tolerant to drier conditions would occur in higher topographical areas, which is specifically analysed in Chapter 6.

5.1.1 Introduction to the pilot study

Specific quantifiable attributes of the plants were required to be determined. Through a pilot study these attributes were identified as: number of buds, shoot length (cm), diameter at the bottom (mm), diameter at the apex (mm), number of leaves, wet leaves and dry leaves biomass (g) and root biomass (g). Leaf biomass and leaf area was also measured in randomly selected cuttings. This decision was made based on the time consuming exercise and to get a representative result for the whole experiment. The type of cuttings used (rooted or unrooted), soil, water, frequency of watering, temperature and humidity control were also identified. These parameters were considered to be measured because they show the growth responses and the rate of change can be analysed in relation to the effects of water availability. The pilot study was run to understand how rooted and unrooted cuttings of these species grew in clay soil and to test the feasibility of root washing (rooted and unrooted cuttings) at the glasshouse facilities in Cranfield University. Water table levels variations were not included in the pilot study.

5.2 Methods

5.2.1 Methodology for setting up the pilot study

Soil of the floodplain forest site and water of the River Great Ouse were used. Soil put onto the experiment was mixed to form a relatively homogeneous topsoil layer (TPT *pers. comm.*). Soil type was mainly clay soil in the floodplain

forest according to the analysis done in April 2013 (Table 3-9, section 3.3.4. page 103) and resulting soil triangle (Appendix F) and was collected from the target area (Figure 3-1 in page 56) where most of the planting was done. Sediments were reassembled in each pot in the facilities. It was not possible to reassemble sediment layers with exactly the same degree of packing as they had in the field. In total about 1 T and 244 kg of sediment was supplied by TPT operator's field site to complete the experiments. The water of the River Great Ouse supplied by TPT's operators was stored in two 110 L water butts located in the glasshouse facilities. Water was added to the buckets as necessary manually to compensate for daily evaporation. Water quality of the river was analysed from May to June in 2013. Results of water quality are displayed in Figure 3-18 in page 118. These data shows that during the period that the water was extracted from the River Great Ouse it remained consistent in water quality.

A total of 12 clones of tree cuttings were purchased: 3 rooted (60-90 cm length) and 3 unrooted (30 cm length) *P. trichocarpa x deltoides* and 3 rooted (60-90 cm length) and 3 unrooted (30 cm length) *S. viminalis*. The pilot study lasted for 7 weeks (from the 14th February 2014 until the 4th of April 2014). The number of buds was kept as constant as possible. Cuttings were received and planted into pots (20 cm diameter) on 17th February 2014. To encourage growth in the winter conditions, pots were placed in a compartment covered with a plastic sheet where buds development and shoot growth were monitored (Figure 5-1 (a)). A small Linux computer with a sensor (Figure 5-1 (b)) was installed to monitor internal temperature (°C) (in the compartment) and external ambient temperature (°C) (in the glasshouse), relative humidity (%), relative light values (%) and shoot and buds development by camera. Pots (Figure 5-1 (c)) were supervised on a daily basis and watered every 2 days.

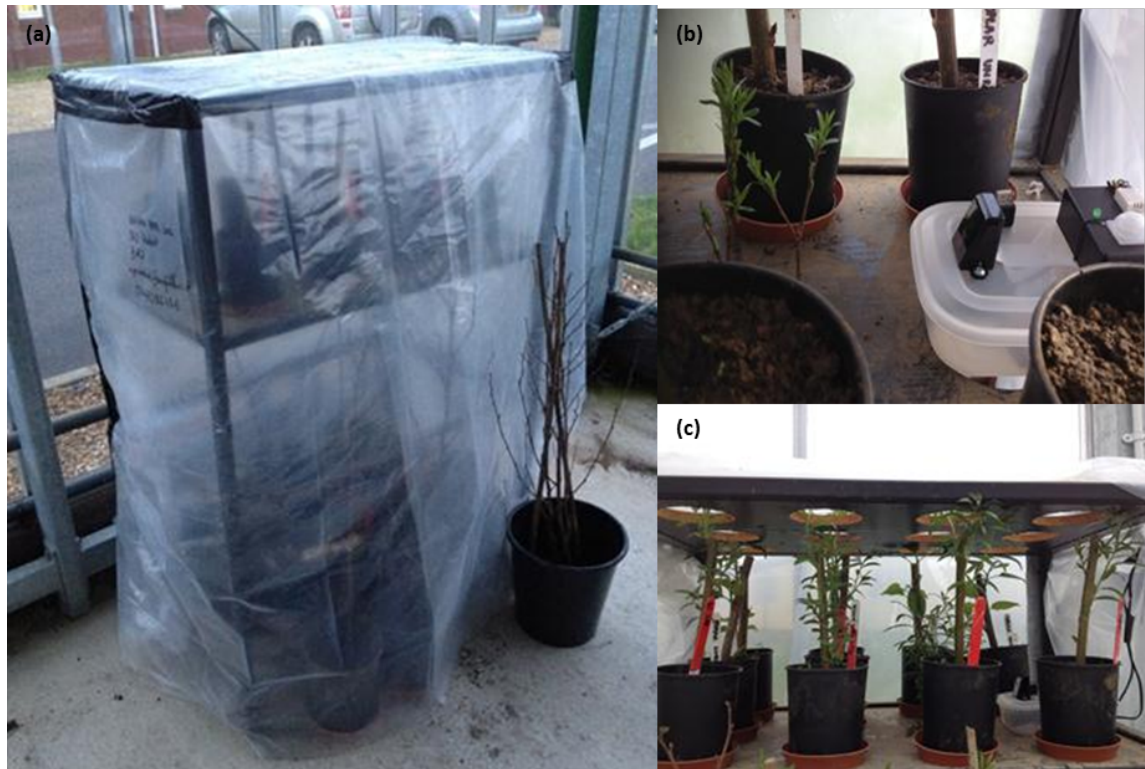


Figure 5-1 (a) Pots in compartment covered with a plastic sheet to encourage buds growth and shoot development. (b) Small Linux computer monitoring shoots and buds development of some pots in the compartment. (c) Unrooted *S. viminalis* and *P. trichocarpa x deltoides* shoot development.

In early March 2014, when conditions within the glasshouse improved sufficiently for growth (18°C-20°C approx.), the cuttings were moved out of the compartment (Figure 5-2 (a)). Figure 5-2 (a) shows the unrooted *P. trichocarpa x deltoides* cuttings at the front row and the rooted *S. viminalis* at the back. Figure 5-2 (b) shows an unrooted *P. trichocarpa x deltoides*.

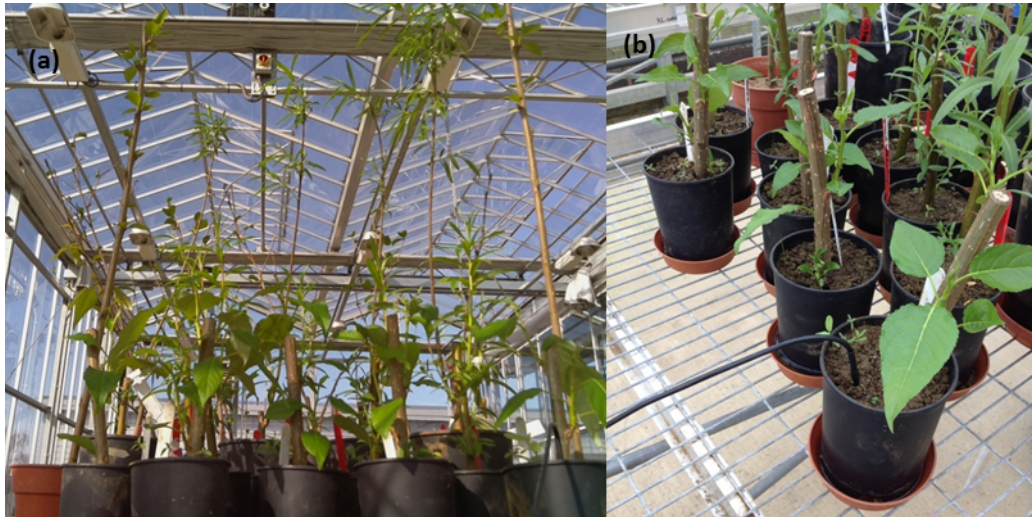


Figure 5-2 (a) Picture of cuttings taken by the small Linux computer out of the compartment in the glasshouse. The front row shows the unrooted cuttings, the rooted cuttings are at the back in this picture. (b) Unrooted *P. trichocarpa x deltoides*.

The number of root washings events and leaf area and biomass measurements for the pilot study are displayed in Table 5-1 below. It displays the dates where each root-washing event took place plus the type of cuttings (rooted or unrooted) and species selected. A total of 8 cuttings (4 rooted and 4 unrooted) of the initial 12 ordered were selected for analysis. Remaining cuttings were donated to a forest-planting scheme.

Table 5-1 Pilot study root washing and leaf area and leaf biomass events.

Root washing and leaf area and leaf biomass events	Date	Cuttings
1 st	6 th March 2014	1 rooted <i>S. viminalis</i> and 1 rooted <i>P. trichocarpa x deltoides</i>
2 nd	19 th of March 2014	1 unrooted <i>S. viminalis</i> and 1 unrooted <i>P. trichocarpa x deltoides</i>
3 rd	26 th of March 2014	1 rooted <i>S. viminalis</i> and 1 rooted <i>P. trichocarpa x deltoides</i>
4 th	2 nd of April 2014	1 unrooted <i>S. viminalis</i> and 1 unrooted <i>P. trichocarpa x deltoides</i>

Gyssels and Poesen (2003) tried to answer whether the below ground biomass is of no or negligible importance with respect to soil erosion by concentrated flow. They also propose that increasing the plant root density in the topsoil could be a viable erosion control strategy. Roots provide the soil with mechanical reinforcement. Comparable mechanical effects of roots in topsoils can be thought of controlling soil erosion by concentrated water flow (Morgan and Rickson, 1995). Methods for root washing were considered in discussions with different experts. Professor Karl Ritz (Soil ecologist at University of Nottingham) suggested making the root washing with Sodium hexametaphosphate in order to ease the task of remove soil from the roots. Professor Jane Rickson (Professor of soil erosion and conservation at Cranfield University) suggested considering non-destructive technique such as CT-Scan (Computed Tomography). It consists of the application of X-ray CT for visualising roots. This discussion led us to visit University of Nottingham facilities and meet Dr. Sacha Mooney (Professor in Soil Physics at University of Nottingham) and Dr. Craig Sturrock (Senior Research Fellow in University of Nottingham) who showed an example of how the Micro-CT used. Finally, based on the advice from the experts, time available and within financial restrictions, rooted cuttings were chosen and washed in a bucket under warm water running to soften the soil and ease the root washing. It was an easy method, cheap and feasible with the cuttings selected in the initial pilot study.

Roots were cut and placed per individual in a tray and left overnight in the oven at 105°C. The harvested root matter was then dried for 12 h before weighing. ImageJ (<http://rsb.info.nih.gov/ij/download.html>) was used to measure leaf biomass, leaf area and root length. Assessment of leaf area was complemented with digital photography. Initially it was thought that the leaves could be scanned in a flatbed scanner, and this produced very good images of a high quality. However, photographs with a digital camera proved to be sufficient for software analysis and were much quicker. Leaves were arranged on a clear desk, white background and photographed by a 5 megapixel digital camera mounted on a tripod and held perpendicular to the desk with an object of known

size to provide scale for area determination. Leaves were picked by hand from each sample and collected in garden waste bags. Measurement of wet leaf biomass took place the same day as the root washing as the leaves rapidly lose moisture especially under high temperature (i.e. warm weather). Leaves were taken to the soil laboratory and weighed immediately to obtain a wet weight. Preparing and measuring the wet leaf area from the cuttings took 1 hour approximately. After leaf area measurement, all leaf samples were placed in foil trays inside the oven and left overnight to dry at 105°C. Samples were reweighed the following day to determine the total leaves dry matter content.

To process the leaf collection a number of leaves were pulled at once free from the twig. In addition, running a hand against the direction of growth, down a branch easily removed the leaves without recourse to picking each individual leaf. It was noted that buds from the base of the petiole and sometimes the unignified current season's growth was also included in the measurement.



Figure 5-3 Example of photograph used for leaf area determination with *S. viminialis* leaves.

JPG images were opened in ImageJ and a scale set based using the university id card width (8.54 cm) – *Analyse > Set Scale* (Figure 5-3). Images were then *Converted to binary* using *Process>Binary>Make Binary* (Figure 5-4).

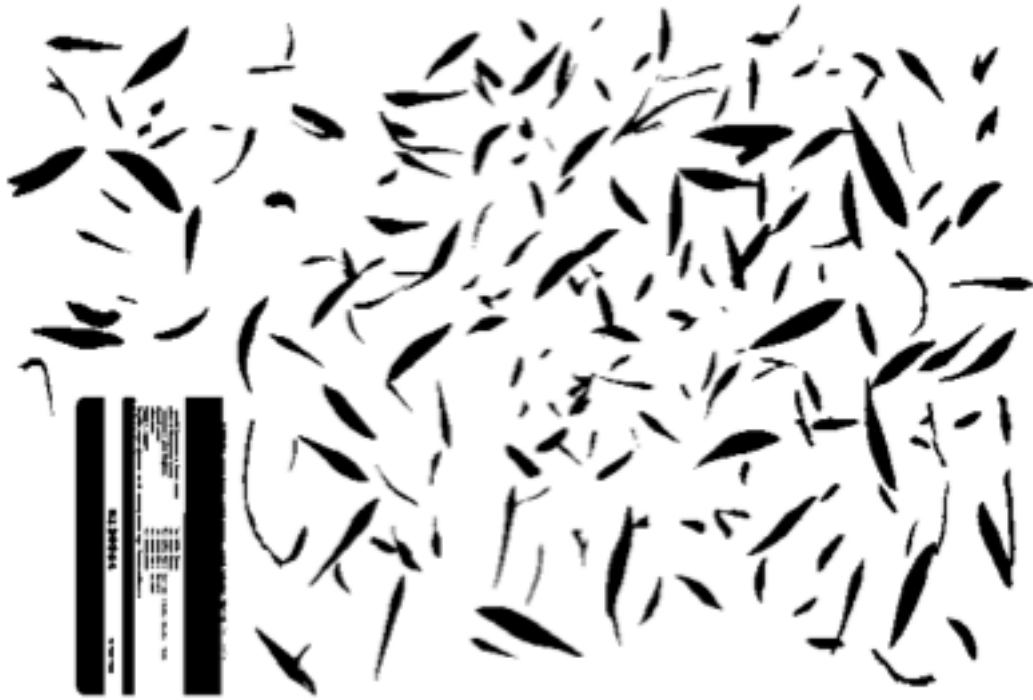


Figure 5-4 Image converted to Binary with *S. viminalis* leaves.

Using the freehand selection tool the scale object was highlighted, and the selection inverted using *Edit > Selection > Make Inverse*. The number of black pixels was then counted using *Analyse > Analyse Particles*. *Show Outlines function* was used to check the validity of measurements (Figure 5-5) and gives the total area.

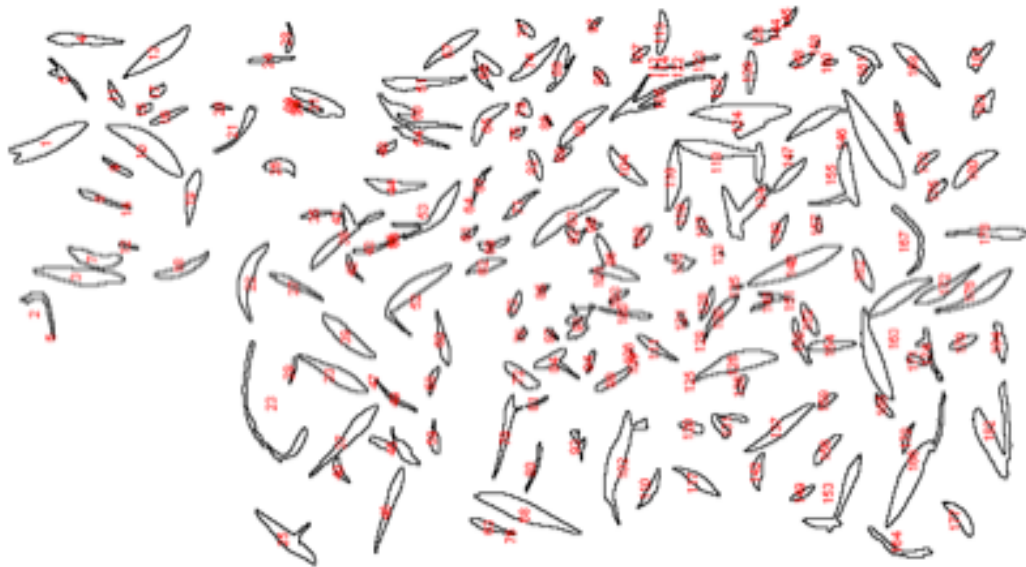


Figure 5-5 'Show Outline' output with *S. viminalis* leaves. Note red numbers are the polygon numbers listed in the 'show results'.

5.2.2 Glasshouse experiment

Based on the previous pilot study, unrooted cuttings were chosen because they were easy to wash on clay soil and parameters to measure were easier to quantify from the beginning of the experiment as all cuttings were identical (i.e. clones) at the starting point (30 cm length with no roots). The experiment was conducted during 13 weeks (Table 5-2).

By varying the water-table levels depth in buckets, it was possible to provide a replicated system of different water table conditions for cuttings and examine the growth response per individual. The constant water-table levels were selected based on many studies that have indicated that altered water regimes can change species distribution and composition, especially in wetlands bordering water bodies, such as riparian zones (Elder 2003; Leyerd 2005; Catford *et al.* 2011 cited in Sarneel *et al.*, 2014 in p.1007). The three water-table level depths chosen were: A-Flooded, B-Wet and C-Dry (Adapted from Sarneel *et al.* 2014). The rationale behind these water table depths chosen is because in the complexity of a field situation, a flooding depth just below the soil level, an

intermediate flooding duration and a high flooding frequency provided the best opportunities for maximal germination (Sarneel *et al.* 2014).

The ease of the system to establish constant and/or dynamic water-table depths and its reliability indoors renders it useful for a wide variety of studies involving cutting growth. The system included manually adjusted water-table depth treatment buckets (i.e. transparent buckets with scale and taps to measure and adjust water level manually). Three water-table constant depths were applied manually to the buckets containing the cuttings and remained until the end of the experiment. Water level was above soil level by 13 cm in Flooded (A) water-table depth. To create the Flooded (A) water-table depth, water was added to the top level of the bucket, so cuttings were completely flooded and kept under waterlogged conditions. In the Wet (B) water-table depth (0 cm), water was maintained at soil level (i.e. water was at soil level) and in the Dry (C), the water-table level depth was maintained 5 cm above the bottom of the buckets, hence a small amount of water was available at a level 25 cm below soil level in Dry (C) water-table depth. More information relating to the arrangements of water table constant depth levels is detailed in Phase II: Experimental phase section below.

S. viminalis and *P. trichocarpa x deltoides* cuttings were placed in round vertical growth tubes (50 cm length, 68 mm diameter and 4 mm thickness). Sediment (i.e. clay substrate) was bulked and mixed together and homogenized manually filling the growth tubes. The growth tubes were placed into the transparent buckets (25 litres capacity, 43 cm length, top diameter 36 cm and bottom diameter 30 cm). Taps attached to near the bottom of the buckets were used to regulate the water level inside the buckets. Ten holes (72 mm) were drilled in the lid of each bucket to allow the growth tubes to stand vertically inside the bucket. The glasshouse averaged temperature was 21°C during the experiment. A mobile roof covering the glasshouse facility was unfolded automatically if temperatures became higher than 25°C. Relative humidity varied from 24.2% to 80% and there were 13-16 hours light approximately per

day during the glasshouse experiment (July-September 2014). No extra light or heating was provided during the experiment.

The experiment was divided in three phases: (I) Cuttings establishment, (II) Experimental phase and (III) Cuttings measurement (Table 5-2). Phase I took place during the first two weeks. Phase II took place for one week. Phase III lasted for 10 weeks.

Table 5-2 Glasshouse experiment calendar time.

Phase	Time	Date	Root washing event
I. Cuttings establishment	Week A	16 th -29 th June 2014	-
	Week B	30 th June 2014-6 th July 2014	-
II. Experimental phase	Week C	7 th July 2014- 12 th September 2014	-
III. Cuttings measurement	Week 1	7 th - 13 th July 2014	11 th July 2014
	Week 2	14 th -20 th July 2014	17 th July 2014
	Week 3	21 st -27 th July 2014	24 th July 2014
	Week 4	28 th July 2014- 3 rd August 2014	28 th July 2014
	Week 5	4 th - 10 th August 2014	5 th August 2014
	Week 6	11 th -17 th August 2014	11 th August 2014
	Week 7	18 th -24 th August 2014	21 st August 2014
	Week 8	25 th -31 st August 2014	28 th August 2014
	Week 9	1 st -7 th September 2014	3 rd September 2014
	Week 10	8 th -12 th September 2014	11 th September 2014

Phase I: Cuttings establishment

Cuttings arrived in mid June 2014 and were stored at 4°C and soaked in water of the River Great Ouse for two days. During Phase I, all cuttings were stood in

and then allowed to drain to allow setting of sediments in the growth tubes. The water level in all buckets was maintained at 10 cm above the bottom of the buckets surface for 14 days following planting to allow for cutting establishment. It was expected that ambient temperatures in the laboratory encouraged adventitious root formation and buds development.

Phase II: Experimental phase

A total of 300 cuttings were placed individually in the buckets (150 *P. trichocarpa x deltoides* and 150 *S. viminalis*). Each bucket had a constant water-table depth level value assigned (A-Flooded, B-Wet and C-Dry) (see Figure 5-6). There were a total of 30 buckets with 10 cuttings each. Five of each species considered were placed at random within a bucket. Therefore, there were ten vertical growth tubes containing 5 cuttings of *P. trichocarpa x deltoides* and 5 cuttings of *S. viminalis* per bucket. In the facilities, buckets were laid out randomly within an area in the centre of the glasshouse of 4 x 1 m approximately. Owing to the constant conditions and the space available in the facilities there were no expected gradient factors associated with the glasshouse layout potentially affecting the growth response. The primary focus was the species attributes and the water table level in sufficient replication to analyse the growth response.

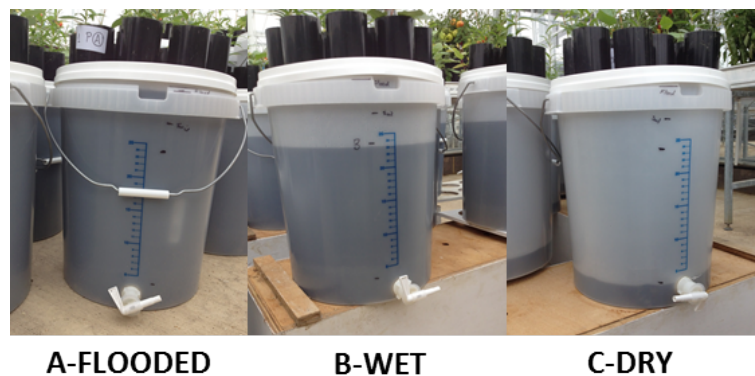


Figure 5-6 Water-table depth systems: A-Flooded, B-Wet and C-Dry.

Phase III: Cuttings measurement

Some constant measurements in selected cuttings were made whilst the remaining cuttings were growing. This was supplemented by the destructive sampling (i.e. after root and leaf removal cuttings were disposed) over the 10 weeks. Figure 5-7 below shows how cuttings were selected for root washing by Cranfield University technician.



Figure 5-7 Nigel Janes (Water technician at Cranfield University) selects randomly one cutting for root washing at the glasshouse facilities in the 4th week of cuttings growth.

Ten events of root washing took place (Table 5-2). Thirty cuttings were washed, measured (root biomass, wet leaf biomass and dry leaf biomass) and disposed per week). Six out of these thirty cuttings were randomly selected and destructively sampled at each root washing event every time, giving a total of 60 samples that were analysed for root shoot length, leaf area and leaf biomass following methodology stated in the pilot study.

An object of known size was included in each photograph to provide scale for length determination (in this case, a 30 cm ruler, Figure 5-8) for shoots and root length analysed using ImageJ. The different species displayed slightly different

root morphologies (Appendix K). Once the scale was settled a segmented line was used to draw the root length and for taking the measures at the same time (Figure 5-8).



Figure 5-8 Root length determination using ImageJ with number 145 *S. viminialis* shoot with C-Dry water treatment in the glasshouse experiment.

The experiment was a fully replicated study and involved destructive measurements of growth through time. Collected data were analysed using the analysis of variance on Statistica® platform.

Based on the glasshouse outputs a ranking score system was implemented to classify cuttings of the species considered according to their status and interaction with the water level depth. It was expected during the experiment that some cuttings may not proliferate and some of the parameters remain static (i.e. no change). Outputs of dead/dormant cuttings were represented by “0” in all parameters for the first root washing event but left blank in further weeks of experiment. Health of all cuttings were measured at weekly intervals in order to

quantify growth rates and health through the experiment; leaves (L) and roots (R) were assessed on a three-point scale (Table 5-3), with “0” representing a plant with no sign of growth (i.e. dead/dormant), “1” stands for growing plant but with sign of stress for the stage of growth (discoloration, rotten roots etc.) and “2” presents an apparently good status (Adapted from Barsoum and Hughes, 1998). “L” and “R” values were scored according to Table 5-3 score values plus the shoots (i.e. roots status) and leaves pictures taken during the root washing. Final scored value (**S**) is obtained by multiplying “L” by “R” scores and classified according to Table 5-4. Leave area (%), roots area (mm²) and roots length (mm) outputs for the ranking-score system were obtained from ImageJ software. Average values were obtained and included as final results for the species considered.

Table 5-3 Score values for leaves and roots ranking system.

Score	Status	Description
0	Dead/dormant	No leaves, no roots visible. No sign of growth.
1	Alive plant with sign of stress for the stage of growth	Some leaves although visible discoloration. Short roots, in some cases rotten.
2	Apparently plant in good status	Healthy and green leaves and roots without discoloration and not rotten. Cutting status ok according to the stage of growth.

Table 5-4 Final scored (S) classification for cuttings.

I	4	Plant in good status. Appropriate roots and leaves for that stage of growth.
II	2	Either roots ok but poor leaf development or leaves ok but poor root development. But in general an apparently healthy plant in that stage of growth.
III	1	Poor growth and lack of development in roots and leaves in that stage of growth.
IV	0	Dead/dormant plant. Some signs of rotten parts or some kind of disease developing (due to the excess of water).

5.3 Results

5.3.1 Results of the initial pilot study

Outputs gathered within the plastic compartment by the Linux computer during the first 10 days (1st-10th March 2014) is shown in Figure 5-9. The internal ambient temperature (°C) was in red (in the compartment) and external (in the glasshouse) was in blue. This section contains a summary overview of the growing conditions in the pilot study to set the context for the glasshouse experiment.

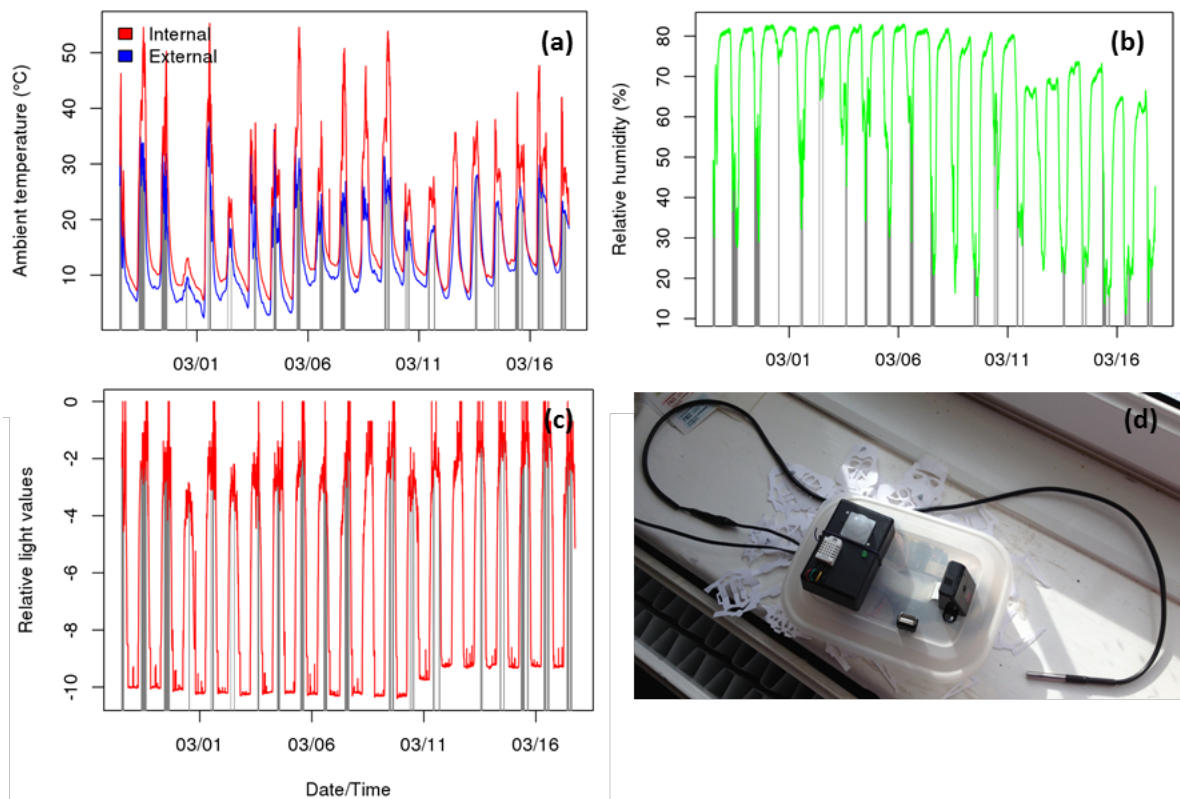


Figure 5-9 Outputs gathered from 1st-16th March 2014. (a) Ambient temperature (°C): from 1st to the 10th of March 2014 internal temperature displayed in red (under the plastic sheet) and external temperature displayed in blue (in the glasshouse facilities). (b) Relative humidity (%). (c) Relative light values. (d) Small Linux computer.

A total of 8 cuttings were included in the analysis (2 rooted *S. viminalis* and 2 unrooted *P. trichocarpa x deltoides*, 2 unrooted *S. viminalis* and 2 unrooted *P. trichocarpa x deltoides*). Results obtained for all parameters measured are displayed in Table 5-5 below. As expected, number of buds in rooted was higher than unrooted for both species as rooted were more developed over time than unrooted. Buds count in *P. trichocarpa x deltoides* was lower than *S. viminalis* for both rooted and unrooted cuttings. Shoot length in all unrooted cuttings did not grow during the pilot study. In contrast, shoot length in all rooted *S. viminalis* was higher than all rooted *P. trichocarpa x deltoides*. Diameter at the apex and diameter at the bottom were lower in rooted *P. trichocarpa x deltoides* than in rooted *S. viminalis*. Diameter at the apex and diameter at the bottom were higher in unrooted *P. trichocarpa x deltoides* than in unrooted *S. viminalis*. Based on the limited data, it was decided to choose those parameters that did indicate more growth over short period of time. Root biomass (g) in unrooted cuttings gradually increased over time (Table 5-5). Wet leaves biomass and dry leaves biomass increased in all rooted and unrooted cuttings over time. For the pilot these differences were not tested statistically due to the low sample size.

Table 5-5 Pilot study results.

Root washing event	Species	Buds count	Root biomass (g)	Wet leaves biomass(g)	Dry leaves biomass(g)
06/03/14	<i>P. trichocarpa x deltoides</i> rooted	13	0.99	0	0
06/03/14	<i>S. viminalis</i> rooted	22	0.41	1.33	0.51
19/03/14	<i>P. trichocarpa x deltoides</i> unrooted	4	0.08	6.8	1.26
19/03/14	<i>S. viminalis</i> unrooted	6	0.12	4.12	0.85
26/03/14	<i>P. trichocarpa x deltoides</i> rooted	11	1.15	7.93	2
26/03/14	<i>S. viminalis</i> rooted	24	2.18	9.55	2.59

Root washing event	Species	Buds count	Root biomass (g)	Wet leaves biomass(g)	Dry leaves biomass(g)
2/04/14	<i>P. trichocarpa</i> x <i>deltoides</i> unrooted	2	0.16	10.59	2.5
2/04/14	<i>S. viminalis</i> unrooted	5	0.43	5.76	1.28

The pilot study provided the basic understanding of the practicalities and methods to use in the glasshouse experiment to be planned appropriately. The main factors were as follows:

- The use of unrooted cuttings instead of rooted.
- Warm water to clean the roots from clay soil.
- Temperature and humidity suitable for cuttings to flourish.
- Frequency of watering the cuttings.
- Parameters to choose and to measure. The main aim of the pilot was to look more at how to collect the most appropriate data. Root biomass, wet leaves biomass and dry leaves biomass were chosen as best indicators as it was proved in the pilot study to show changes in growth in a short period of time.

5.3.2 Results of the glasshouse experiment

A total of 30 weekly root washings events (15 *P. trichocarpa* x *deltoides* and 15 *S. viminalis* cuttings) were successfully completed weekly. Root biomass (g), wet leaves biomass and dry leaves biomass (g) was measured. The results focussed on understanding how the three water tables levels affected growth of root biomass, wet leaf biomass and dry leaf biomass on selected cuttings. Leaf mass and root length were also measured in selected cuttings. Figure 5-10 below displays cuttings growth status on the 6th week of the experiment.



Figure 5-10 Cuttings growth status on the 6th week of glasshouse experiment.

The raw data for additional parameters measured (Number of buds, shoot length (cm), diameter at the bottom (mm), diameter at the apex (mm), number of leaves) for cuttings selected are provided in CD attached.

Leaves outputs using ImageJ software for selected cuttings are displayed in Table 5-6. It shows information regarding date, week, sample, cutting, species, water treatment, count, total area, average size, % area and mean.

Table 5-6 Leaves outputs using ImageJ software for selected cuttings for leaf area and leaf biomass in the glasshouse experiment. A = Flooded, B = Wet and C = Dry.

Number	Date	Week	Sample	Cutting	Specie	Water treatment	Count	Total Area	Average Size	% Area
1	11/07/2014	Week 1	5PoplarA	5	Poplar	A	205	61.199	0.299	13.774
2	11/07/2014	Week 1	10WillowA	10	Willow	A	291	44.654	0.153	9.608
3	11/07/2014	Week 1	15WillowB	15	Willow	B	834	69.114	0.083	9.566
4	11/07/2014	Week 1	20PoplarB	20	Poplar	B	116	59.25	0.511	16.753
5	11/07/2014	Week 1	25WillowC	25	Willow	C	354	118.554	0.335	17.348
6	11/07/2014	Week 1	30PoplarC	30	Poplar	C	246	79.696	0.324	23.157
7	17/07/2014	Week 2	35PoplarA	35	Poplar	A	172	81.038	0.471	17.807
8	17/07/2014	Week 2	40WillowA	40	Willow	A	134	81.401	0.607	16.926
9	17/07/2014	Week 2	45WillowB	45	Willow	B	245	162.979	0.665	25.44
10	17/07/2014	Week 2	50PoplarB	50	Poplar	B	217	211.402	0.974	30.51
11	17/07/2014	Week 2	55WillowC	55	Willow	C	247	101.17	0.41	22.497
12	17/07/2014	Week 2	60PoplarC	60	Poplar	C	59	42.666	0.723	21.737
13	24/07/2014	Week 3	65PoplarA	65	Poplar	A	139	34.137	0.246	18.538
14	24/07/2014	Week 3	70WillowA	70	Willow	A	551	133.929	0.243	25.501
15	24/07/2014	Week 3	75WillowB	75	Willow	B	1782	127.731	0.072	19.239
16	24/07/2014	Week 3	80PoplarB	80	Poplar	B	282	69.089	0.245	18.845
17	24/07/2014	Week 3	85WillowC	85	Willow	C	486	76.582	0.158	15.723
18	24/07/2014	Week 3	90PoplarC	90	Poplar	C	439	161.326	0.367	29.185
19	28/07/2014	Week 4	95PoplarA	95	Poplar	A	299	186.718	0.624	37.227
20	28/07/2014	Week 4	100WillowA	100	Willow	A	1431	97.229	0.068	19.701
21	28/07/2014	Week 4	105WillowB	105	Willow	B	3668	210.872	0.057	30.899
22	28/07/2014	Week 4	110PoplarB	110	Poplar	B	403	192.606	0.478	31.833
23	28/07/2014	Week 4	115WillowC	115	Willow	C	269	135.173	0.503	18.888
24	28/07/2014	Week 4	120PoplarC	120	Poplar	C				
25	05/08/2014	Week 5	125PoplarA	125	Poplar	A	79	157.142	1.989	32.146
26	05/08/2014	Week 5	130WillowA	130	Willow	A	262	91.048	0.348	15.01
27	05/08/2014	Week 5	135WillowB	135	Willow	B	358	193.106	0.539	20.41
28	05/08/2014	Week 5	140PoplarB	140	Poplar	B	269	146.27	0.544	29.141
29	05/08/2014	Week 5	145WillowC	145	Willow	C	121	120.718	0.998	21.089
30	05/08/2014	Week 5	150PoplarC	150	Poplar	C				
31	11/08/2014	Week 6	155PoplarA	155	Poplar	A				
32	11/08/2014	Week 6	160WillowA	160	Willow	A	1334	121.995	0.091	19.035
33	11/08/2014	Week 6	165WillowB	165	Willow	B	1029	80.66	0.078	14.403
34	11/08/2014	Week 6	170PoplarB	170	Poplar	B	2198	252.491	0.115	33.025
35	11/08/2014	Week 6	175WillowC	175	Willow	C	2098	85.367	0.041	12.929
36	11/08/2014	Week 6	180PoplarC	180	Poplar	C				
37	21/08/2014	Week 7	185PoplarA	185	Poplar	A	500	109.399	0.219	38.174
38	21/08/2014	Week 7	190WillowA	190	Willow	A	1356	41.669	0.031	6.937
39	21/08/2014	Week 7	195WillowB	195	Willow	B	1985	89.289	0.045	18.037
40	21/08/2014	Week 7	200PoplarB	200	Poplar	B	134	230.643	1.721	37.193
41	21/08/2014	Week 7	205WillowC	205	Willow	C				
42	21/08/2014	Week 7	210PoplarC	210	Poplar	C				
43	28/08/2014	Week 8	215PoplarA	215	Poplar	A				
44	28/08/2014	Week 8	220WillowA	220	Willow	A	440	89.674	0.204	16.706
45	28/08/2014	Week 8	225WillowB	225	Willow	B				
46	28/08/2014	Week 8	230PoplarB	230	Poplar	B	283	225.042	0.795	33.792
47	28/08/2014	Week 8	235WillowC	235	Willow	C	589	73.752	0.125	14.23
48	28/08/2014	Week 8	240PoplarC	240	Poplar	C				
49	03/09/2014	Week 9	245PoplarA	245	Poplar	A				
50	03/09/2014	Week 9	250WillowA	250	Willow	A	4171	123.219	0.03	16.184
51	03/09/2014	Week 9	255WillowB	255	Willow	B				
52	03/09/2014	Week 9	260PoplarB	260	Poplar	B	912	204.631	0.224	32.122
53	03/09/2014	Week 9	265WillowC	265	Willow	C				
54	03/09/2014	Week 9	270PoplarC	270	Poplar	C				
55	11/09/2014	Week 10	275PoplarA	275	Poplar	A				
56	11/09/2014	Week 10	280WillowA	280	Willow	A	1416	13.376	0.009	2.344
57	11/09/2014	Week 10	285WillowB	285	Willow	B	2441	27.753	0.011	3.668
58	11/09/2014	Week 10	290PoplarB	290	Poplar	B	1633	443.48	0.272	48.149
59	11/09/2014	Week 10	295WillowC	295	Willow	C	1278	129.737	0.102	15.736
60	11/09/2014	Week 10	300PoplarC	300	Poplar	C				

Appendix L shows leaf and area biomass calculation, binary images and outlines for selected cuttings. It displays the root and leaf growth in selected cuttings (*S. viminalis* *P. trichocarpa* x *deltoides*) per week under different water table depth. It is worth noting some of the *P. trichocarpa* x *deltoides* cuttings did not display any sign of growth during the experiment for the flooded water depth (i.e. 120-P-C, 150-P-C, 180-P-C, 210-P-C, 240-P-C, 270-P-C, 300-P-C, Appendix L). In contrast, *S. viminalis* showed in most cases higher root growth for all water table depths (i.e. 160-W-A, 135-W-B, 190-W-A, 165-W-B, 190-W-A, 250-W-A, 115-W-C, Appendix L).

Main results were analysed with ANOVA (species and water treatment interaction) and rANOVA (time, species and water treatment interaction) for root biomass (g), wet leaf biomass (g) and dry leaf biomass (g).

ANOVA results

Root biomass

Figure 5-11 displays that the two species showed different root biomass growth for all the water treatments with *S. viminalis* growing the best (ANOVA $F = 5.09$, $p = 0.025$ in Table 5-7). The difference in growth of the species in relation to water level was significant (Table 5-7), with *S. viminalis* growing well in the flooded and wet treatments. Furthermore, *S. viminalis* grew the most in the flooded water treatment compared to the other treatments (Figure 5-11). Table 5-7 shows that there was a significant difference between the root biomass (g) of the two species (ANOVA $F = 21.45$, $p = 0.0006$). *P. trichocarpa* x *deltoides* had relatively poor root growth (g) particularly in flooded treatment (Figure 5-11). No significant difference was overall found in root biomass growth with water treatments ($F = 2.14$, $p = 0.160$).

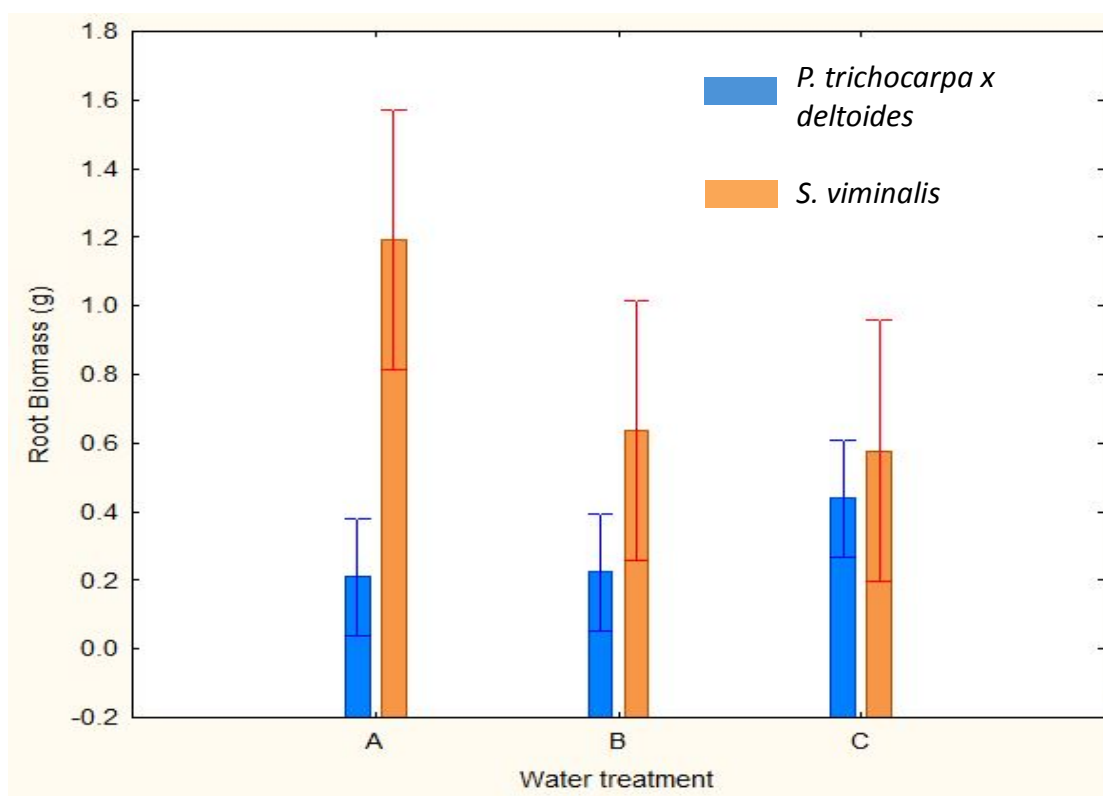


Figure 5-11 Root biomass (g) of *P. trichocarpa x deltoides* and *S. viminalis* with three different water treatments: A-Flooded, B-Wet and C-Dry. Bars show the mean values $\pm$ standard deviation.

Table 5-7 ANOVA results for root biomass (g).

Root biomass (g)	F	p
Species	21.45193	0.000578
Water treatment	2.14133	0.160227
Species*Water treatment	5.09446	0.025019

Wet leaf biomass

Figure 5-12 displays that the two species showed different wet leaf biomass growth for all the water treatments (ANOVA $F = 0.50$, $p = 0.612$ in Table 5-8), *S. viminialis* response was similar in flooded and dry water treatment (Figure 5-12). The difference in growth of the species was also significantly more for *S. viminialis* in the flooded and wet treatments. Furthermore, *S. viminialis* grew the most in the wet water treatment compared to the other treatments (Figure 5-12). Table 5-8 shows that there was a significant difference between the wet leaf biomass (g) of the two species (ANOVA $F = 13.53$, $p = 0.0015$ in Table 5-8). *P. trichocarpa x deltoides* had relatively poor wet leaf growth (g) particularly in flooded and dry treatment (Figure 5-12). No significant difference was overall found in wet leaf biomass growth with water treatments ($F = 5.20$, $p = 0.0152$ in Table 5-8).

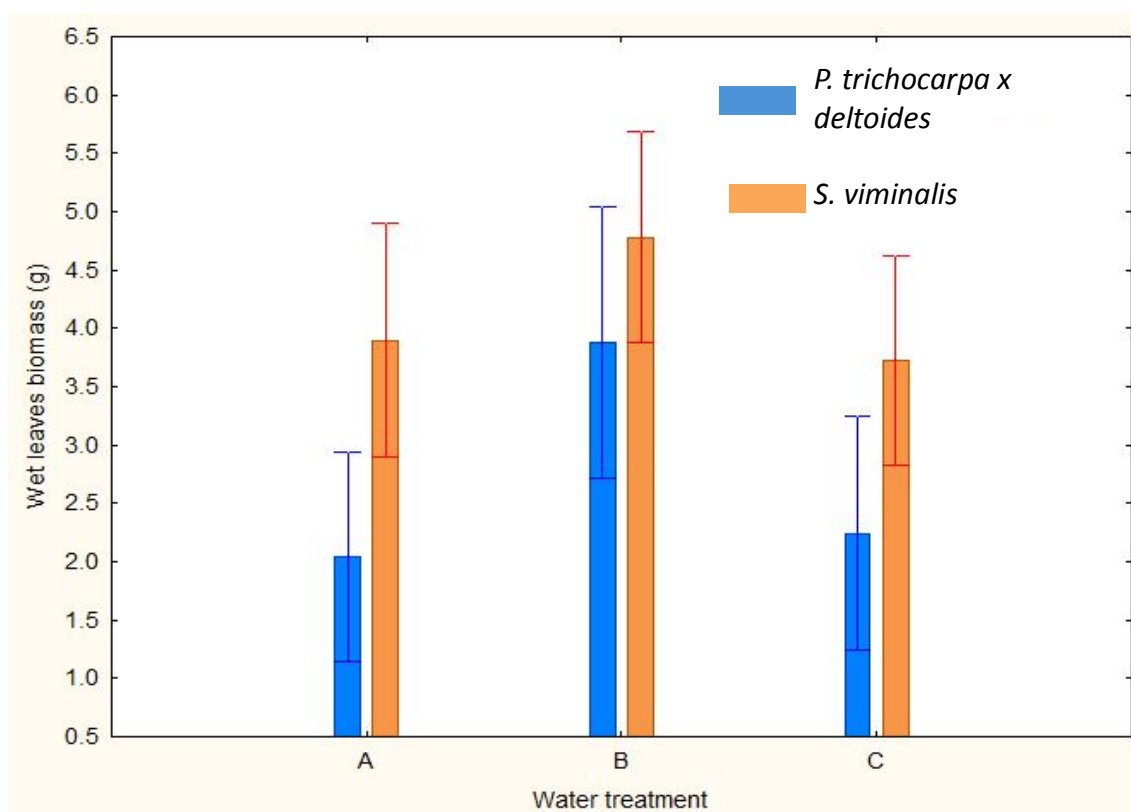


Figure 5-12 Wet leaves biomass (g) of *P. trichocarpa x deltoides* and *S. viminialis* with three different water treatments: A-Flooded, B-Wet and C-Dry. Bars show the mean values $\pm$ standard deviation.

Table 5-8 ANOVA results for wet leaves biomass (g).

Wet leaf biomass (g)	F	p
Species	13.5271	0.001492
Water treatment	5.2001	0.015189
Species*Water treatment	0.5027	0.612322

Dry leaf biomass

Figure 5-13 displays that the two species showed different dry leaf biomass growth for all the water treatments with *S. viminalis* response similar in flooded and dry water treatment (ANOVA $F = 0.37$, $p = 0.693$ in Table 5-9). The difference in growth of the species was also significantly more for *S. viminalis* in the flooded and wet treatments. Furthermore, *S. viminalis* grew the most in the wet water treatment compared to the other treatments (Figure 5-13). Table 5-9 shows that there was a significant difference between the dry leaf biomass (g) of the two species (ANOVA $F = 26.48$, $p = 0.00003$ in Table 5-9). *P. trichocarpa x deltoides* had relatively poor dry leaf growth (g) particularly in flooded and dry treatment (Figure 5-13). No significant difference was overall found in dry leaf biomass growth with water treatments ($F = 4.41$, $p = 0.0234$ in Table 5-9).

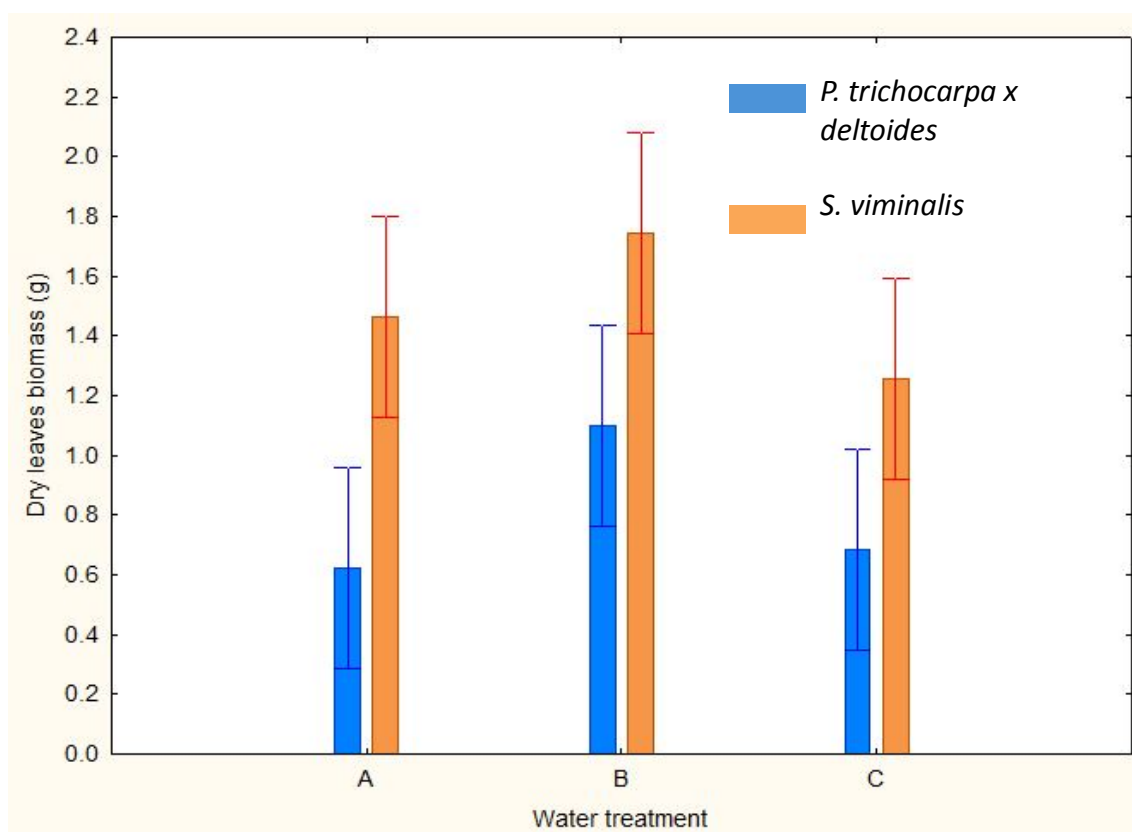


Figure 5-13 Dry leaves biomass (g) of *P. trichocarpa x deltoides* and *S. viminalis* with three different water treatments: A-Flooded, B-Wet and C-Dry. Bars show the mean values $\pm$ standard deviation.

Table 5-9 ANOVA results for dry leaf biomass (g).

Dry leaf biomass (g)	F	p
Species	26.4772	0.000029
Water treatment	4.4094	0.023392
Species*Water treatment	0.3725	0.692915

rANOVA results

Root biomass

Figure 5-14(a) and figure 5-14(b) display that the two species showed different root biomass growth over time ($F= 2.015$, $p=0.04$ in Table 5-10). The difference in growth of root biomass for water treatments over time was significant ($F=1.95$, $p=0.02$). Furthermore, *S.viminalis* grew the most in the flooded water treatment compared to the other treatments (Figure 5-14(b)). *P. trichocarpa x deltoides* had relatively poor root growth (g) particularly in flooded and dry treatment (Figure 5-14(a)), showing peaks of growth for the wet treatment. No significant different was overall found in species and water treatment interaction for root biomass growth over time ($F= 1.55$, $p= 0.09$ in Table 5-10).

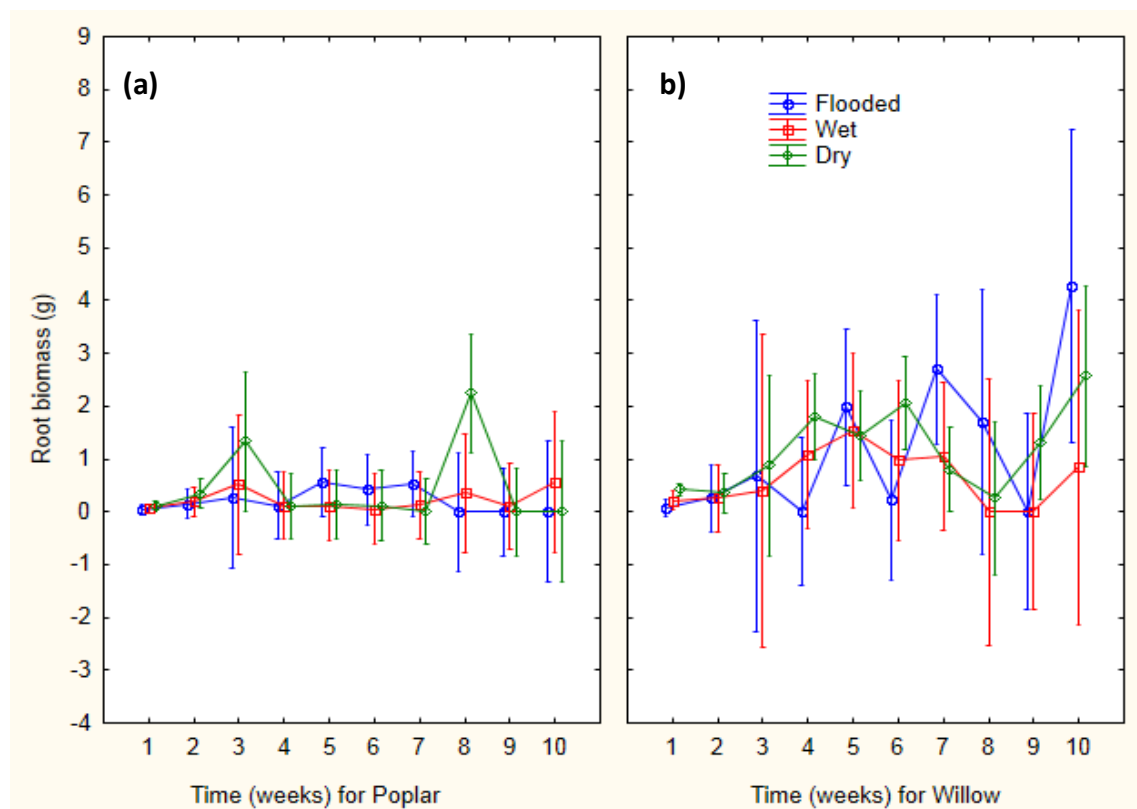


Figure 5-14 (a) Root biomass (g) of Poplar (*P. trichocarpa x deltoides*) with three different water treatments over time. (b) Root biomass (g) of Willow (*S. viminalis*) with three different water treatments over time. Mean values $\pm$ standard deviation are displayed per week.

Table 5-10 rANOVA results for root biomass (g).

Root biomass (g)	F	p
Time*Species	2.01465	0.044322
Time*Water treatment	1.94636	0.019141
Time*Species*Water treatment	1.54649	0.088037

Wet leaf biomass

There was not a significant difference between species wet leaf biomass (g) over time ($F=1.02$, $p= 0.425$ in Table 5-11). Water treatments did not appear to have any significant effect on wet leaf biomass over time ($F= 1.413$, $p= 0.129$ in Table 5-11), although as shown in Figure 5-15 (a) and Figure 5-15 (b), *P. trichocarpa x deltoides* and *S. viminalis* were significantly greater in wet treatment ($F=1.794$, $p= 0.029$) respectively. *P. trichocarpa x deltoides* (Figure 5-15 (a)) was lower in flooded treatment over time and *S. viminalis* (Figure 5-15 (b)) was lower in dry treatment over time.

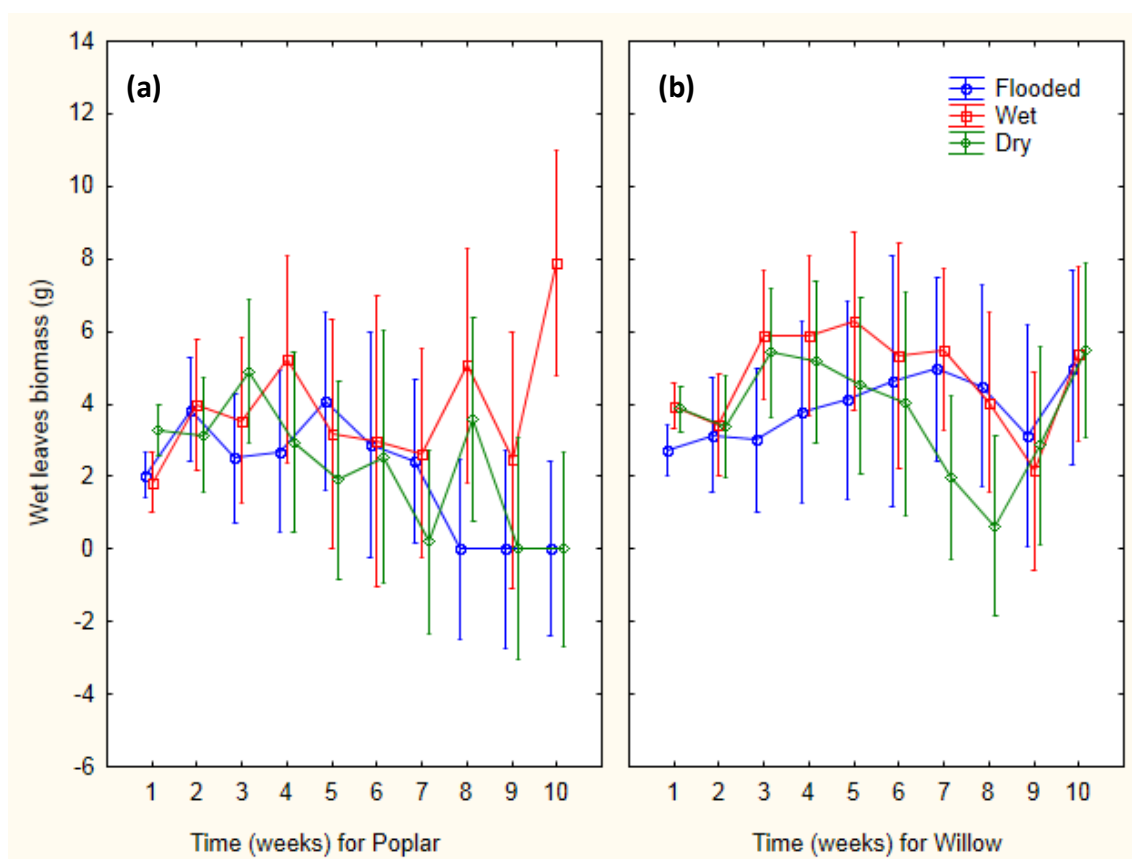


Figure 5-15 (a) Wet leaves biomass (g) of Poplar (*P. trichocarpa x deltoides*) with three different water treatments over time. (b) Wet leaves biomass (g) of Willow (*S. viminalis*) with three different water treatments over time. Mean values $\pm$ standard deviation are displayed per week.

Table 5-11 rANOVA results for wet leaf biomass (g).

Wet leaf biomass (g)	F	p
Time*Species	1.0214	0.424613
Time*Water treatment	1.4129	0.129812
Time*Species*Water treatment	1.7939	0.028866

Dry leaf biomass

There was a significant difference between species dry leaf biomass (g) over time ($F=3.17$, $p= 0.0013$ in Table 5-12). Water treatments did not appear to have any significant effect on dry leaf biomass over time ($F= 1.15$, $p= 0.302$ in Table 5-12). There was not significant difference in species interaction over time ($F=1.33$, $p= 0.169$ in Table 5-12). *P. trichocarpa x deltoides* dry leaf growth was significantly greater in wet treatment (Figure 5-16(a)) and lower in flooded over time. Whereas *S. viminalis* (Figure 5-16(b)) dry leaf growth was lower in dry treatment over time and higher in flooded treatment over time.

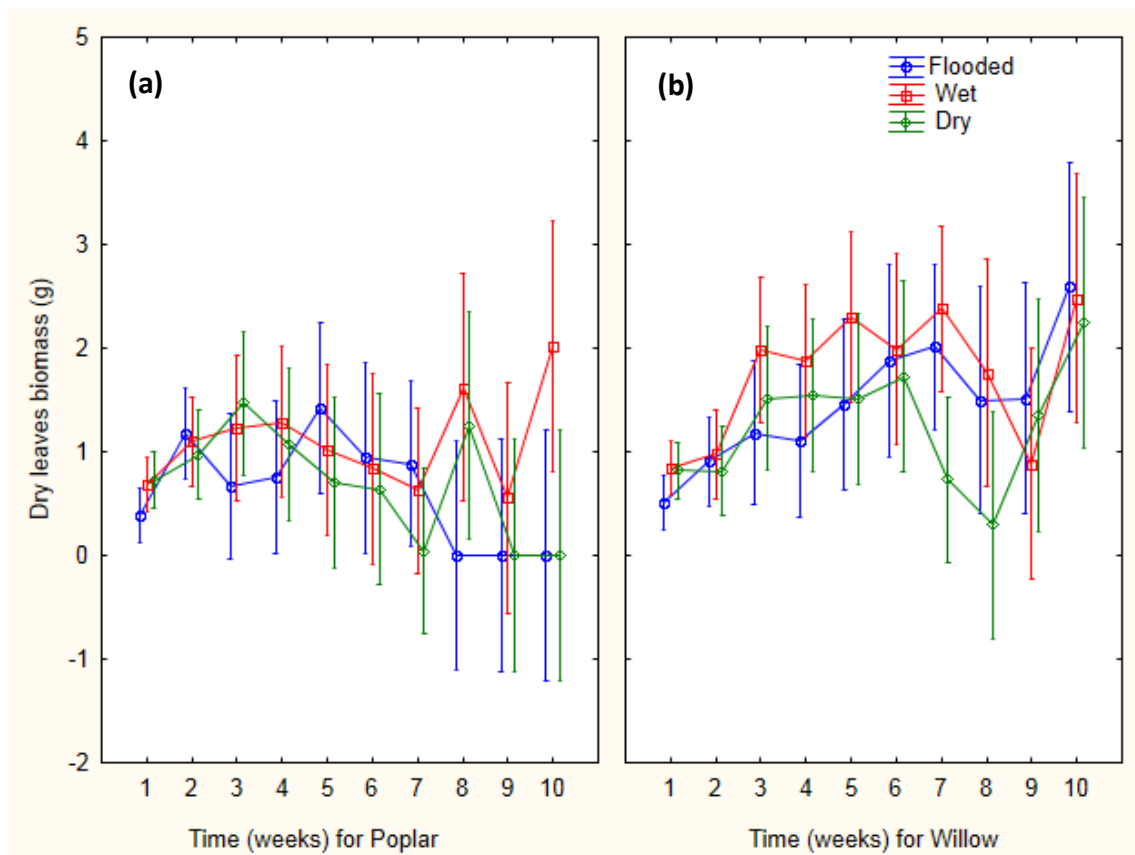


Figure 5-16 (a) Dry leaves biomass (g) of Poplar (*P. trichocarpa x deltoides*) with three different water treatments over time. (b) Dry leaves biomass (g) of Willow (*S. viminalis*) with three different water treatments over time. Mean values $\pm$ standard deviation are displayed per week.

Table 5-12 rANOVA results for dry leaf biomass (g).

Dry leaf biomass (g)	F	p
Time*Species	3.1744	0.001266
Time*Water treatment	1.1542	0.302216
Time*Species*Water treatment	1.3331	0.169138

Table 5-13 shows the Ranking/scoring system to classify *P. trichocarpa x deltoides* and *S. viminalis* cuttings status. **L** and **R** values were scored according to Table 5-3 plus the shoots (i.e. roots) and leaves pictures taken during the root washing. Final scored value (**S**) was obtained by multiplying **L** by **R** and classified according to Table 5-4. *S. viminalis* majority scores fall over II, which means the cuttings are generally healthy although some signs of deterioration (poor leaves development, poor root growth) are present. Score IV is present in at least four cuttings for wet and dry treatments. This means there was no dead/dormant cutting for the flooded treatment.

P. trichocarpa x deltoides majority scores fall over IV for flooded and dry treatments (i.e. extreme water table depths), with no scores falling into the wet treatment. This means most of cuttings were dead/dormant or present some sign of rottenness. There are also cuttings falling in I, II (generally good and healthy cutting status) and a minority of III (lack of growth). Overall, there are more dead/cuttings in *P. trichocarpa x deltoides* than in *S. viminalis*, being the latter more resistant to extreme water treatments (flooded and dry).

Table 5-13 Ranking/scoring system to classify *P. trichocarpa x deltoides* and *S. viminalis* cuttings status. N – ID number of cutting selected for leaf and root measurement, WT – Water-table depth Treatment (A-Flooded, B-Wet and C-Dry), W - week number, L - leaves score value, R - root score value and S - final scored value.

N	WT	<i>S. viminalis</i>			W	L	R	S
		Leave Area %	Roots Area (mm ²)	Roots Length (mm)				
10	A	9.2	10.8	76.4	1	2	2	I
15	B	9.6	34.1	210.1	1	2	2	I
25	C	17.3	43.3	255.7	1	2	2	I
40	A	16.9	22.4	139.3	2	2	2	I
45	B	25.4	20.4	125.8	2	2	2	I
55	C	22.5	14.7	100.5	2	2	2	I
70	A	25.5	81.3	425.1	3	2	2	I
75	B	19.2	29.3	140.3	3	1	2	II
85	C	15.7	566.5	566.1	3	1	2	II
100	A	19.7	24.6	140.4	4	1	2	II
105	B	30.9	44.2	232.1	4	1	2	II
115	C	18.9	47.5	296.9	4	2	2	I
130	A	15.0	25.2	171.5	5	2	2	I
135	B	20.4	39.8	317.3	5	1	2	II
145	C	21.1	36.8	262.7	5	1	2	II

N	WT	<i>S. viminalis</i>			W	L	R	S
		Leave Area %	Roots Area (mm ²)	Roots Length (mm)				
160	A	19.0	37.2	256.1	6	1	2	II
165	B	14.4	41.8	332.2	6	1	2	II
175	C	12.9	23	200.1	6	1	2	II
190	A	6.9	26	148.4	7	1	2	II
195	B	18.0	32.8	189.5	7	1	2	II
205	C	0	0	0	7	0	0	IV
220	A	16.7	45.8	262	8	1	2	II
225	B	0	0	0	8	0	0	IV
235	C	14.2	59	396.3	8	1	2	II
250	A	16.2	63.8	397.3	9	1	2	II
255	B	0	0	0	9	0	0	IV
265	C	0	0	0	9	0	0	IV
280	A	2.3	44.4	298.9	10	1	2	II
285	B	3.7	47.2	288.6	10	1	2	II
295	C	15.7	248.9	480.3	10	1	2	II

N	WT	<i>P. trichocarpa x deltoides</i>			W	L	R	S
		Leave Area %	Roots Area (mm ²)	Roots Length (mm)				
5	A	13.8	6.35	49.4	1	2	2	I
20	B	16.8	10.9	83.8	1	2	2	I
30	C	23.2	39.9	283.7	1	2	2	I
35	A	17.8	10.9	67.9	2	2	2	I
50	B	30.5	472.3	472.5	2	2	1	II
60	C	0	0	0	2	1	0	IV
65	A	18.5	7.2	55.4	3	1	1	III
80	B	18.8	20.1	126.9	3	2	1	II
90	C	29.2	28	154.7	3	1	2	II
95	A	37.2	22.7	141.3	4	2	2	I
110	B	31.8	42	263.2	4	1	2	I
120	C	0	0	0	4	0	0	IV
125	A	32.1	40.4	257.1	5	1	2	II
140	B	29.1	31.9	211.3	5	2	2	I
150	C	0	0	0	5	0	0	IV

N	WT	<i>P. trichocarpa x deltoides</i>			W	L	R	S
		Leave Area %	Roots Area (mm ²)	Roots Length (mm)				
155	A	0	0	0	6	0	0	IV
170	B	33.0	18.5	146.8	6	1	2	II
180	C	0	0	0	6	0	0	IV
185	A	38.2	38	229.6	7	1	1	III
200	B	37.2	29.4	154.6	7	1	1	III
210	C	0	0	0	7	0	0	IV
215	A	0	0	0	8	0	0	IV
230	B	33.8	43.2	273.5	8	1	2	II
240	C	0	0	0	8	0	0	IV
245	A	0	0	0	9	0	0	IV
260	B	32.1	42	245.8	9	1	2	II
270	C	0	0	0	9	0	0	IV
275	A	0	0	0	10	0	0	IV
290	B	48.1	47.1	277.4	10	1	1	III
300	C	0	0	0	10	0	0	IV

5.4 Discussion

The pilot study enabled the decision to be made on which cuttings (rooted or unrooted) and which parameters were most suitable to measure in the glasshouse experiment to support the overall testing of the main hypothesis (Figure 3-7 in section 3.3). On the other side, the glasshouse experiment demonstrated a significance influence of water table depths on root biomass, wet leaf biomass and dry leaf biomass growth of *S. viminalis* and *P. trichocarpa x deltoides*.

Analysis of variance (ANOVA) was used for overall differences in cuttings growth parameters. Repeated measures analysis of variance rANOVA (with outliers removed) was used for the analysis of changes in cuttings growth parameters through time. Although rANOVA is generally used to analyse the same sample over time, it is perhaps considered unorthodox to use this statistical approach as the sampling of individual plants was destructive (i.e. root washing event). However, rANOVA was assumed valid for analysing the data over the ten-week period as all the samples of species individuals were genetically identical (i.e. clones) and replicates were under constant water table depth treatments. Authors have used this ANOVA approach with clones before (e.g. Amlin and Rood (2002) with *Salix exigua* clones in a sapling study and Souch and Stephens (1998) with hybrid poplar clones). Therefore, these statistical analyses have been considered as suitable for the experiment in this PhD research.

Overall there was a significant effect of water table depths on both species over root biomass (g), wet leaf biomass and dry leaf biomass. *S. viminalis* shows greater root growth for flooded treatment whereas *P. trichocarpa x deltoides* shows the lower root growth (Appendix K). Some strong water-table depth preferences were apparent for *S. viminalis*. Overall, *S. viminalis* displays higher root growth for flooded, wet and dry treatment than *P. trichocarpa x deltoides*. It showed the preference that *S. viminalis* roots growth has to waterlogged conditions. Such a response would suggest that *S. viminalis* are less vulnerable

to flooded conditions than *P. trichocarpa x deltoides*. There was an overall greater vulnerability to dry treatment for *P. trichocarpa x deltoides* rather than for *S. viminalis* cuttings. It is known that poplar genera may be less able to limit transpirational water loss by stomatal closure and other physiological responses (Amlin and Rood, 2002). These results focussed on understanding how the different constant water tables affected the growth of cuttings and assessed how roots biomass, wet leaf biomass and dry leaf biomass responded. There was an overall greater vulnerability to dry treatment for *P. trichocarpa x deltoides* rather than for *S. viminalis* (i.e. *P. trichocarpa x deltoides* were significantly affected at dry water table level). In addition, the *P. trichocarpa x deltoides* cuttings quite clearly could not tolerate waterlogging and also became susceptible to low water conditions. Under conditions of acute stress associated with severe climatic drought or water table declines, *Populus sp.* has been found to display more extreme morphological responses in comparison to other riparian species (Ellison and Woolfolk 1937, Albertson and Weaver 1945, Stromberg 1993, Rood and others 1995 cited in Scott et al. 1999, p. 348). Most conditions (soil and water from the floodplain forest) were simulated to be close to field conditions in the glasshouse. Hughes *et al.* (1997) state that clearly a number of early successional riparian species cannot tolerate rapid drawdown rates following flooding and some, also cannot tolerate waterlogging for any length of time.

Guilloy *et al.* (2011) found differential vulnerability with willow genera being the most resistant compared to poplar genera. However, Amlin and Rood (2002) stated that willow genera are more vulnerable to abrupt changes in water level. Plants like the sandbar willow (*Salix exigua*), which are naturally established at lower elevations, would require more gradual rates of stage change (Amlin and Rood, 2002). Hence, the root biomass production that was found in the glasshouse experiment may be less significant if the water level change is abrupt. Water level changes refer back to Chapter 4, where the hydrology of the site was studied (i.e. water table fluctuations). Chapter 4 findings indicated where there were some changes in the water levels recorded in the floodplain

forest but there were only short periods where the levels could be considered as largely different and hence abrupt. The floodplain forest at Ouse Valley Park site has been designed to have variation in the water levels across the site (from permanently wet to elevated areas and variable wetness in between these extremes). Manual water table measurements (Chapter 4) show that the water levels varied widely through much of the year, hence supporting the approach of the importance of assessing the effects of continuous but water levels in the glasshouse experiment. It has been demonstrated in the experiment that *S. viminalis* has greater tolerance to abrupt changes in water depths (flooded and dry). However, in Amlin and Rood (2002) they concluded that *Salix exigua*, which are naturally established at lower elevations, would require more gradual rates of stage change, this means that different *Salix sp.* has different wetness requirements, so further studies may be required. Future work should consider the rate of change as this can have additional effects such as different water table preferences depending on the specie genera (Amlin and Rood, 2002) and different water table drawdown rates (in sediments in field or in glasshouse facilities, as experiment of Barsoum and Hughes (1998).

The studies of Amlin and Rood (2002) and Barsoum and Hughes (1998) using an experimental approach clearly showed how the relationship between vegetation development and soil wetness can be analysed in order to determine specific outcomes of water table level differences within a floodplain forest site, which was one of the main objectives in this research project (Chapter 1). All these studies cited earlier provide important context behind how such experiments are a useful way to understand the functional response of the plants and the effect that water table has on parameters such as root biomass growth and leaf biomass.

The ranking/scoring system implemented indicates some of the cuttings during the experiment did not proliferate (dead/dormant, score 0 in Table 5-13). Overall results relate that *P. trichocarpa x deltoides* scores display the majority of dead cuttings under flooded water depth whereas *S. viminalis* was mostly in good status when the cuttings were under flooded water depth. In addition, the

ranking system confirms the ANOVA analysis because the *S. viminalis* had a healthier appearance than *P. trichocarpa x deltoides* in root biomass particularly for the flooded and dry treatments.

An understanding of the relationship between water table differences and plant response is important to enable land and water managers to consider how water and land management activities on site could effect the desired water-associated vegetation (Shafroth *et al.* 2000). These outputs could be integrated in a prediction tool to identify the habitat water table preferences in the floodplain forest. This aspect is further developed in Chapter 6.

6 Landscape approach

6.1 Introduction

The floodplain forest landscape is characterised by heterogeneous environments with a number of important processes such as flood flows, sediment transport and vegetation dynamics. The spatial and composition heterogeneity of floodplains contributes to the regulation of ecological functions and habitat dynamism, which in turn provides the important ecosystem services (Leyer *et al.* 2012). By increasing habitat diversity and development in the landscape, factors such as erosion could be reduced. Also, Lamb (2007) suggests that an increase in the forest cover within the landscape improves water quality and encourage colonization of older plantations by native plants. Floodplain forest landscapes provide multiple goods and cultural services as detailed in Chapter 1. Consequently, approaches to determine ecosystem changes to floodplain forests at micro- and macro- environmental economic scales (i.e. within and between floodplains, respectively) are essential (Baker, 1989). In addition to the benefits (i.e. goods and services) obtained from floodplain forest, there are also further anthropogenic factors to be taken into account when considering restoration. These anthropogenic factors cause changes to landscape and habitat characteristics at a smaller temporal scale than other processes that occur naturally (Piegay and Salvador, 1997). Urban development and human activities over the years have had a negative impact on floodplain landscapes and their ecosystem services, hence ecological restoration is considered important. The practice of ecological restoration may benefit by an increased focus on how and when ecological theory can guide restoration efforts and a focus on how and when ecologists can use restoration settings to gain insight into how natural communities work (Palmer *et al.* 1997). It is unlikely to establish the pristine conditions where floodplain habitats previously existed but a framework that promotes the maintenance of a floodplain forest for environmental and human benefits and a landscape approach for predicting emerging habitats will be beneficial for managers and stakeholders. Restoration of floodplain forest adds landscape diversity to river corridors especially where it is integrated into a wider vision of restored

floodplain land uses (Hughes, 2003). The creation of different habitat/landscape features (i.e. channels and water bodies) in the floodplain forest will increase diversity and connectivity for species between corridors. Hence, approaches to determine ecosystem changes to floodplain forests at scales across which they occur are important.

Species development is directly affected by water table variations as seen in Chapter 2 (2.2.2. The link between hydrological processes and vegetation- *Vegetation vs. water table depth as a proxy to assess success*). These authors expected the floodplain forest to vary with hydrology (water level) and topography, leading to differences in habitats across the site. Conclusions gathered from those experiments demonstrate how typical floodplain forest tree species will change across the site with inundation or drought periods and how varying topography will result in differences in vegetation across the site (Amlin and Rood, 2002). Findings in Chapter 5 corroborated that willows (*S. viminalis*) typically occur at lower elevations and would be less drought tolerant but more flood tolerant than cottonwoods (*P. trichocarpa x deltoides*) that usually are closer to the stream (Amlin and Rood, 2001; Shafroth *et al.* 1998).

The heterogeneity of floodplain landscape features, require flexibility and adaptation, which means that different plant communities tend to prefer particular topography and hydrological requirements. Consequently, floodplain forests need a diverse range of landscape approaches, where ecological and hydrological processes of tree species establishment can be successful (Hughes *et al.* 2003). The elevation parameters should be refined for each species considered. Topographical and manual water table outputs gathered in Chapter 3 and Chapter 4 respectively are used in this chapter to create the landscape ecology approach of the floodplain forest.

6.1.1 Landscape restoration approaches

Landscape ecology approaches have progressed significantly over the last decades. In an attempt to guide restoration efforts for biodiversity enhancement, Wu and Hobbs (2002) have made a synthesis based on the visions of landscape ecology collective participants of the "Top 10 List for

Landscape Ecology in the 21st Century” organized at the 16th Annual Symposium of the US Regional Association of International Association of Landscape Ecology, held at Arizona State University (Tempe, Arizona, USA) during April 25–29 in 2001. Six key aspects and ten priority research subjects were identified as part of this list. The key aspects were: (1) interdisciplinarity or transdisciplinarity, (2) integration between basic research and applications, (3) Conceptual and theoretical development, (4) education and training, (5) international scholarly communication and collaborations, and (6) outreach and communication with the public and decision makers. The top 10 research subjects are: (1) ecological flows in landscape mosaics, (2) causes, processes, and consequences of land use and land cover change, (3) nonlinear dynamics and landscape complexity, (4) scaling, (5) methodological development, (6) relating landscape metrics to ecological processes, (7) integrating humans and their activities into landscape ecology, (8) optimization of landscape pattern, (9) landscape sustainability, and (10) data acquisition and accuracy assessment (Wu and Hobbs, 2002). These key aspects and research subjects can be used as a guidance when designing a landscape ecology approach. For the current case study, some of these have been taken on board. For instance, research of the floodplain forest key variables that can be integrated in the landscape approach (i.e. topography and manual water table data acquisition) and its applicability has been implemented. Also, communication with the decision makers (TPT) of management practices at the floodplain forest has been fluent and periodical to identify the main species to include in the landscape approach.

There are other existing approaches that can be used as a reference to build up a landscape ecology approach. From the terrestrial realm, Forest Landscape Restoration (FLR) is an analytical approach to managing the dynamic and often complex interactions between people, natural resources and land uses that comprise a landscape (Maginnis, *et al.* 2007, cited in Rietbergen-McCracken *et al.*, 2007, p. 1-2). FLR has a good potential application to the needs of quantifying changes (i.e. habitat outcomes) in a floodplain forest context. The FLR approach looks to achieve a balance between human and biodiversity

needs by restoring some forest functions within a landscape. It puts in practice common approaches to agree the many land-use arrangements of stakeholders with the purposes of restoring ecological integrity in the landscape and enhancing the biodiversity. Another approach based on modelling studies of landscape evolution, is the assessment of floodplain biodiversity and its restoration. It can be done through the development of simulation models based on specified channel styles, and involving simplified hydrodynamics and successional changes (Richards *et al.*, 2002). These types of studies evaluate the ecological succession by implementing different management practices that modify the dynamics of a restored ecosystem. Disturbances also have an important influence on landscape approach. The disturbance regime affects the morphology and generates a typical mosaic of plant communities and different succession stages (Stanford *et al.*, 2005, cited in Formann *et al.* 2014, p. 324). Simulation models have been implemented as important tools to predict future landscape change based on understanding the behaviour of managed ecosystems. In the last decade, interest in Species Distribution Models (SDMs) of habitat and communities has risen. According to Guisan and Zimmermann (2000), SMDs are empirical models relating field observations to environmental prediction variables, based on statistically or theoretically derived response surfaces. These SDMs can forecast changes on mosaics of habitat biodiversity at different spatial scales and forecast other existing anthropogenic effects. Guisan and Thuiller (2005) propose population dynamics, biotic interactions and community ecology into SDMs at multiple spatial scales. Other authors, such as Austin (2002) proposes using statistical modelling to predict species distribution; three major components are needed for this framework, ecological modelling concerning ecological theory, how data are going to be collected or measured to be used or tested and statistical modelling concerning the statistical theory and methods used. A framework to optimise biodiversity by focussing on landscapes that would result in greater conservation benefits is presented by Tambosi *et al.* (2014). It consists on quantifying the habitat amount and connectivity, using landscaping ecology theory and ranking landscapes according to their importance as corridors. Da Silva and Girard (2004) proposed approaches for an integrated management of the Brazilian Pantanal and

catchment area based on improving databases and the empowerment of the stakeholders' groups.

Evidently, modelling approaches are useful when trying to predict how communities will develop through time. Tockner *et al.* (2000) use landscape approaches to elucidate how flood processes influence landscape heterogeneity and biodiversity patterns. This approach is very interesting for the floodplain forest as it gets flooded periodically and it affects the landscape. Leyer *et al.* (2012) state that landscape level restoration of floodplain forests can be effectively supported by iterative approaches. These approaches are based on ecological and hydraulic modelling techniques and are aimed to identify an optimum scenario. An optimum scenario can be achieved by combining habitat-distribution models and two-dimensional hydrodynamic-numerical model and hydrological processes to predict how species can develop successfully without exceeding the critical water levels identified. Hirzel *et al.* (2006) have developed a threshold independent evaluator to reclassifying habitat suitability classes. Store and Kangas (2001) studied the multi criteria decision for habitat suitability modelling; they described the habitat requirements as map layers within GIS so that each map represented one criterion. For the current case study, GIS tool has been implemented creating a Digital Elevation Model and for defining three case scenarios based on water table depth thresholds. More detailed information is in methods section of this chapter. Landscape approaches assess ecological integrity of river-floodplain systems and develop restoration strategies where needed.

Within restoration projects often the main objective is to restore habitat types across a landscape area and therefore approaches that can reflect vegetation community development and change are regarded as useful for restoration management. For instance, Malekmohammadi and Blouchi (2014) provided a framework for wetland management developing a wetland-zoning map based on risks that threaten the wetland by using Multi Criteria Decision Making and visualised within a Geographic Information System. The landscape ecology approach here defines three scenarios based of the soil-wetness properties. Another approach, such as the umbrella species, may provide an effective

framework to guide habitat restoration (Branton and Richardson, 2014). An umbrella is a surrogate species approach considered an effective mean of conservation planning; it allows conservationist to identify land based on the needing protection requirements of a small number of species (Favreau *et al.*, 2006). Umbrella species approach identifies potential mechanisms by which co-occurring species benefit from conservation of these umbrella species. Some of these approaches in the literature have tried to integrate landscape diversity with floodplain forest restoration taking into account the dynamism of this type of ecosystem. Nevertheless, it also needs to be highlighted the assumption that systems reach a climax condition and are then keep steady, this is rarely the case (Sayer, 2005 cited in Mansourian *et al.* 2005, p-103). Therefore, the dynamism of these types of ecosystems needs to be taken on board when designing a landscape ecology approach.

Vegetation communities' distribution zones

Junk *et al.* (1989) termed the floodplain area the "Aquatic/Terrestrial Transition Zone" (ATTZ) because it alternates between aquatic and terrestrial environments; every place in this zone can be considered a point on a gradient reflecting the degree of annual flooding (i.e. each species has its optimum position on this gradient). The preferred definition here is the ATTZ as the zone of periodic flooding (adapted from Junk *et al.* 1989). Vegetation communities are distributed in the ATTZ according to the hydrology of the river-floodplain system (i.e. hydrology covers water table level in the floodplain and discharge of the river). Shafroth *et al.* (2000) subjectively selected in their study eight sites to represent a range of geomorphologic and vegetative conditions. At three of those sites, a cross-valley transect was established perpendicular to the stream channel, and different patches of vegetation were identified along the transect based on a combination of overstory dominance and geomorphic setting. Although this method is good for describing the vegetation included along the transect, the information between transects is missing and information gathered may not be representative of that specific landscape. In order to be fully representative, data should be collected also between transects, therefore all the information in/between transects will be included. Alternatively, transects

could be placed at very short distance from each other, making sure all the vegetation data will be gathered both between transects and along the transects. However, such a method will be highly labour intensive. This method is important because provides an understanding on how the vegetation distributes and to classify the geomorphic and vegetative conditions at different ranges. It contributes to fill the gap in knowledge of building up an integrated criterion of how to classify landscapes according to existing habitat patterns.

6.1.2. Critic of previous work

Based on the review of approaches above, key elements that suggests a landscape approach is best are spatially based analysis of a heterogeneous landscape (as a result of different wetness, topography and soil-water relationship) using two focal species typical of a floodplain forest (*S. viminalis* more associated to flooded conditions than *P. trichocarpa x deltoides* which prefers drier zones). Three main components that integrates this landscape ecology approach are: (1) landscape ecology theory and available methods (i.e. DEM, topography data in chapter 3), (2) implementing theory and conclusions from experiments in a real case study (water table interaction with *S. viminalis* and *P. trichocarpa x deltoides*) (3) study the resulting scenarios for specific periods of time (duration/distribution of water table in the floodplain forest). Despite the existence of these approaches for landscape restoration, there is a lack of an integrated criterion that combines ecology, topography and hydrology at landscape level for river-floodplain systems. Existing frameworks and predictive scenarios are not applied to a newly created floodplain forest. As stated in Chapter 2, species develop with different water levels and have diverse hydrological needs when talking about existing methodology for determining regeneration success (i.e. Recruitment Box method and Sum Exceedance Values methodologies). These methodologies could be used as a reference/starting point to study the hydrological impact on specific species growth in a specific ecosystem. Vegetation communities found at different successional stages in the landscape can be attributed to both aquatic and terrestrial vegetation that coexist in a floodplain forest. The idea of presenting the landscape ecology approach here as a spatial and temporal analysis based

on these given examples relies on incorporating inputs (i.e. topography and manual water table) for a specific period of time to predict habitat patterns in the floodplain forest after gravel extraction. It will be useful for visualising the potential development of vegetation communities linked with the key variables identified earlier.

6.1.3 Models used to represent spatio-temporal landscape variability

Benjankar *et al.* (2011) proposed “CASiMiR Vegetation” (Computer Aided Simulation Model for In-Stream flow and Riparia; www.casimir-software.de). This model is potentially capable of representing the spatio-temporal landscape variability typically observed across natural riparian ecosystems (Egger *et al.* 2013, cited in Maddock *et al.*, 2013, p.408) and found during the site surveying, covered in Chapter 3. Furthermore, during each model run it verifies whether the topography of the study area has changed from the previous iteration (simulated year) (Egger *et al.* 2013, cited in Maddock *et al.*, 2013, p.416). In this study this verification on topographical changes will be useful as when doing this PhD research, the gravel extraction process was in course, so topography will change over time during works until the floodplain forest will be fully created

Gilmour (2007) suggests that because of the complex nature of most forest landscapes, it is usually necessary to use several maps, preferably of the same scale, that can be overlaid on each other to build up a composite picture. For the current case study, defined water table depth thresholds, elevation and floodplain forest boundaries (i.e. target area of study) were considered three potential informative layers of information.

No consensus about criterion in community structure across small-scale restoration project has yet been established despite a general recognition that landscape and vegetation communities respond to changes in water table level and a diverse range of topographical features within floodplain forest. By knowing how these two parameters distribute in an ecosystem, a range of vegetation communities’ preferences in terms of hydrology and topographical characteristics could be predicted. In the restoration context, very few studies

have linked water table level measurements with topography and its applicability to a real case study.

6.1.4 Key components for the landscape level representation: the case study of the floodplain forest

Landscape mosaics are made up of different components, pieced together to form an overall landscape-level “patchwork” that can be represented using maps, tables of different attributes and written descriptions (Gilmour, 2007). It is evident that several components are required to form an overall landscape level representation. Through the research in this project, three key components have been identified and collected:

- Topographic data (DEM in Chapter 3).
- Manual water table data (Chapter 4).
- Hydrological preferences of *S. viminalis* and *P. trichocarpa x deltoides* to different water table depth (Chapter 5).

The research reported here focuses on bring these key components together within a landscape ecology approach to aid prediction of habitat type development across the floodplain forest site.

6.2 Methods

In addition to the three main components that represent landscape ecology approach, scenarios thresholds for identifying different habitats in the floodplain forest were defined. Based on Chapter 3, root biomass indicated to be one of the parameters measured that responded the most to different water treatments applied. Root biomass (i.e. fine roots and root tips) is key elements in nutrients and water uptake by plants. Al Afas *et al.* (2008) run a study of below ground characteristics of *Populus* clones (*Populus deltoides* x *Populus nigra* and *Populus trichocarpa* x *P. deltoides*). They concluded that fine root biomass varied significantly among clones and among soil layers being the topsoil layer (0-5 cm) the richest in fine roots; the fine root biomass and distribution of all clones decreased with increasing soil depth. Joslin and Henderson (1987) and Hendrick and Pregitzer (1996) carried out other forest ecosystem studies and

concluded that fine roots were most excessive in the uppermost soil layer while their density gradually diminished with rising depth. Dickmann *et al.* (1996) studied fine-root dynamics of two field grown hybrid poplar clones (*Populus x euramericana* and *Populus tristis x Populus balsamifera*). *Populus x euramericana* produced a greater length and number of fine roots in the top 30 cm of soil than *Populus tristis x Populus balsamifera*. Therefore, it was decided to use the topsoil layer (0-5 cm) to divide the water table level values into three different landscape coverage categories (flooded, wet and dry) for defining the scenarios of the floodplain forest.

Manual water table values were used to extrapolate a water table surface using Inverse Distance Weighted (IDW) extrapolation method in ArcGIS 10.2 (ESRI, 2014); the same technique used in Chapter 3 for calculating the Digital Elevation Model (DEM). IDW does not provide an estimation of the prediction error but is simple and quick (Mueller *et. al*, 2004). IDW uses weighted values measured in a local neighbourhood to estimate the value of a target variable at a non-measured location. Webster and Lark (2013) state that it is an effective procedure to calculate local weighted averages using a window which can be moved over the region of interest to create as many local predictions as desired, that is why IDW was considered suitable for this analysis although it has also some limitations. The major limitations are that estimates are bounded by the extrema in the sampled values (Watson and Philip, 1985). For this reason, water table measurements taken upstream and downstream of the River Great Ouse that fall outside the target area where the landscape ecology approach was applied were not included in the scenarios analysis. Thus, IDW assumes that each measured point has a local influence that diminishes with distance. So the closer known-measurements the less noise expected during analysis. The best results from IDW are obtained when sampling is sufficiently dense with regard to the local variation you are attempting to simulate (Watson and Philip, 1985). IDW is based on the assumption that the nearby values contribute more to the interpolated values than distant observations and works best with evenly distributed points; unevenly distributed data clusters could result in introduced errors (i.e. sensitive with outliers) (Azpurua & Ramos,

2010). In the current research, all the sampling values included for analysis were measured within the same area.

6.2.1 Data analysis

A topography technique has been used, applying the manual water table levels to the resulting DEM to develop a spatially explicit scenario model of wetness distribution based on ecological properties. This methodology has been used to assess and quantify the spatial distribution of wetness values in the floodplain forest. The temporal dynamics has also been applied to capitalize on the understanding of this model for restoration purposes.

The specific steps for implementing the landscape approach in the target area of the floodplain forest were: (1) creating a DEM based on contour lines (Appendix I), (2) creating a water table depth (WTD) model using manual values gathered in Chapter 4 and (3) combining the DEM and the WTD model.

As a result the landscape coverage categories of different water table depth over the floodplain forest will be defined. Step (2) is a tool of ArcGIS that works in a similar way to DEM but by using an indicator value to reclassify the water table levels selected (topsoil 0-5 cm).

A contour line elevation model < 10 cm resolution was completed in December 2013 for the entire floodplain project (54 ha). To improve spatial and elevation accuracy, GPS control points were used by Quest UAV to obtain < 10 cm in vertical and horizontal accuracy of the digital elevation model. The contour lines were clipped to the extent of the area. A triangulated irregular network (TIN) was created using the contour lines to create a Digital Elevation Model (DEM) with a spatial resolution of 5 cm. The clipped file was converted into the TIN and a grid was generated. This pixel resolution of 5 cm was used to match the water table surface and to account for possible spatial variability of water measurements in the field. The projection used for this case study is British National Grid (Spatial reference > Projected Coordinates System > National Grids > Europe > British National Grid in Arc GIS). The projection tools are used

to assign a projection, so if other layers are added in the future, they will match spatially to other layers added to be consistent.

The water table level was subtracted from the DEM value in centimetres by adding a “field” into an attribute table of the point-locations and subtracting the water table depth from the DEM. The water table DEM was subtracted from the topography DEM in centimetres with the same spatial resolution and a surface water table depth was obtained. Using map algebra (i.e. Maths tool > Minus in Arc GIS), negative values indicate that the water table is below the surface elevation and hence these are water bodies. Figure 6-1 below shows what happens when negative values create a water body.

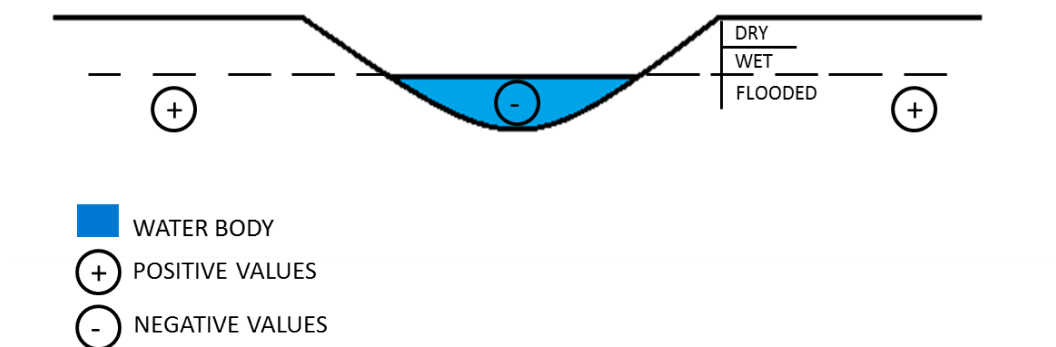


Figure 6-1 Model diagram of how a water body is created.

The next step was to classify scenarios and define intervals of water table data in the floodplain forest. For doing this, a tool called "Reclass" (Reclass tool > Reclassify in Arc GIS) and the topsoil value (0-5 cm) has been used as a reference. “Reclass” tool created a surface of the manual water table according to the topsoil value therefore the potential areas of three different levels of flooding were identified. Flooded stands for negative values, wet stands for 0-5 cm and dry stands for more than 5 cm.

To demonstrate how water table changed over time and the duration of water bodies in the floodplain forest, different periods of water table depths were combined in pairs. Three combinations depending on data available were

made: “June 2013 and June 2014”, “October 2013 and October 2014” and “January 2014 and April 2014”.

6.3 Results

Figure 6-2 displays the landscape category coverage (%) for selected periods during 2013-2014 at the floodplain forest after applying the topsoil value. Each stacker bar for each month visually shows the relative amount of landscape in flooded, wet or dry category. Basically for each of the three categories the % combined will be 100%. In January 2014, April 2014 and June 2014, the blue bars (flooded coverage) are higher and the beige ones (dry coverage) that are lower. Green bars (wet coverage) represented the smaller % in the graph. The highest beige bars (dry coverage) were found in January 2013, October 2013 and October 2014.

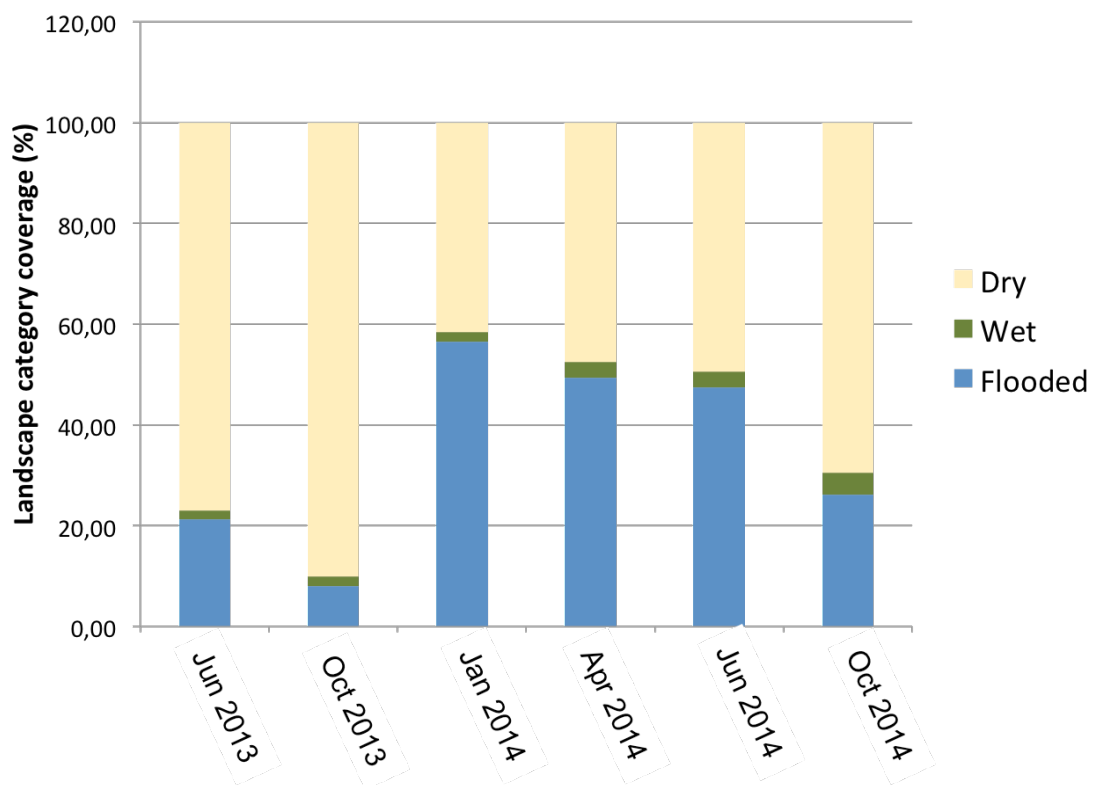


Figure 6-2 Landscape category coverage (%).

Figure 6-3, Figure 6-4, Figure 6-5, Figure 6-6, Figure 6-7 and Figure 6-8 display the landscape category coverage for six different scenarios applicable to the target area of the floodplain forest described in page 102 in section 3.3.3.

Scenarios were defined by applying the topsoil value and highlight the permanent water bodies (i.e. flooded category in blue) and the parts that are dry most of the time (i.e. dry category in beige). Green areas displayed are the wet zones of the floodplain forest.

January 2014 (Figure 6-5), April 2014 (Figure 6-6) and June 2014 (Figure 6-7) were the most flooded scenarios, followed by June 2013 (Figure 6-3), October 2013 (Figure 6-4) and October 2014 (Figure 6-8) as the driest scenarios. June 2013 (Figure 6-3) was drier than June 2014 (Figure 6-7). October 2013 (Figure 6-4) was drier than October 2014 (Figure 6-8). January 2014 (Figure 6-5) and April 2014 (Figure 6-6) have a similar flooded pattern, although April 2014 (Figure 6-6) is slightly drier.

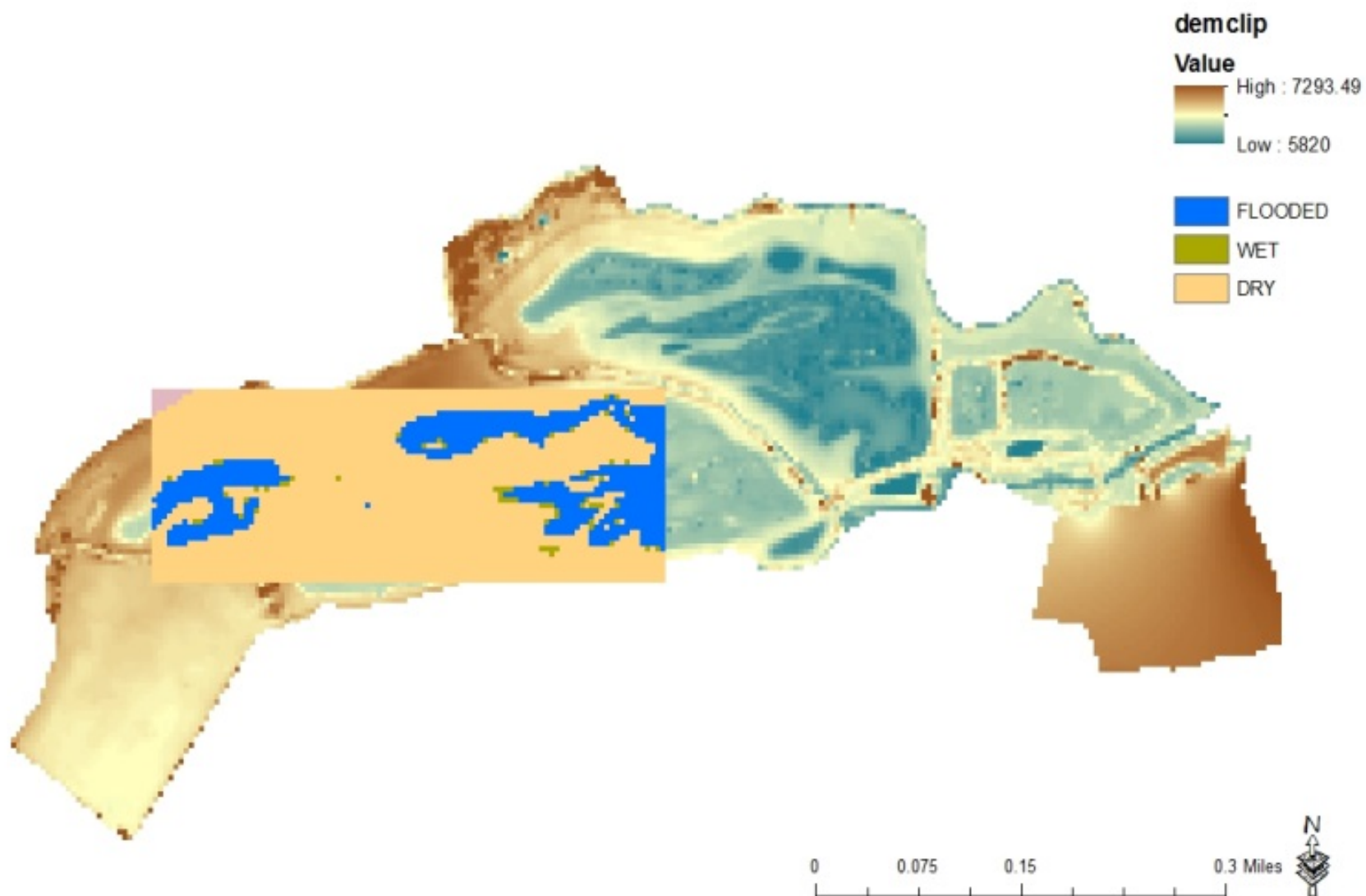


Figure 6-3 Landscape category coverage (in mAOD) in the floodplain forest for June 2013.

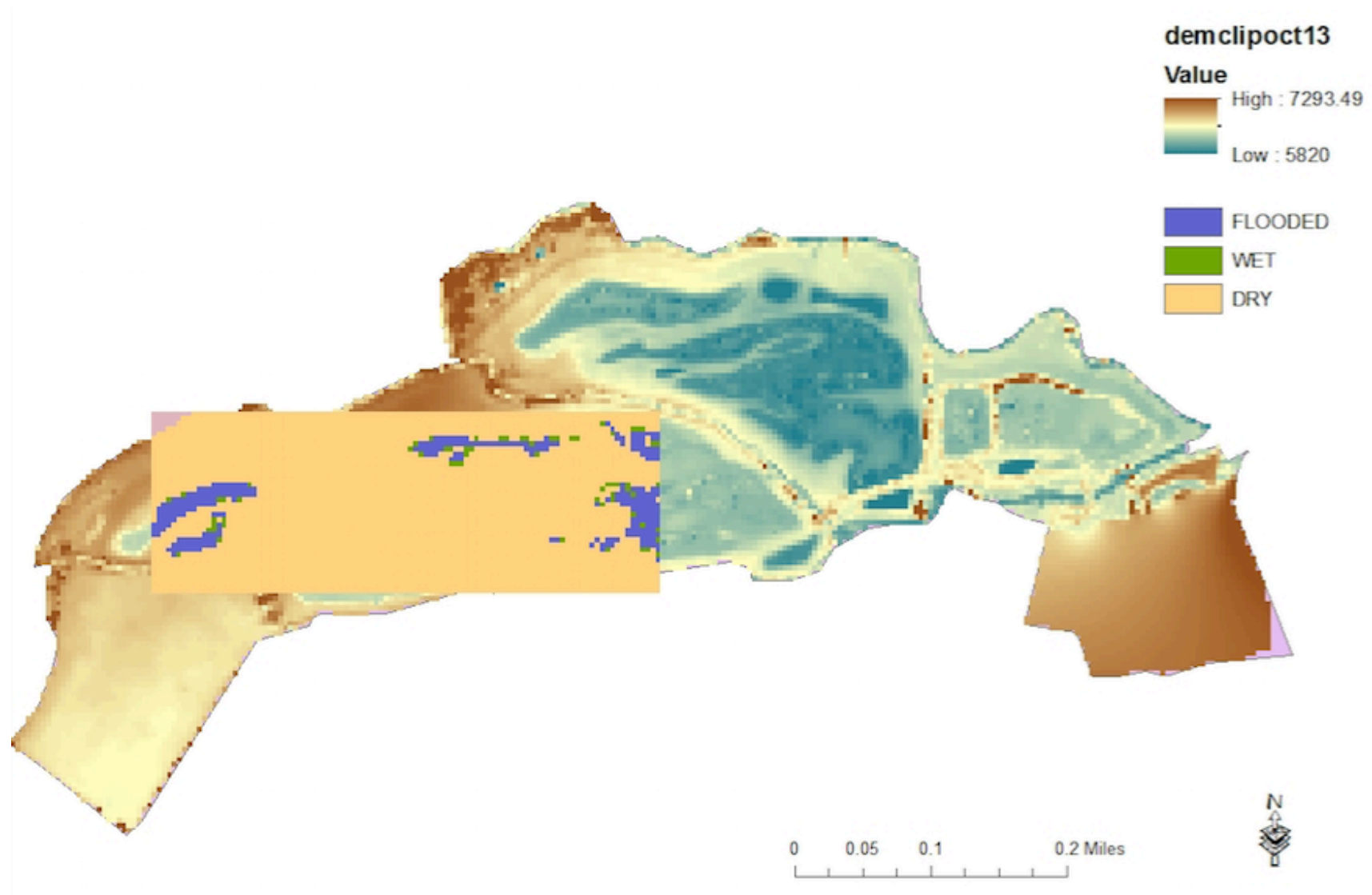


Figure 6-4 Landscape category coverage (in mAOD) in the floodplain forest for October 2013.

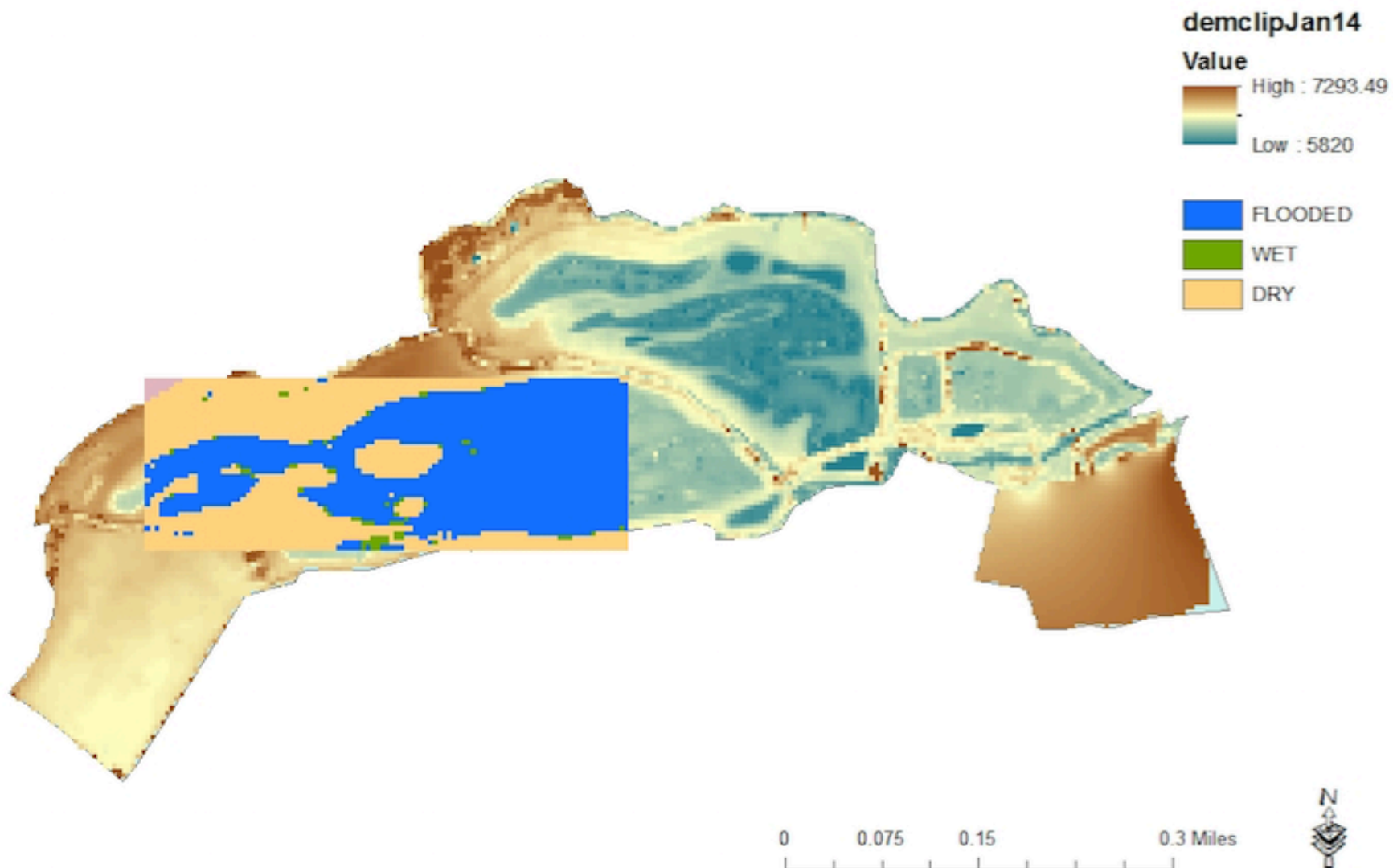


Figure 6-5 Landscape category coverage (in mAOD) in the floodplain forest for January 2014.

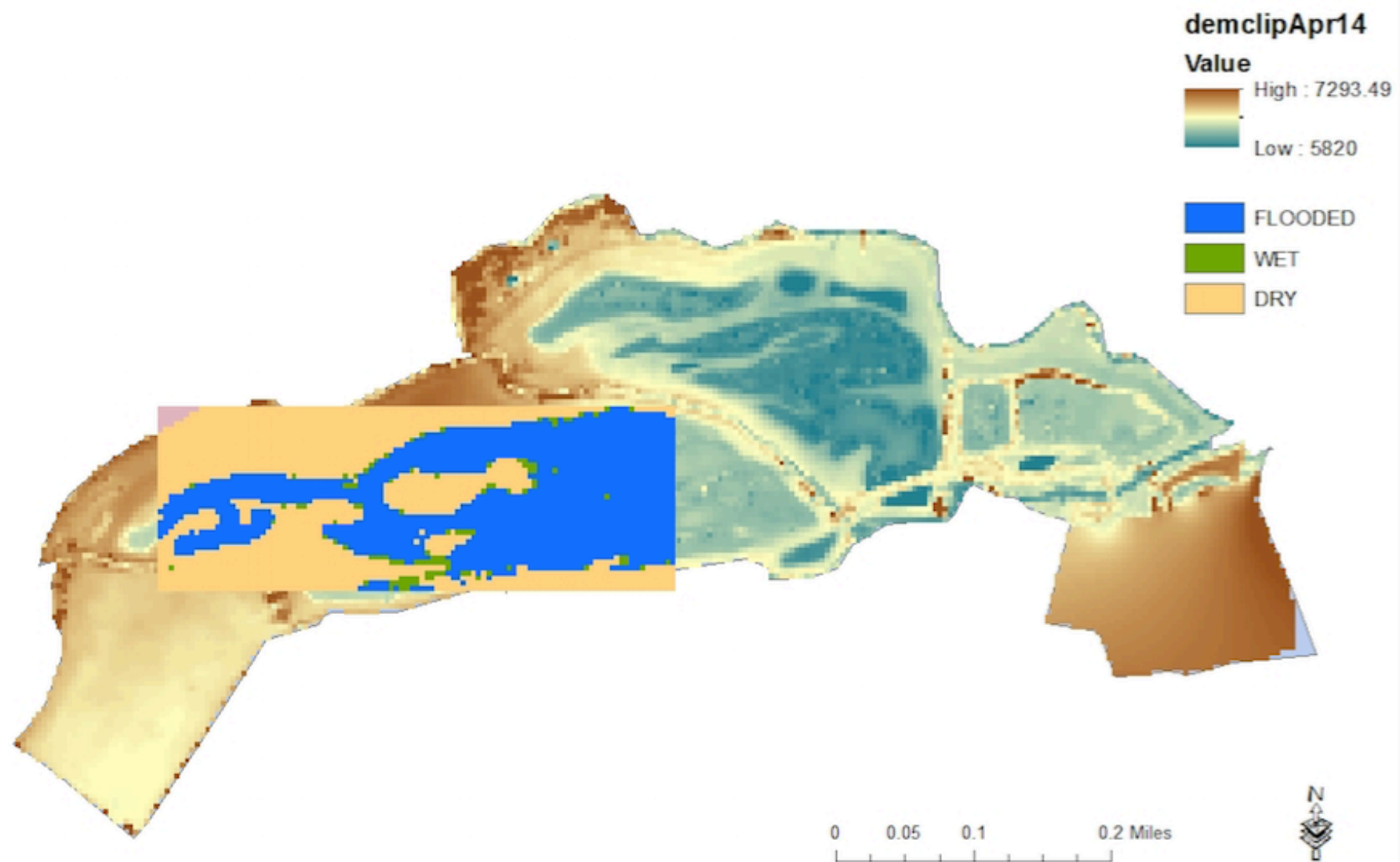


Figure 6-6 Landscape category coverage (in mAOD) in the floodplain forest for April 2014.

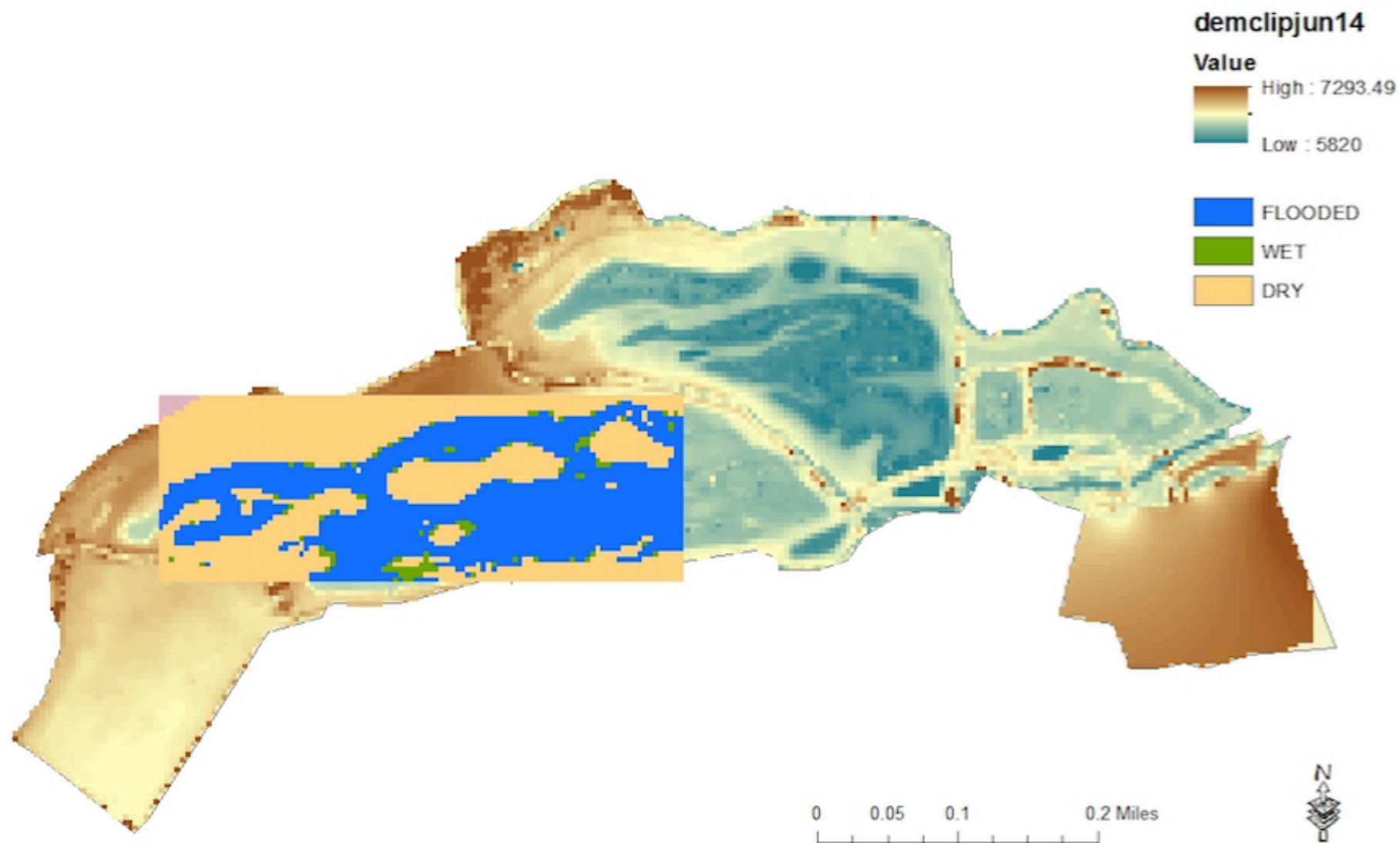


Figure 6-7 Landscape category coverage (in mAOD) in the floodplain forest for June 2014.

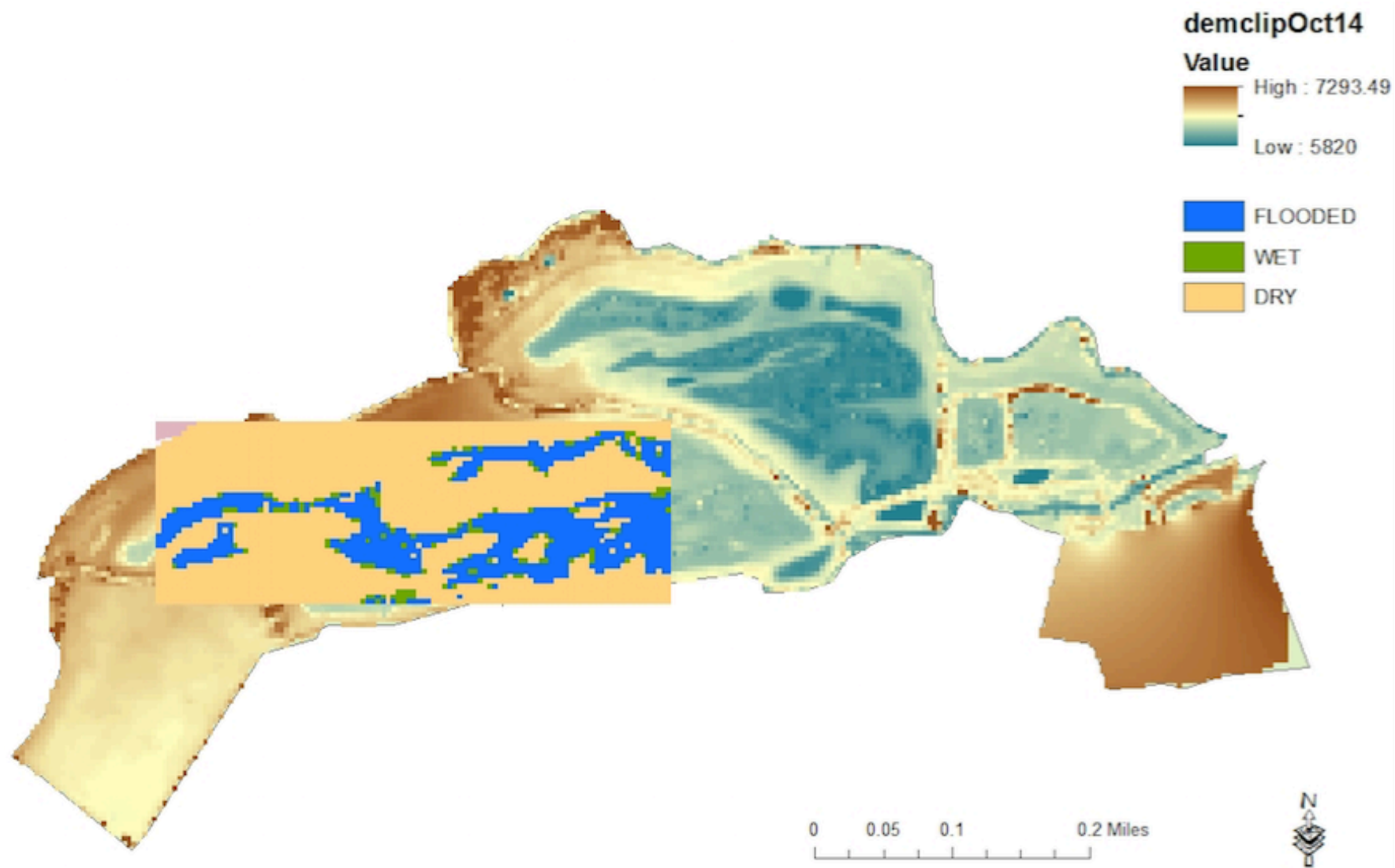


Figure 6-8 Landscape category coverage (in mAOD) in the floodplain forest for October 2014.

6.4 Discussion

This set of scenarios is the first landscape approach for habitats prediction of an artificially created floodplain forest using hydrological and topographical parameters for six specific periods of time. The landscape approach is used for determining the likely habitat-mosaic preferences to water table depth (flooded, wet and dry) distribution of two tree species (*S. viminalis* and *P. trichocarpa x deltoides*) in the floodplain forest and the approach has wider applicability if the baseline data for particular species or habitat types are available.

In chapter 3 it was hypothesized: “*The ratio of wet/dry vegetation within the floodplain forest is determined by the site topography and water table level*”. Hence it was predicted that vegetation communities’ (i.e. habitats) would respond to differences in average water table depths across the newly created floodplain forest site depending on the topography. According to chapter 5 that looked at species response to different wetness levels, it is expected that water tolerant species such as *S. viminalis* would occur in areas where the topography is low and there are areas more subject to permanent water bodies. Conversely, the species less tolerant to water changes such as *P. trichocarpa x deltoides* would stand in elevation areas where the topography is high and terrain will be dry most of the time. Landscape approach presented here was aiming to draw all these findings together. The resulting approach displays a spatially explicit representation of the potential habitats across several months based on landscape category coverage (flooded, wet and dry) within the target area of the floodplain forest. It reflects how water tolerant preference species are distributed on the flooded, wet and dry coverage on the map.

In the experiment carried out in chapter 5, the results indicated some strong water-table depth species preferences for *S. viminalis* particularly the effect on root growth (g) of A-Flooded treatment (Figure 5-11). *S. viminalis* root biomass production was high under flooded conditions compared to the remaining water-table depth treatments (wet and dry). It indicated the preference that *S. viminalis* roots growth has to waterlogged conditions (i.e. blue areas in the

scenario). Such a response would suggest that *S. viminalis* is less vulnerable to flooded conditions than *P. trichocarpa x deltoides*. *P. trichocarpa x deltoides* prefers wet, but not flooded, areas with less water table variability (i.e. green areas from Figure 6-3 to Figure 6-8). *P. trichocarpa x deltoides* was vulnerable to waterlogged (flooded) and dry conditions and prefers wet areas in the landscape approach. Guilloey *et al.* (2011) found differential vulnerability with willow species being the most resistant compared to poplar species. The permanent aquatic systems (Flooded), wet system and terrestrial system (*terra firme*) (Dry) relate to predict species habitats water preferences (*S. viminalis* and *P. trichocarpa x deltoides*) (Adapted from Junk *et al.* 2012).

The landscape approach could also serve as a tool to identify other species habitat distribution in the floodplain forest according to their water table depth preferences and topography characteristics. Scenarios consist of an adaptive tool open to the inclusion of new species as long as the specific water table regime of that species and the topography are known. The scenarios tool could be applied to other restoration sites; however, it is important to acknowledge that the key factors that influence the restoration need to be understood in the context of the site. If the water table requirement of specific species and where that level of water table stands in the floodplain forest in every season are known, it is possible to predict where that new specific species added will succeed and when its is the desirable timing to planting them to succeed. Habitats depend on water table level availability. According to Junk *et al.* (1989), habitats shift horizontally and vertically according to the water level and the differences in the duration of flooding result in small-scale habitats in the form of narrow, roughly parallel zones. By knowing water table level variability and the topography of the floodplain forest after gravel extractions finishing, it will be possible to assess flooded, wet and dry zones (i.e. permanent water bodies or areas that are permanently dry). This information was useful for stakeholders for deciding where and when to plant species according to their water table tolerance.

This method analysed different scenarios and used the results as a way to provide predictive information. Outputs of this research contribute as guidance on how site management practices could be carried out in the future. Further applicability of these scenarios on other restored ecosystems or similar forests will facilitate comparison between restored ecosystems and their habitat mosaics at a global scale. They could be used as reference scenarios for similar ecosystems. The landscape approach used in this research is tailored to the floodplain forest; however, it could be used for other sites of similar nature and characteristics. The utility of the approach is practical, by using inputs such as topography of the site and water table level data, it is able to predict the zones of permanent water bodies (flooded), and those areas that are most of the time dry.

There are classification systems that are currently used at different scales and are not able to take into account local scale changes. Other international classification systems for habitats are the US Fish and Wildlife Service (USFWS) classification system (Cowardin *et al.*, 1979) in which floodplains are not treated as specific wetland category. The Scientific Committee on Problems of the Environment (SCOPE) includes the category “floodplains” but does not distinguish minor sub-units (Gopal *et al.*, 1990). It would be useful to create a universal classification system where floodplains and other units such as permanent water bodies will be clearly identified/classified.

There is a need to understand how the landscape functions, how it has evolved to its present state, and the causes of human-induced modifications before improving or restoring any landscape patch (Dufour and Piégay, 2005). There is an extensive amount of data available of the floodplain forest regarding historical analysis, land-survey maps, aerial photos, vegetation inventories, groundwater analysis and written forestry reports, dated prior to the gravel extraction. Therefore, there is a need of gathering updated information prior studying the landscape. The landscape has been heavily modified and it has evolved from open fields of species-poor pasture grassland to a new created floodplain forest.

Forest restoration is almost always a long-term and multidisciplinary process; it requires recreating within a few years (usually less than 10 to 15 years) an embryo ecosystem that will only be fully developed after several decades (Vallauri *et al.* 2005). The artificial floodplain forest at Ouse Valley Park is still at a very early stage of development. These types of restoration studies require in most cases expertise from ecology and outputs of long-term monitoring and assessment. In this research, obvious indicators have been measured (water table level, soil characteristics etc.), however there is still the need of covering those indicators that refers to the naturalness of the floodplain forest created (sediments deposition, erosion, rainfall, evapotranspiration, infiltration rate etc.). The landscape analysis provides an indication on the dynamism of the target area of the floodplain forest. The landscape approach proposed could easily be used to assess the outcome of management recommendations and how to implement them effectively. Scenarios could be useful for stakeholder interpretation, communication purposes and for management strategies planning. It can be used to assess the habitat outcomes after gravel restoration and take the suitable management decisions to maintain the habitat. Some of the suggested steps and recommendations for a restoration site suggested by Lamb (2007) and adapted from De Jong (2007) are further developed in Chapter 7. Therefore, next chapter will help to understand how all the parts of the research are applicable to future site management by stakeholders and other such organizations.

7 Discussion & Conclusion

7.1 Overview discussion

The research undertaken within this PhD has provided an enhanced understanding and structured analytical thinking of the key aspects to consider when implementing a landscape approach to monitoring and assessing the potential changes in vegetation development that can occur across a newly created floodplain forest. Adding new steps to the Adaptive Monitoring Framework (AMF) to which added more to the baseline monitoring of the floodplain forest enhanced the traditional monitoring approach. The resulting baseline provides an overview of key variables after gravel extraction. By assessing hydrological dynamics of the floodplain forest and topography it has been possible to test the hypothesis of comparing elevation and soil wetness with respect to two typical floodplain forest tree species. Furthermore, applying these outputs to a real case study has demonstrated how a landscape approach can be integrated into site management recommendations and can be used as a prediction tool. Finally, these recommendations can be aimed at application for future restoration projects of similar characteristics and goals.

Projects to restore floodplain forests are underway in many parts of the world as they are seen as one of the most threatened ecosystems/habitats but which have key ecosystem service value in terms of flood retention within a catchment and for biodiversity enhancement. In the UK, Government agencies and landowners work together to re-establish natural floodplains to enhance the landscape to increase biodiversity and create space for water, a valuable protection from flooding. For instance, DEFRA (2004) ran a consultation exercise to develop a new Government strategy for flood and coastal erosion risk management in England (i.e. “Making space for water”), further supported by the Pitt Review of flooding in 2007. The main theme was to improve sustainability of water resources through risk management, strengthening sustainable approach, planning & building, awareness, and appropriate funding. Subsequently, the Flood and Water Management Act (2010) came into law to

address the need to manage flooding appropriately both in terms of surface water and groundwater.

Many floodplain forest restoration projects are being planned or considered as a result of more integrated environmental legislation, for example the EU's Habitats and Floods and Water Framework Directives. There are studies where there have been predictions of the possible habitats that may flourish as a result of floods in floodplain forests. Hughes and Cass (1997) evaluated the potential diversity of vegetation in a lowland floodplain forest in Vermont (USA) as a way of predicting the range of possible communities that might develop when the natural system is subjected to flood control or other common perturbations. Whereas the focus of this research has been the development of a scientifically justifiable hypothesis driven adaptive monitoring framework for assessing habitats outcomes of a new created floodplain forest with application to ecological management.

Several studies demonstrate how floodplain associated species depend on water regime for their survival, capacity to reproduce and growth. Bradley *et al.* (2002) presented a simulation of a succession of annual hydro-periods describing water table variations in a British floodplain wetland (Narborough Bog); they revealed the importance of the water storage function of the wetland and indicated the varying relationship of the wetland to the lowland river. Burt *et al.* (2002) provided for the first time a detailed view of the spatial & temporal dynamics of floodplain hydrology during both in-bank and out-of-bank flood events for a variety of antecedent and local conditions. They concluded that in smaller floods, water continues to move from slope to floodplain, although coupling between slope and channel is only re-established later in the recession. Another example was found in the guidelines developed by Roberts and Marston (2011), where they studied wetland and floodplain plants and their ecological dependency on water regime in the Murray-Darling basin in Australia. They covered a wide range of species including Willows (*Salix spp.*), and showed that Willow ecology is closely related to flooding and to dry conditions. The glasshouse experiment presented in this research demonstrated S.

viminalis preference to flood and dry water table depth. As floodplain forests are part of dynamic systems, their conservation and restoration must take into account the hydrogeomorphic processes that are important for vegetation structure within a catchment and the landscape evolution (Dufour and Piégay, 2005).

Finding a tailored methodology that fits all restoration projects is a difficult task, due to each landscape being subjected to different restoration practices, nature and scales. A methodology was studied to assess the role of landscape approaches in past studies, and the use of past and on-going restoration management practices to increase our understanding of large-scale approaches and improve restoration projects was proposed. Using a number of alternative analytical approaches that have been implemented in restoration schemes and habitat management but have yet to be adopted in landscape ecology has been suggested. The possibility of using a landscape approach that has been successfully implemented in a real case study is presented here.

7.1.1 Assessing habitat outcomes in a dynamic ecosystem

When considering the hydrological variation of the floodplain forest ecosystem, the time frame of vegetation community development, habitat outcomes and ecological succession the progress of the project was not going to be fully assessed within the 3-year period that the PhD research lasted. In fact the actual timeframe over which floodplain forests development will take place is unknown but as indicated by Junk *et al.* (1989), that depending on the position of the river channel and its dynamics, habitats may be ephemeral or rather stable over decades or centuries. Consequently, the landscape approach was proposed to assist in the determination of the outcomes related to hydrological dynamic of the floodplain forest over period of time that can be defined by the user.

By using different water level scenarios across the topographical variation of the site the research tested the hypothesis [*The ratio of wet/dry vegetation within the floodplain forest is determined by the site topography and water table level*].

The scenarios and the supporting research from the baseline monitoring, the hydrological assessment and the glasshouse study formed the basis for assessing habitats outcomes of the floodplain forest management.

For assessing how the changes at the site will occur over the long term, a monitoring programme for the floodplain forest was designed for taking repeated samples of the key variables (Appendix M). As the monitoring programme progresses, if all influential factors remain similar, then it is expected the ecosystem will reach a dynamic equilibrium as explained in section 2.2 (Determining success of restoration projects: novel ecosystem in Chapter 2). It also needs to be highlighted that the assumption that systems reach a climax condition and therefore remain steady is rarely the case (Sayer, 2005 cited in Mansourian *et al.*, p-103). Ecologically monitoring should occur throughout the project over an appropriate time scale to assess the habitat community' outcomes of the created floodplain forest and hence the ecological status. Restored river systems must develop for several years to decades to achieve a (dynamic) equilibrium, with an equally lengthy period before evaluation is possible (Formann *et al.*, 2014). Outputs provided by the landscape approach could be used, as a prediction tool because they indicate what areas of the floodplain are more suitable for water tolerant species and what areas prefers dry soil tolerant species. By knowing elevation patterns and water table distribution, the landscape approach can be applied in a specific site. Mori (2011) presents a review of the non-equilibrium ecology, conservation and management of terrestrial ecosystems and landscapes. He refers to natural disturbances that are difficult to define as they can be nested interacting with others qualitative and quantitative disturbances in an ecosystem. This research applied to the floodplain forest case study has referred to dynamic equilibrium, however because any factor or change in variables disrupt any shift towards an equilibrium, the floodplain forest is prone to long term environmental changes and natural disturbances, and thus, is dynamic and non-equilibrating.

A habitat classification system for floodplain forest might be useful for research involving establishment of species, monitoring programmes, identification of

land-use, generalization from site-specific outputs, and assessment of modified ecosystems on floodplain forest and their biota. Variables that can be selected for the habitat classification are based on long-term ecosystems development to cope with dynamic equilibrium, not simply short-term. Habitat and their associated communities can be classified within the context of a regional landscape approach classification. This research presents a framework for monitoring and a landscape approach for a hierarchical habitat classification system based on water table and elevation parameters preference, entailing an organized view of spatial and temporal variation among and within the floodplain forest. Habitat ecosystems distribution on several spatiotemporal scenarios scales, are associated with floodplain geomorphic features and seasonal events. The framework presented here is a perspective that allows systematic interpretation and description of floodplain habitats hydrological preferences and their interaction with topographical variations. As a good example, Junk *et al.* (2012) proposed a dynamic classification system (Permanently terrestrial, permanently aquatic, periodically terrestrial, periodically aquatic and swamp habitat) of major natural habitats of Amazonia white-water river floodplains (várzeas). The classification system, which was based on hydrological, water and soil chemistry and biological parameters, was open to the inclusion of future researched habitats without affecting the entire classification system. This example could be used as a guideline to build a dynamic classification system based on the scenarios obtained through the landscape approach in the floodplain forest.

7.1.2. The importance of habitats and species in the floodplain forest

The creation of the floodplain forest at Ouse Valley Park is an example of collaborative working incorporating biodiversity plans; through the transformation of open fields of species poor pasture grassland into a new ecosystem following extraction of valuable minerals at the site. It was expected to increase the variety of wildlife through changing from an ancient flat agricultural crop landscape to a rich wetland habitat, and by so encouraging biodiversity. The Parks Trust (TPT) expectation was that habitat mosaics would

develop over time and turn into a potentially high quality and rich ecosystem under suitable management practices. There were five main categories of habitat within the floodplain forest the TPT deemed were of specific relevance to biodiversity outcomes – grassland, aquatic, hedgerows, scrub and woodlands, which all have their own distinct species assemblages and management requirements (The Parks Trust, 2010).

The diversity of habitats created by the floodplain forest project potentially provides functional habitat as corridors and refuges for conservation important mammals (i.e. badger (*Meles meles*) and noctule bat (*Nyctalus noctula*), and an important opportunity for species colonization. The corridors will enable wildlife and plant species to spread across the landscape and provide opportunity for a wider establishment, thereby increasing the overall landscape-level diversity and the potential variability of rare species (Lamb, 2007). Shallow pools and other similar habitat features are also very valuable habitat for amphibians (i.e. common frog (*Rana temporaria*), great crested newt (*Triturus cristatus*)), reptiles (i.e. grass snakes (*Natrix natrix*)) and many forms of insect (i.e. dragonflies and butterflies). The fact that in this research variables such as water table and the topography have been measured, should aid in the habitat heterogeneity and therefore hopefully improve habitats for the desirable species cited.

7.2 Monitoring programme

Monitoring is critical to judging the success of a restoration initiative (Hughes and Muller, 2003). The conditions when conducting the initial monitoring as part of the research were not ideal (i.e. gravel works in progress, waterlogged areas). However, Chapter 3 suitably demonstrated the key variables that should be monitored are water table level and topography to determine the baseline for a re-created floodplain forest restoration project. This is because when creating a new ecosystem through gravel extraction the hydrology and the topography will be affected. The water table is dynamic and varies continuously to short-term and long-term changes. Manual water table measurements were the

principal source of information about the hydrologic stresses acting on the floodplain forest and how these affect water table level and recharge. Periodical measurements provide essential data needed to evaluate changes over time, to forecast trends and to design and implement an effective monitoring programme. Topography was heavily modified for re-creating habitat features in the floodplain forest. The implementation of the proposed monitoring programme will aid in determining the changes of key variables over time (soil, water quality, water table etc.) when gravel extraction is finished and the floodplain will be fully created. The designed long-term monitoring programme detailed in Chapter 3 provides the most up to date and scientifically valid monitoring of the floodplain restoration project. The monitoring programme and long-term research can supply important ecological vision and are decisive for the improved management of ecosystems and resources available. Results gathered from previous chapters helped define the most appropriate monitoring. For instance, water table results displayed variability, therefore monitoring should include periodical measurements to assess the change over time. In contrast, topography after gravel extraction is not expected to change drastically over time.

7.2.1 Examples of good management practices

Some good examples of good management practices are:

- A complete understanding of the relationship between water table declines and plant response that enable land and water managers to avoid activities that is likely to stress desirable riparian vegetation (Shafroth *et al.* 2000). Regarding the water table level relationship with species' growth, an initial analysis of what species coexist in the site and their water table requirement is encouraged. This could be achieved by carrying out an experimental approach to study the water requirements of specific species of interest as in the floodplain forest case study presented in this PhD with *S. viminalis* and *P. trichocarpa x deltoides*.

- It is strongly encouraged prior planting to survey the area to assess the state of natural regeneration. It is advised to set up the initial site activities at an early stage of the restoration, so a better understanding of “what species to plant”, “where” and “when” effective guidelines will be well-established and it will also potentially help to save in restoration costs. Some species could take longer time to develop by natural regeneration, and may need longer periods of time to grow or require management practices assistance. It is essential to have a complete understanding on floodplain forest monitoring. Although natural regeneration is the best method to encourage vegetation within the floodplain forest, some species need to be planted or seeded. Blackham *et al.* (2014) state blanket planting of large areas with a low diversity of expensive saplings makes no ecological sense and planting should focus on suitable areas that need planting. In the floodplain forest, stakeholders have been informed about which are the more flooded and the driest areas during specific periods of time so they can take decision about what species should be planted or seeded according to their water requirements. In the current case study, it is advised to plant *S. viminalis* close to edges of permanent water bodies whereas *P. trichocarpa* x *deltoides* is advised in drier areas.
- Measure water table level periodically (i.e. ideally on a monthly basis). The idea is to use water table level data to maximise the diversity of vegetation communities (i.e. habitats) captured with the sampling strategy; the larger the water table level variability, the larger the habitat diversity represented. Giles (1992) states that the process of ecological succession can be halted at given stages by active habitat management in differencing reserve areas to produce a complex mosaic of open water, submerged weed beds, reedbeds, willow/alder scrub and wet woodland. Depending on the season, it is expected to have permanent water bodies’ habitats in the floodplain forest. The water table is the main

indicator for defining habitats presents in the floodplain forest and mosaics can be designed relying on long-term vegetation data available. Still it is a very early stage for the created floodplain for defining a set of habitats maps based on water table variations. However, it is expected on the long term monitoring to obtain sufficient data to create habitats maps that inform how species proliferate in the re-created floodplain forest.

7.2.2 Suggested steps for floodplain forest landscape managers

Suggested steps based on the outcomes of the research in the context of Lamb (2007) and adapted from De Jong, (2007) for forest landscape managers and its applicability for the floodplain forest case study are provided in Table 7-1.

Table 7-1 Suggested steps and its applicability to the floodplain forest case study as an example.

Suggested steps	Application to the floodplain forest case study
Define adequate units and boundaries in the landscape of interest (2)	<i>50 ha in the floodplain forest at Ouse Valley Park (Milton Keynes, United Kingdom)</i>
Identify the relevant stakeholders and arrange regular meetings (2)	<i>The Parks Trust (TPT), Environment Agency (EA), Cranfield University (CU), Nature After Minerals (NAM), Hanson.</i>
Identify the actions of relevant stakeholders and their impact on the forest landscape (2)	<i>TPT in charge of management practices and planting schemes, EA in charge of hydrology dynamics and change in river discharge and water quality, CU to design a monitoring programme to be implemented in a long-term period measuring how parameters change over time. NAM to spread the word about the importance of restoring quarries into habitats improving wildlife. Organise periodical catch up and follow up meetings between relevant stakeholders. Hanson to design the landscape features, plan gravel extractions and discuss with TPT and EA regarding the water diversion and opening the back brock channel etc.</i>

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Identify links (2)	<i>Define economic and policy environment. Political position of stakeholders and how it affects to the landscape management.</i>
Analyse the results (2)	<i>Conceptual model of the stakeholders and their roles.</i>
Understanding the current landscape-mosaic and land use pattern (1)	<i>Validating the scenario model every year for making comparisons over time.</i>
Defining existing problems and where they are located (1)	<i>Some limitations and problems could arise. It is important to identify them, inform to stakeholders during regular meetings and address them accordingly. Planning alternative ways of solving these problems, specifying the locations of different restoration options.</i>
Developing alternative scenarios to show how compromises might be made to satisfy stakeholders (1)	<i>By applying the landscape approach, scenarios can be predicted and outputs can be used as a prediction tool. If for example there is more interested in a specific period, over a specific area of the floodplain and under a specific water table depth etc.</i>
For each scenario, identifying whether compensation or other incentives are needed to encourage the new land uses (1)	<i>It could happen that an area which is fully dry for most of the year be proposed for a different purpose. For instance, building a public footpath or a bird's observatory.</i>

Suggested steps	Application to the floodplain forest case study
Consulting stakeholders to assess their preferences for particular scenarios (1)	<i>If they are willing to plant specific species and their water table preferences are known, the landscape approach for scenario modelling could be tailored for its needs (see chapter 6 for details about how landscape approach works)</i>
Establishing priorities for action, which things must be done first with the resources available, and what can be left for the longer term (1)	<i>Make a priority list. The designed monitoring programme in Appendix M is a good starting point regarding what to measure, how, where and how often. It could be called PIM (Planning, Implementing and Monitoring) principle applicable to the floodplain forest case study.</i>
Creating a global dynamic habitat classification system based on key variables (i.e. water table level)	<i>Three scenarios (flooded, wet and dry) in the floodplain forest have been identified. A classification system can be designed accordingly the key variables outcomes.</i>
Elaborate a list of possible factors and management strategies	<i>Change in the habitat, change in flow regime, over exploitation of natural resources, public path construction, invasive species growth, wildlife control (Adapted from Malekmohammadi and Blouchi, 2014).</i>
Initiating a restoration programme	<i>Setting up the monitoring programme, sampling locations and frequency.</i>
Defining restoration needs implementing restoration	<i>Gathering hydrological information after gravel extraction to understand hydrology variation and its interaction with tree species that co-exist in the floodplain forest.</i>
Defining restoration strategy and tactics	<i>Define a long term monitoring programme as part of the restoration strategy. Identify key variables to measure: soil, water quality, water table, topography and vegetation.</i>

Source: Lamb (2007) (1) and adapted from De Jong (2), (2007)

Managers and practitioners could use the first column in Table 7-1 as guidance and then populate the second column with their own parameters for their sites object of study. Analyses run by De Jong (2007) and Lamb (2007) could be adapted to other similar projects or be used as a reference. Identifying relevant stakeholders, defining existing problems and where they are located, prioritize

actions and defining restoration strategy are assumed to be the most relevant to the floodplain forest.

7.3 Advantages and disadvantages of the research project

The research conducted has provided valuable scientific material on two levels: (1) a baseline ecological database of a new created ecosystem and (2) a study of water table and topography preferences of typical floodplain forest species *S. viminalis* and *P. trichocarpa x deltoides* at a rehabilitated mineral extraction site. Knowledge of future scenarios occurring in the floodplain forest often provides advantages in terms of access to and control over the critical resources and management practices decisions. An important question in this context is how monitoring responses affect the structure and function planning of floodplain forest. It is expected habitats in the ecosystem evolve over time depending on hydrology and other external factors (i.e. rainfall, evapotranspiration, meteorology etc.). To address this habitat heterogeneity, a hypothesis driven adaptive monitoring programme has been illustrated and a landscape approach has been implemented. Further, a baseline, tools and techniques have been identified and that can be used for an integrated floodplain ecosystem approach.

Conversely, some limitations found were that floodplains vary between terrestrial and aquatic phases and therefore require knowledge from both limnology and terrestrial ecology (Junk, 1999). In addition to ATTZ (Aquatic/Terrestrial Transition Zones), other riparian zones described in a river-floodplain system are the aquatic zone, bank zone, floodplain zone and wetland zone; the bank zone and the floodplain zone have dominant species such as *Populus spp.* and *Salix spp.* among others (Egger *et al.* 2013, cited in Maddock *et al.*, 2013). There is not a unique ATTZ that fits all the ecosystems, so these zones have to be defined and tailored according to the case study considered. The elevation and variability in hydrology that co-exist in the floodplain forest were studied through this research. It was demonstrated that depending on the topographical features in the floodplain forest there would be different water table level distribution. Flooded, wet and dry zones defined in the scenarios as

part of the landscape approach have similarities to the ATTZ approach described above based on the water table level preferences of the predominant species that coexist in the floodplain forest.

Apart from these limitations, stress factors that affect an ecosystem (they could be biological, environmental, physical and chemical) should be taken into account in a rehabilitation project. Change in habitat and change in flow regime are considered typical of floodplain forests. At the time of the research, vegetation was at a very early stage of development. Therefore, habitats will be formed over time. An abrupt change in the flow regime of the River Great Ouse (i.e. by opening any channel, diverting water etc.) will have a direct effect on the existing water table levels and on species communities and vulnerable species. Therefore, any practice that could affect hydrology have to be re-considered beforehand depending on the effect over other vegetation communities. Grazing is an activity that was carried out prior creating the floodplain forest and could be implement on a rotational basis as part of the management strategies. TPT has plans to open the floodplain forest to the public by building public paths and birds' observatories. Over exploitation of natural resources and invasive species growth could be a factor of risk if management strategies are not properly implemented. However, TPT controls invasive species by spraying herbicides during the recommended period and makes rotational coppicing in the floodplain forest for conservation purposes.

7.4 Final conclusion

The outputs of this research are conceptually applicable to a wide range of floodplain forest or other hydrogeomorphic dominated ecosystems types. This is because the key factors identified are always going to be major determinants of the outcome to vegetation planting and management at such a site like the floodplain forest. Key variables such as water table and topography have demonstrated the effect they have over successful habitat communities. Focussing on a case study allowed elements/factors to be analysed effectively and the rationale behind the variables measured provide a sound basis for

future case examples which would confirm and validate these findings in a more general context. For future projects there is a need to create a general database for these types of restoration works so all attributes and restoration practices can be classified for further reference and potential application. Some authors, such as O'Connor *et al.* (2005) state it would be beneficial for restoration projects to develop common assumptions, indicators, and methods as well as metrics of long-term success. The research reported here adds to this common database suggestion.

Determining the overall success of a restoration project is challenging. It is a hard task to assess success in floodplain habitats that are dynamic ecosystems. Several authors have looked at developing guidelines to assess restoration success as discussed in 2.2.1 (How to assess restoration success: main ecosystem attributes to consider in page 35). SER (2004) suggested the comparison of the restored ecological patterns to a set of reference values for restoration appraisal. The comparison of these reference values over time will help to assess the changes and to quantify the success. Despite the existing SER Primer for evaluating restoration success, it is not yet very clear what they consider success in restoration processes. Landscape managers should implement basic steps to achieve a successful restoration project. Some of these suggested steps to follow for forest landscape managers were summarized in section above (Adapted from De Jong, 2007).

This research took the approach of Scenario Modelling (SM) to illustrate the main outputs. SM is a tool for making the choices explicit and exploring different restoration options with stakeholders (Lamb, 2007). For the current research, all options have been discussed with TPT. The use of scenarios has led to advice TPT on management practices based on water table and topography preferences of *S. viminalis* and *P. trichocarpa x deltoides* in the floodplain forest for specific periods of time. The SM tool is potentially useful in predicting how the site will develop, thereby helping to identify where change may likely to occur and focussing on field sampling and measurements spatially. Linking information on how species respond to water table level variations (e.g.

glasshouse trials, sum exceedance predictions etc.) also show which areas would be likely preferred by particular species depending on the relationship between topographical features and the hydrological circumstances (e.g. predominantly flooded, wet or dry). There were also static areas that displayed no hydrological variation over a year period (these are the drier areas); the stakeholders could consider these areas for building birds observatories or public footpaths for visitors. Public footpaths could be a good idea to encourage people about biodiversity, attract volunteers to be involved in TPT management practices etc. However, they should be built at a minimum distance of habitat spots to avoid disturbing species refuges (e.g. nesting birds). It is crucial to maintain the connectivity of the floodplain-river ecosystem and establish a link between ecological corridors within the site. Applying the landscape approach and reproducing the observed temporal variation in water table just after quarry works finished, will illustrate the range of water table features in the floodplain and its link with topography to help to understand how the floodplain forest progresses. It also has the advantage of enabling proactive management decisions based on the predictions, rather than relying on uncertainty. Variability in seasonal hydrology dynamics was studied at the new created floodplain forest. Topography and its pattern also contribute to the habitat distribution along patches by creating different features depending on these water-table preferences. The temporal dynamics for six scenarios from the applicability of the landscape ecology approach showed the water table distribution during the growing season. Three types for landscape category coverage were applied to the scenarios. Although the spatial scale of the case study is small, this PhD research has implications for a diversity of issues in hydrological modelling and ecological restoration. First, an accurate knowledge of existing monitoring programmes will provide a foundation for better understanding and studying re-created ecosystems (i.e. novel ecosystems), many of which are subject to a dynamic equilibrium. Second, since water table data are fundamental to integrate a landscape ecology approach for studying the wetness preferences of specific species, this work will provide a basis for characterising habitats

outcomes at the floodplain forest. Third, understanding relationships between habitats and the hydrology and topographical patterns will be helpful to improve the spatial arrangement of planting locations in the site.

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Appendix A List of datasets that are of relevance to the study

Available data	Data holder	Description
Ecological status of water bodies data- Ecological Quality Ratio (EQR)	EA(2)	Water Framework Directive data. The EU Water Framework Directive (European Commission, 2000) requires the establishment of methods to quantify the ecological status of water bodies. In order to assess ecological status, biological indicators play a key role. "Ecological Quality Ratio" is a numerical scale to express biological assessment results. Numerical ratio to express the ecological status of a water body. Values close to zero represents a bad status whereas values close to one represent a reference value.
Fish records- National Fish Population Data (NFPD)	EA(2)	A detail survey of Spined Loach (<i>Cobitis taenia</i>) at the Ouse catchment carried in 2009. National Fish Population Data (NFPD) is linked with RHS sampling sites. Informs about which species has been collected in number and how in every sampling spot carried out by River Habitat Survey.
Water table data- Hanson data loggers	Hanson	Results from a drainage level assessment carried out by Envireau water are available. (Envireau water, 2012)
River geomorphology data- River Habitat Survey (RHS)	EA(2)	River Habitat Survey (RHS) includes Habitat Quality Assessment (HQA) and Habitat Modification (HMS) scores. Unfortunately data from the spot located in the floodplain forest are missing.
River invertebrate, plant and algae data-BYOSIS	EA(2)	Invertebrate, plant and algae data. BYOSIS consists of a Biological monitoring database which includes macrophytes and diatoms data. Information includes sample physical data report (algology, macrophyte, bank, land, diatoms, algal blooms, plant cover, sewage, ochre, habitat, influence and channel data) and taxa data including biotic indices such as Average Score Per Taxon (ASPT), Number of taxa (N-taxa) and Biological Monitoring Working Parking (BMWP).
Hydrological data obtained from ADCP or current meter-BIBER	EA(2)	Hydrological data. Gauging data obtained from ADCP (Acoustic Doppler Current Profiler), current meter and spot gauging can be obtained from BIBER database. Discharge and stage data from three EA gauging stations at Newport Pagnell (Stage/discharge), Thornborough (sluice site and only stage available) and Cappenham (Stage/discharge).
Hydrological data from telemetry or data logger- WISKI	EA(2)	Hydrological data. Records of river levels and discharge are also available within the EA hydrometric database (WISKI). The levels may be recorded by telemetry or data loggers. There are also data available from two gauging stations: Cappenham (from 1979 to current date) and Thronborough (from 1979 to current date), both located upstream of the floodplain forest.

Available data	Data holder	Description
Amphibians	TPT (3)	Study of ponds and amphibians species on Parks Trust land. It includes a survey of a pond at Manor Farm, Ouse Valley Park.
Topography and Digital Elevation Data	TPT(3)/ Digimap /Edina	A topographical map of December 2011 of the floodplain forest is available. This information help to identify main features (e.g. cross sections, hatching, road, bottom of the batter, top of the batter, conveyor,water edge, annotation etc.).
Infrared	CU(1)	Infrared data could be used to identify main patterns in vegetation (e.g. mosaics, patches etc.)
Land Cover Map 2000 data	EA(2)	This holds the main land use and land management of the area. The Land Cover Map 2000 (LCM2000) for England & Wales is available on request from EA Brampton database.
Vegetation	TPT(3)	A set of documents written by Mike Street (2002) suggesting which were the most interesting species may be found in a floodplain forest
Birds	RSPB (4)	Bird's species present in floodplain forest and closer areas including current status according UK-BAP. Information is being recorded by volunteers.
Amphibians	TPT (3)	Report of a recent study of ponds and amphibians species on Parks Trust land. It includes a survey of a pond at Manor Farm, Ouse Valley Park. A torch count of this pond revealed it to contain a surprisingly large Great Crested Newt population.

- (1) Cranfield University (3) The Parks Trust
(2) Environment Agency (4) The Royal Society for the Protection of Birds

Appendix B Data gathered within the floodplain forest in the past



- **HANSON loggers:** Results from a drainage level assessment carried out by Envireau water commissioned by Hanson could be made available. The records have made available to Cranfield. The Hanson loggers were installed in stilling tubes immediately up stream and down stream of the River Great Ouse to measure water table level from July 2011 and September 2011.
- **BYOSIS:** River invertebrate, plant (i.e. macrophytes) and algae (i.e. diatoms) data are available from the BYOSIS database. These data are biotic indicators that can be used to assess pollution levels and help to evaluate the ecological quality of a particular reach. Samples were taken twice a year.
- **NFPD (fish records):** Records of fish species present within the site are also available from the National Fish Population Data (NFPD). Records are available from 2 sampling sites across the River Great Ouse; one within the floodplain forest and the other one located in close proximity. These data are linked with the River Habitat Survey data. The survey was carried out in 2004 just once.
- **RHS:** River Habitat Survey (RHS) data is also available at two locations; one located within the floodplain and the other located in close proximity (Appendix C). The River Habitat Survey includes Habitat Quality Assessment (HQA) and Habitat Modification (HMS) scores. HQA score is the habitat quality of an RHS site expressed numerically as a score based upon the extend and variety of natural features recorded (EA, 1998). HMS score is the modification to the channel expressed as a score based upon the type and extend of artificial features at a RHS site (EA, 1998). Unfortunately, these values are missing for this spot but there is still some useful information such as number of trees, flow index, vegetation bars etc.

Appendix C Birds and Fish spotted in the floodplain forest

A large number of birds species identified are included in the BAP from which the most relevant in floodplain areas are:

Birds

Warblers and allies:

- Willow warbler (*Phylloscopus trochilus*)
- Chiffchaff (*Phylloscopus collybita*)
- Tits (i.e. Great tit (*Parus major*))
- Willow tit (*Poecile montanus*)
-

Finches:

- Brambling (*Fringilla montifringilla*)
- Linnet (*Carduelis cannabina*)
- Wrynecks (*Jynx torquilla*)

Woodpeckers, chats and thrushes:

- Great spotted woodpecker (*Dendrocopos major*)
- Green woodpecker (*Picus viridis*)
- Blackbird (*Turdus merula*)
- Mistle thrush (*Turdus viscivorus*)
- Redwing (*Turdus iliacus*)

Pipits and wagtails:

- Yellow wagtail (*Motacilla flava*)
- Meadow pipit (*Anthus pratensis*)

Buntings:

- Yellowhammer (*Emberiza citronella*)
- Treecreepers (*Certhia familiaris*)

Hawks:

- Buzzard (*Buteo buteo*)
- Sparrowhawk (*Accipiter nisus*)

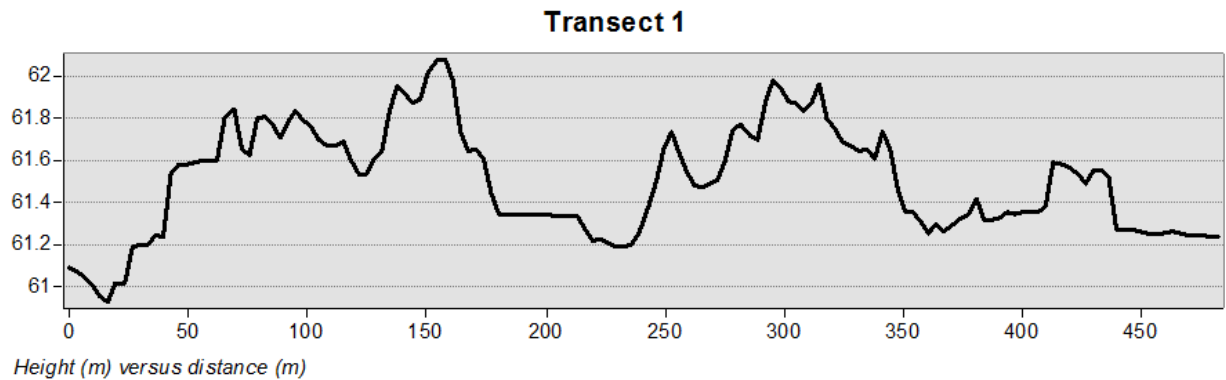
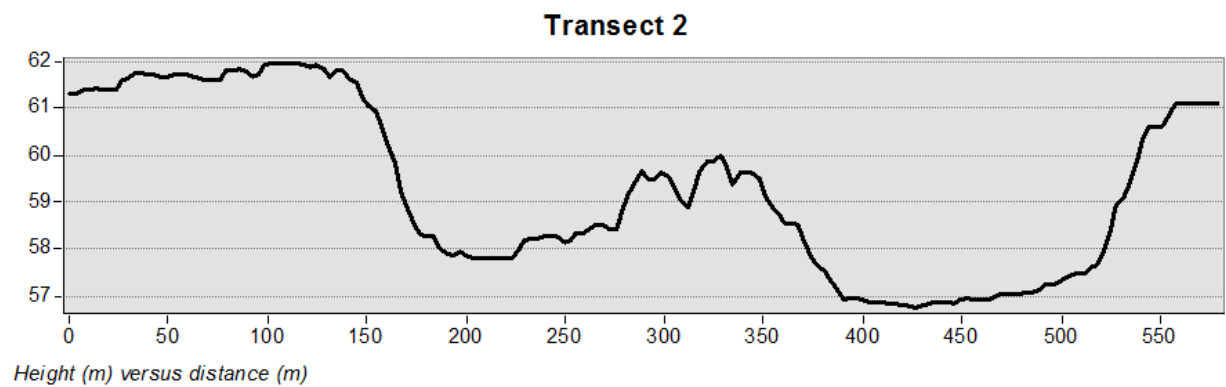
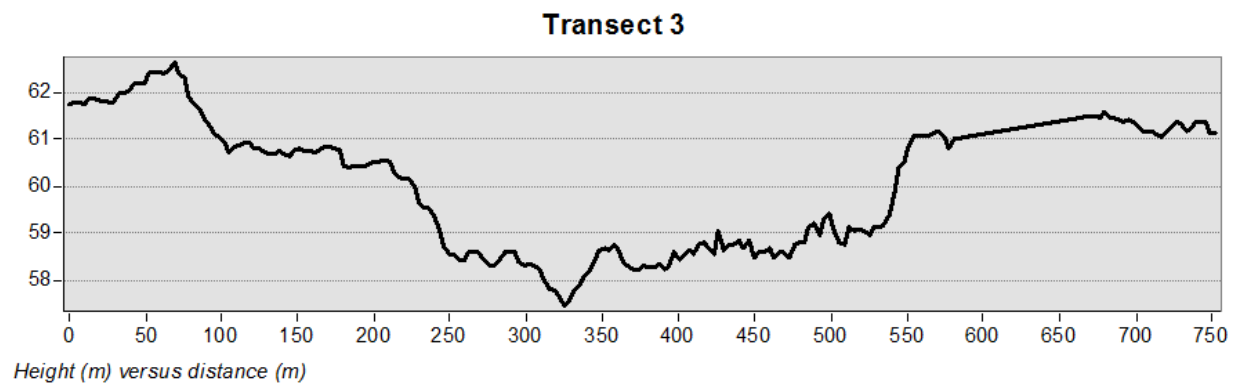
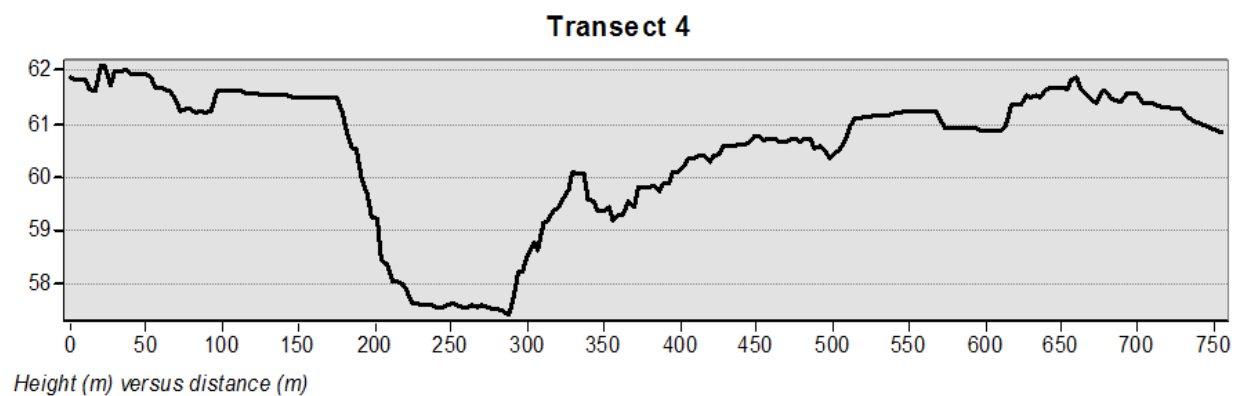
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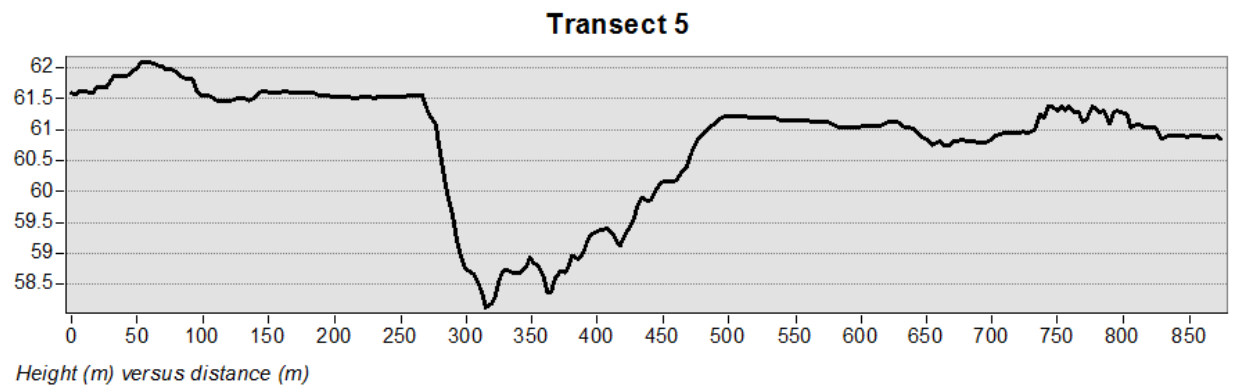
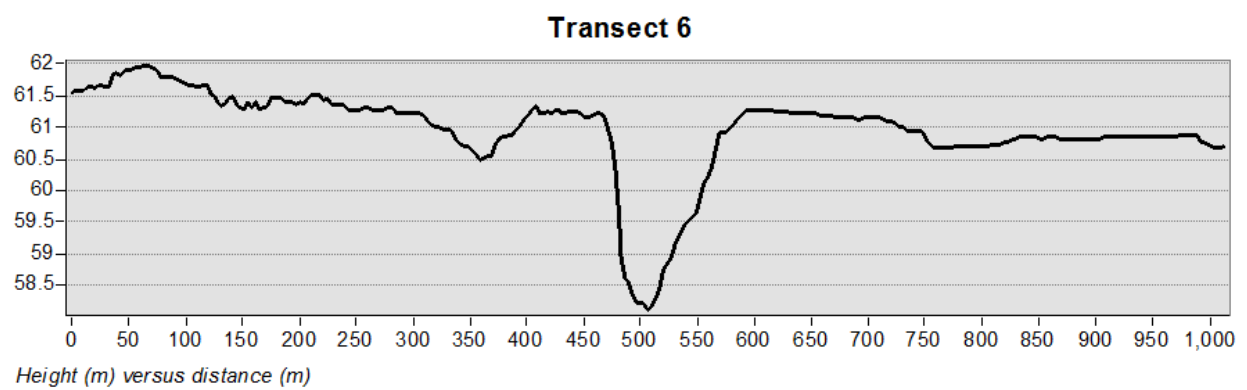
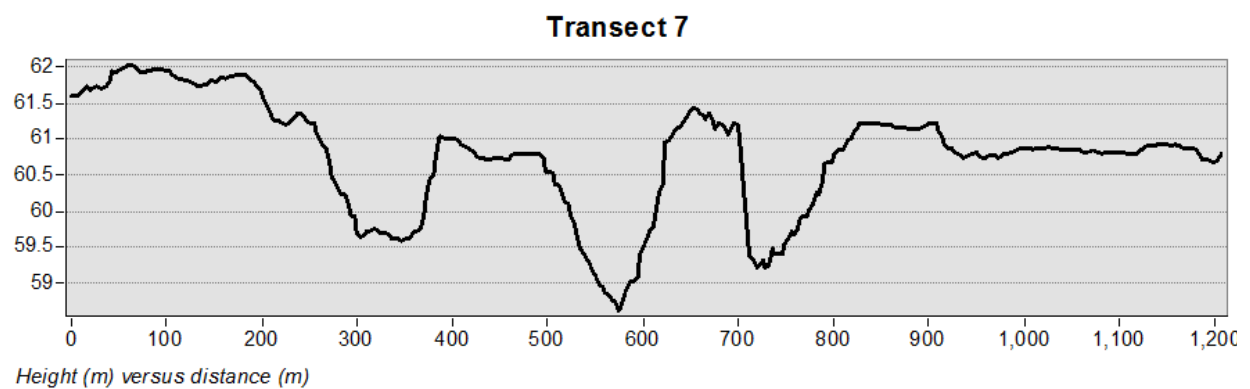
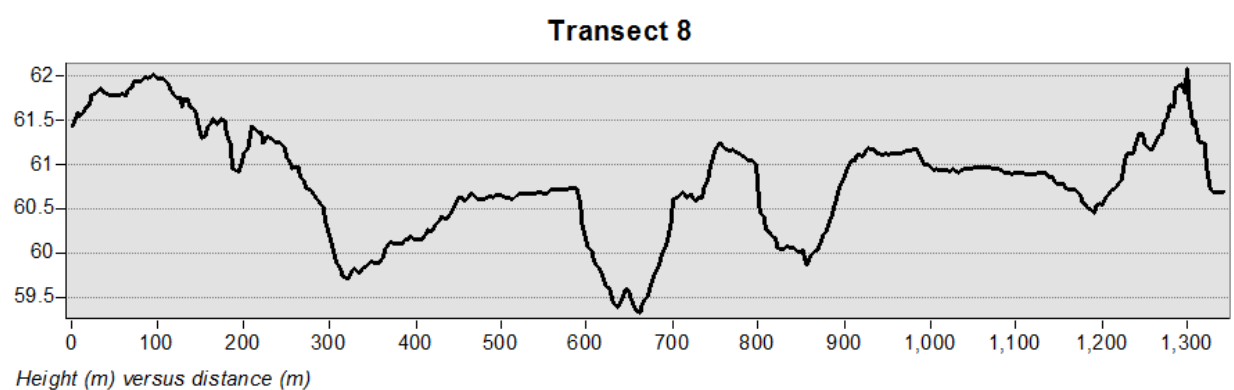
- Little owl (*Athene noctua*)
- Oystercatcher (*Haematopus ostralegus*)
- Dunnock (*Prunella modularis*)

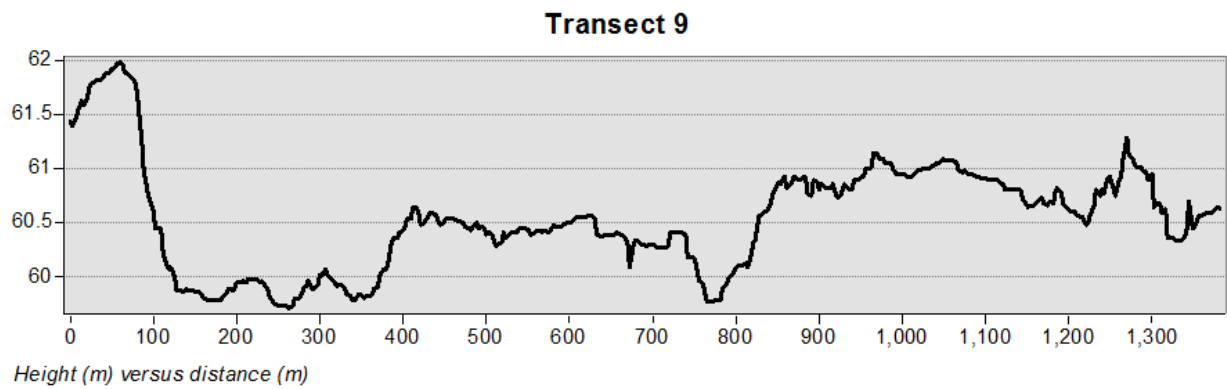
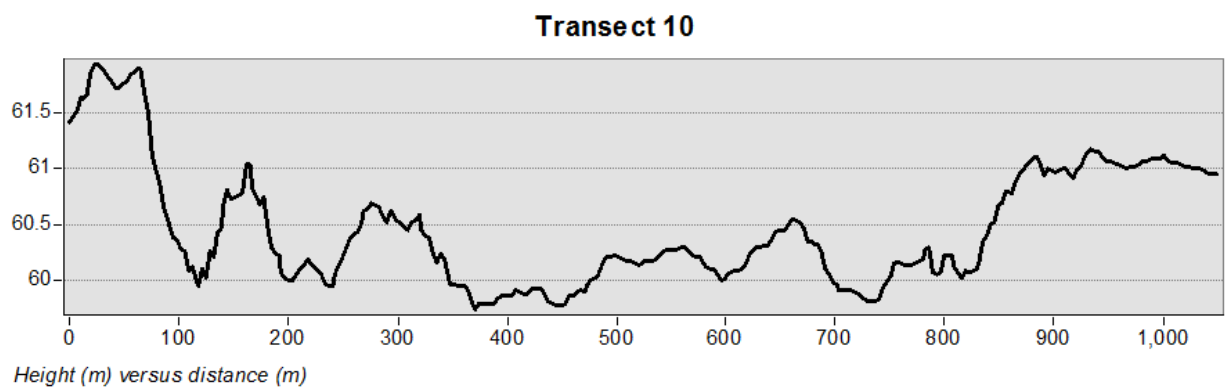
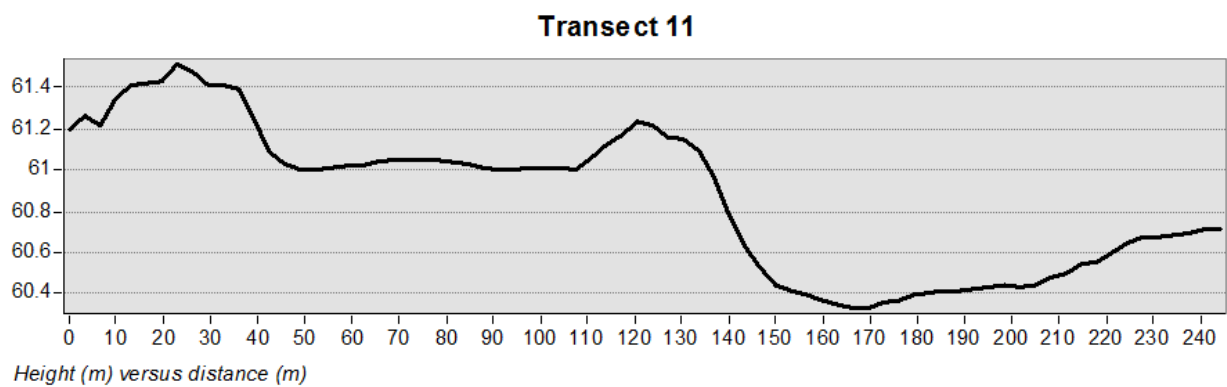
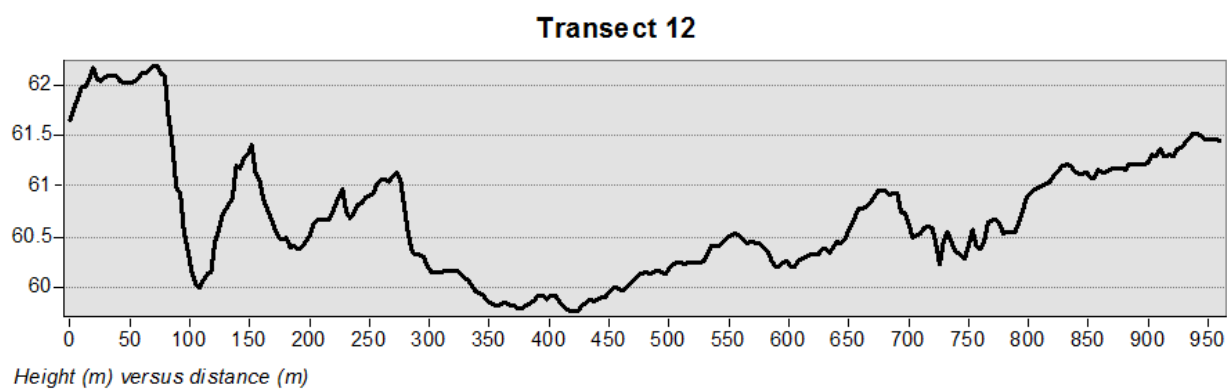
Fish

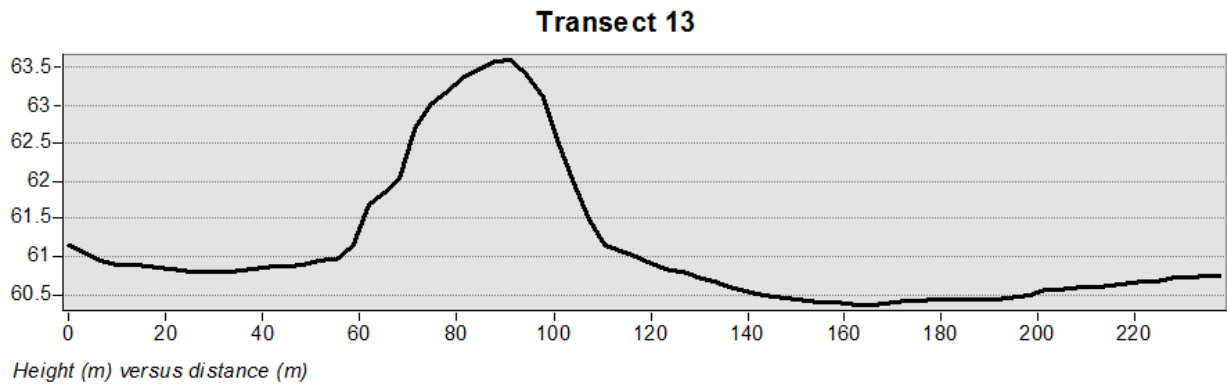
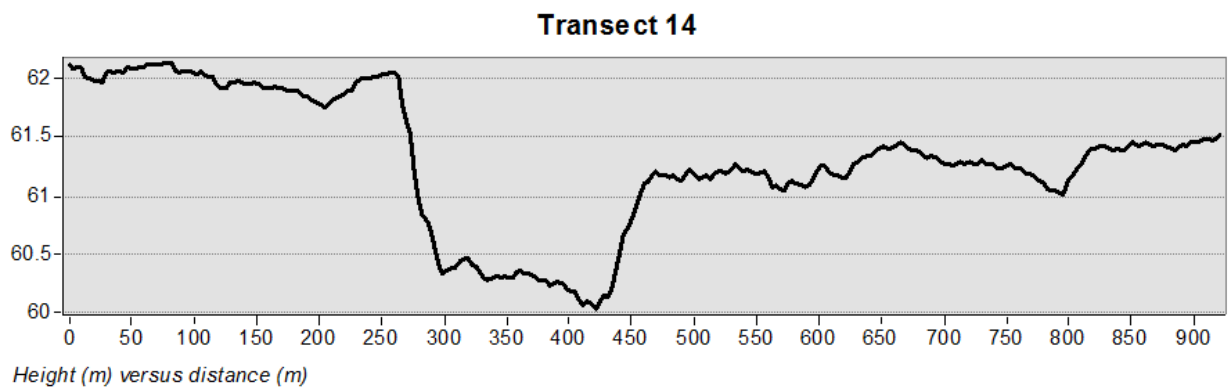
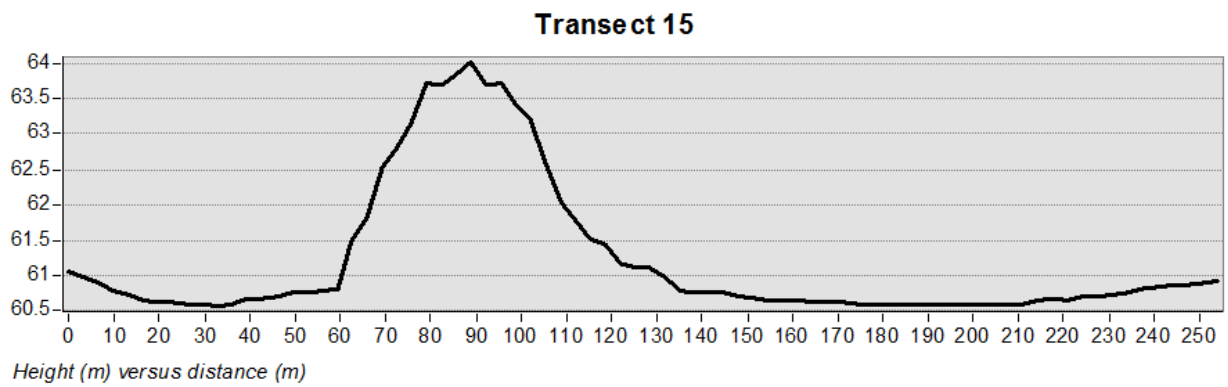
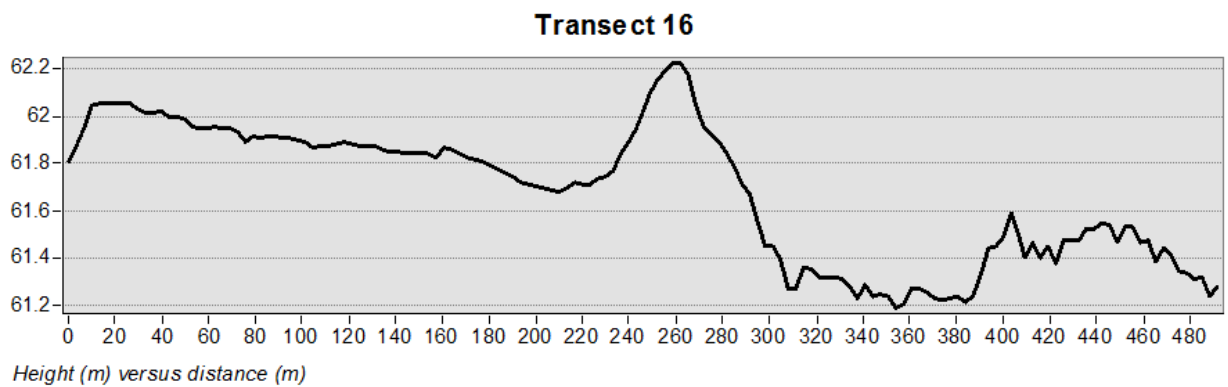
- Common bream (*Abramis brama*)
- Stone Loach (*Barbatula barbatula*)
- Northern pike (*Esox lucius*)
- Gudgeons (*Gobio gobio*)
- Common dace (*Leuciscus leuciscus*)
- European chub (*Leuciscus cephalus*)
- European perch (*Perca fluviatilis*)
- Common minnow (*Phoxinus phoxinus*)
- Common roach (*Rutilus rutilus*)

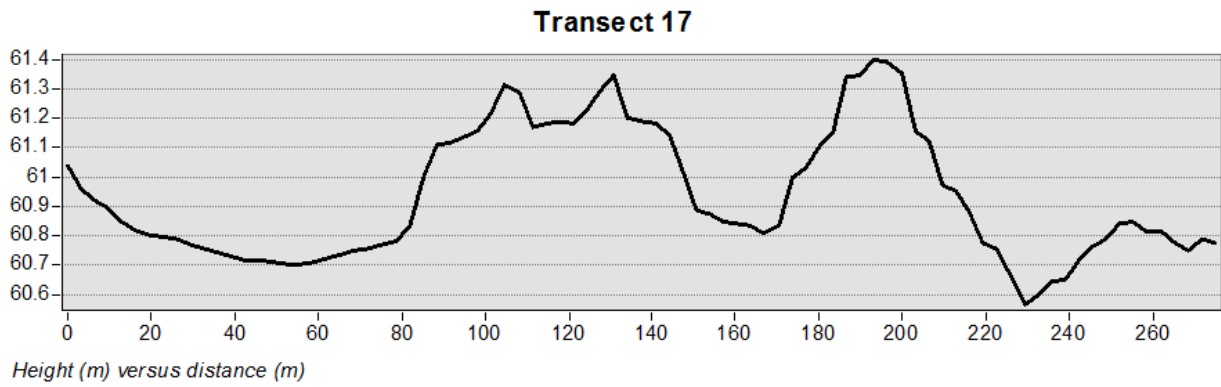
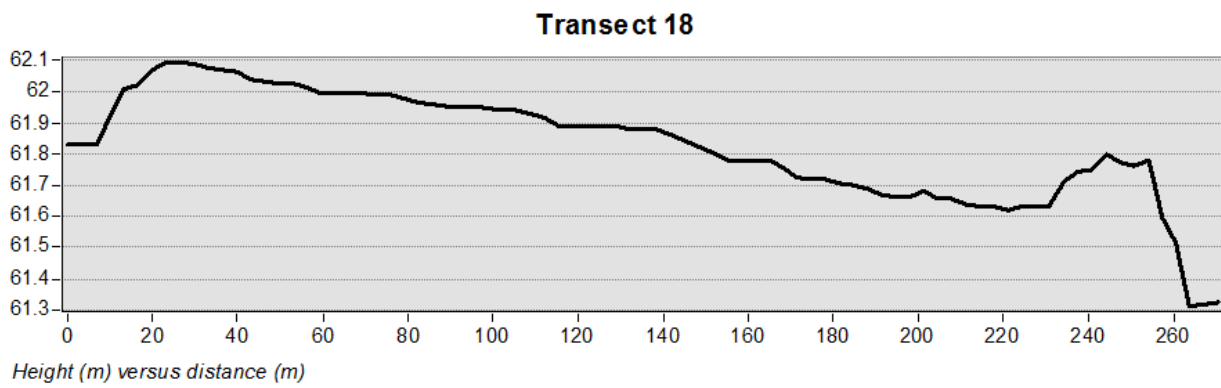
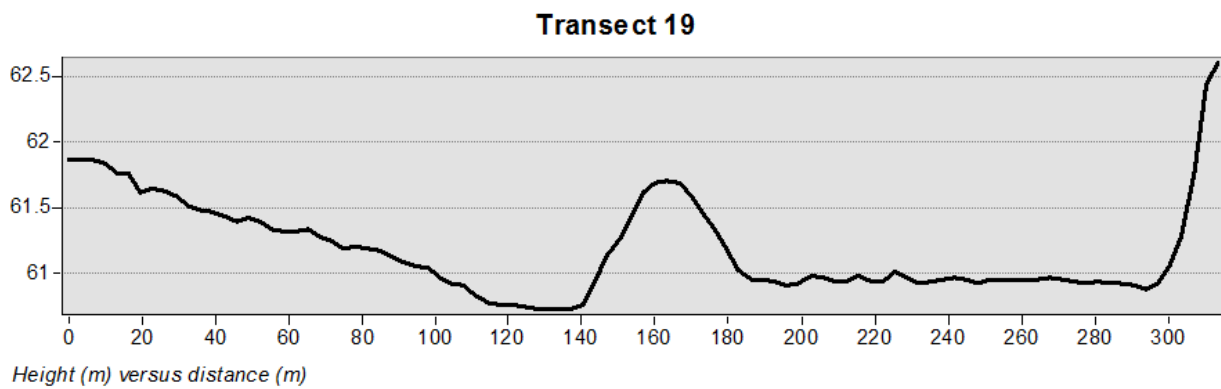
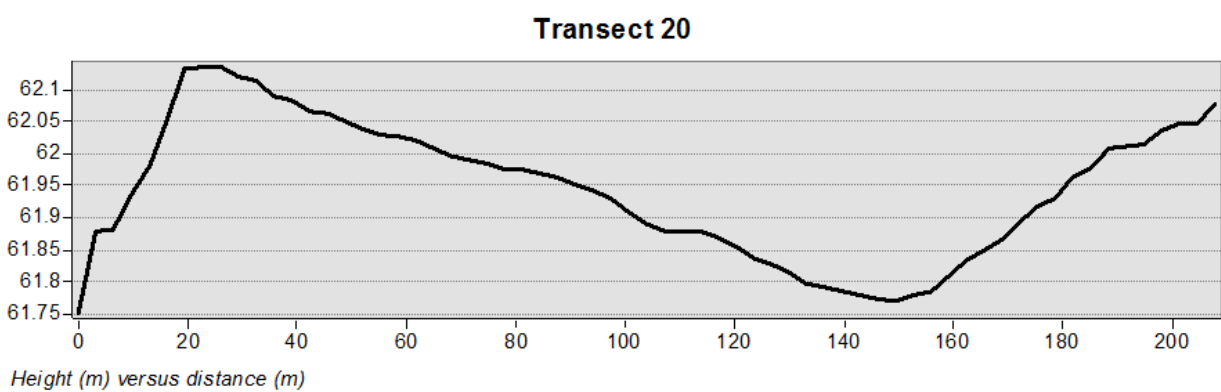
Appendix D Elevation profile for the west-east transects



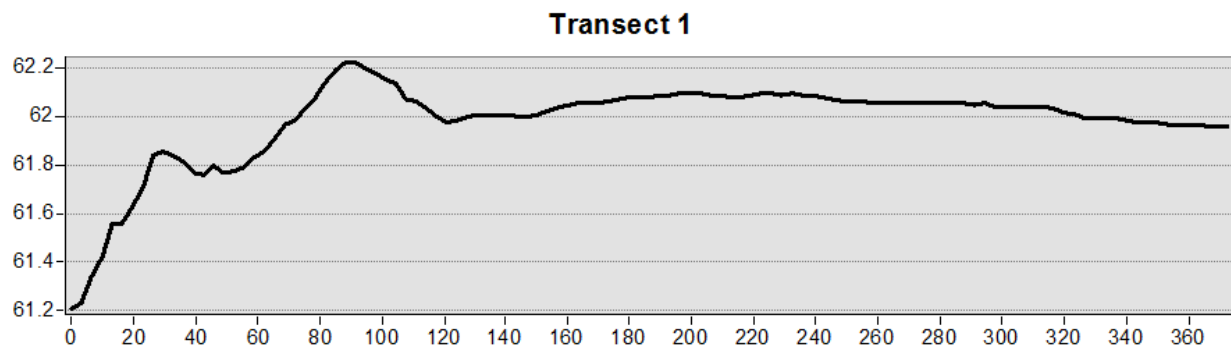
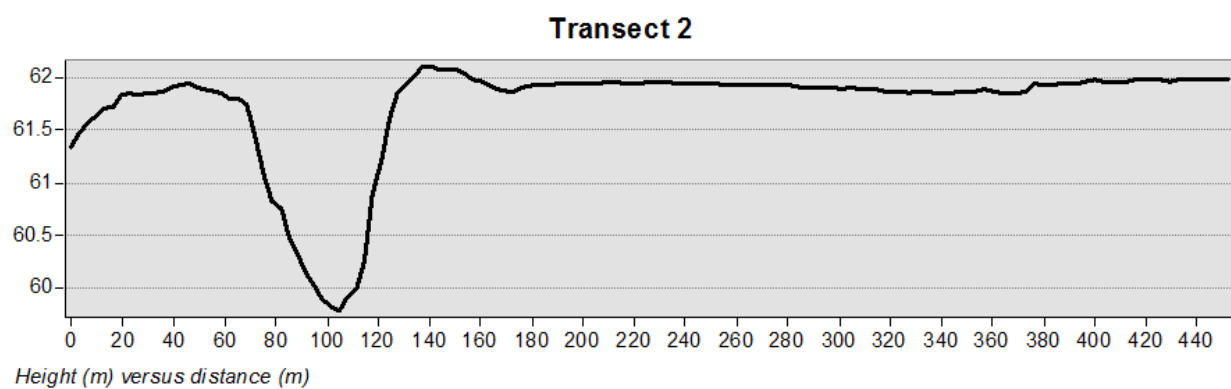
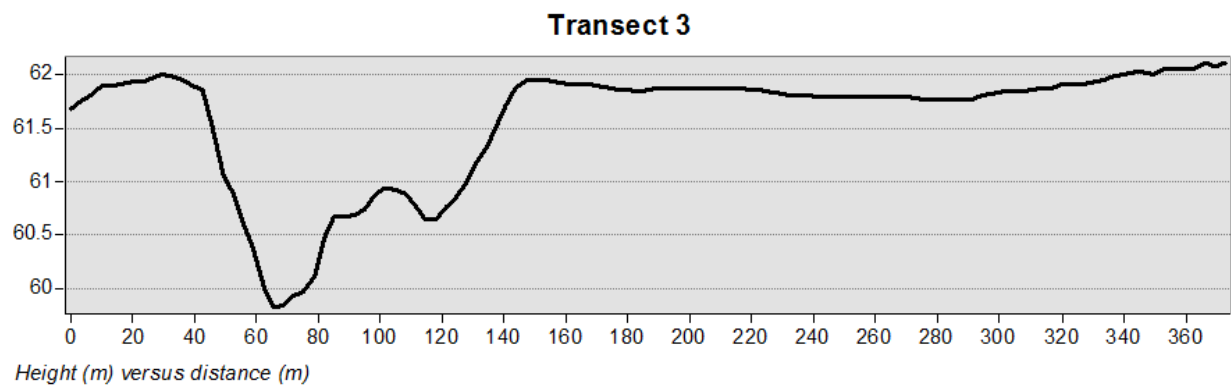
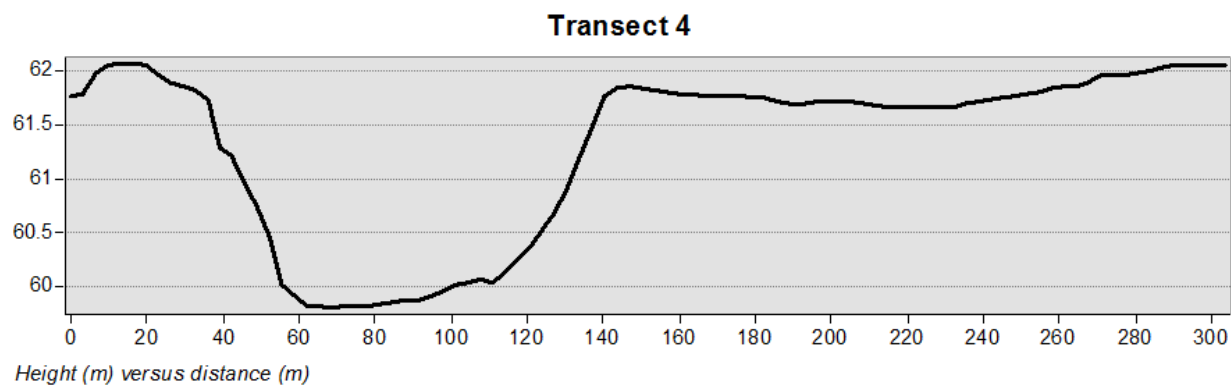


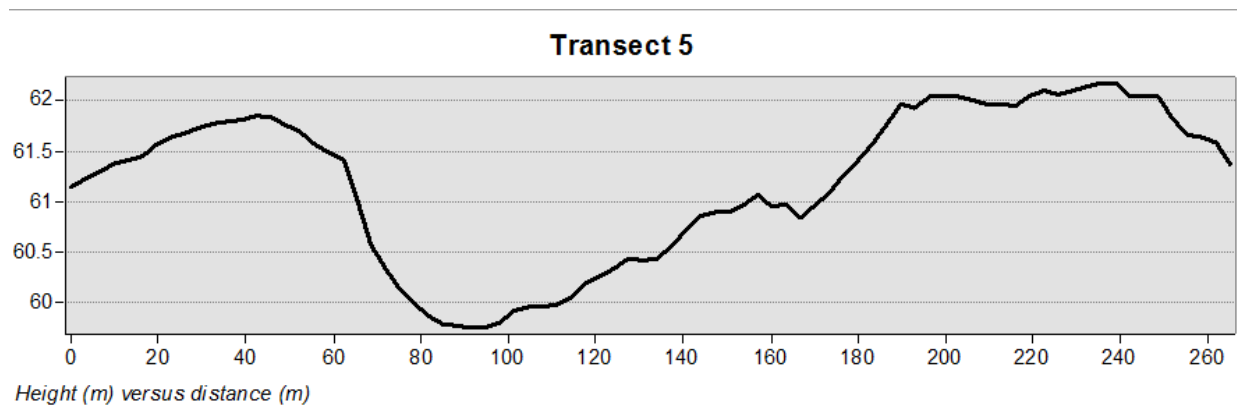
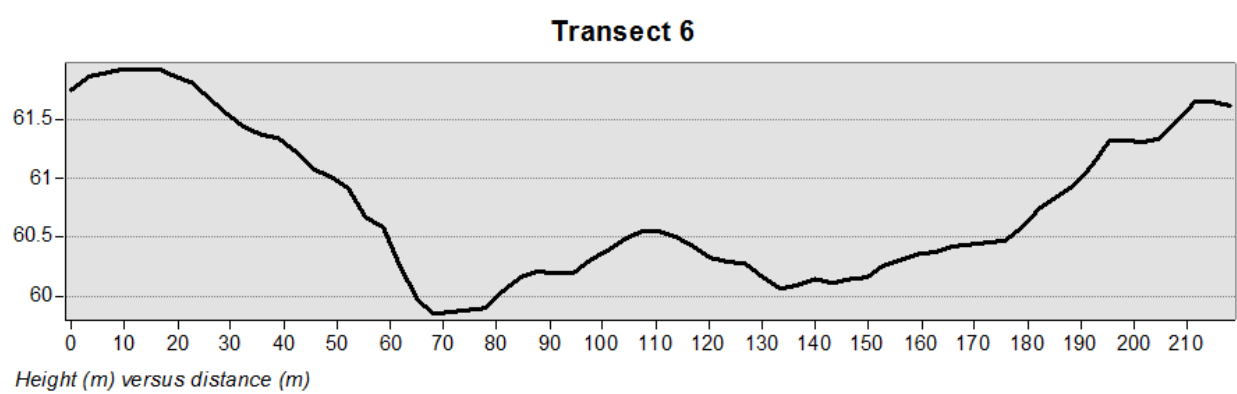
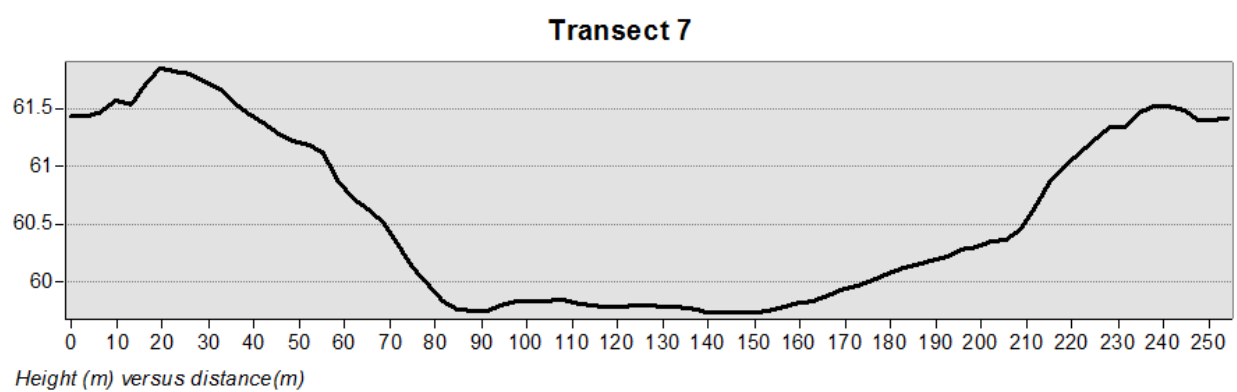
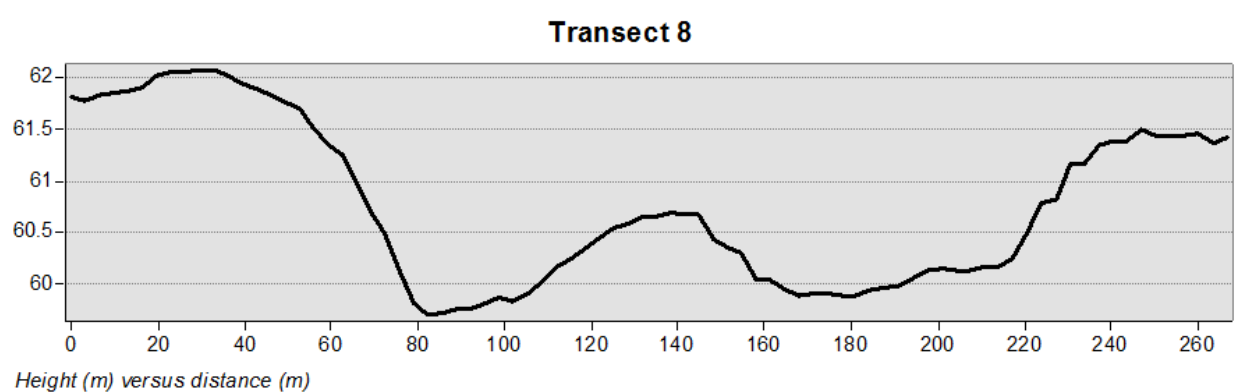


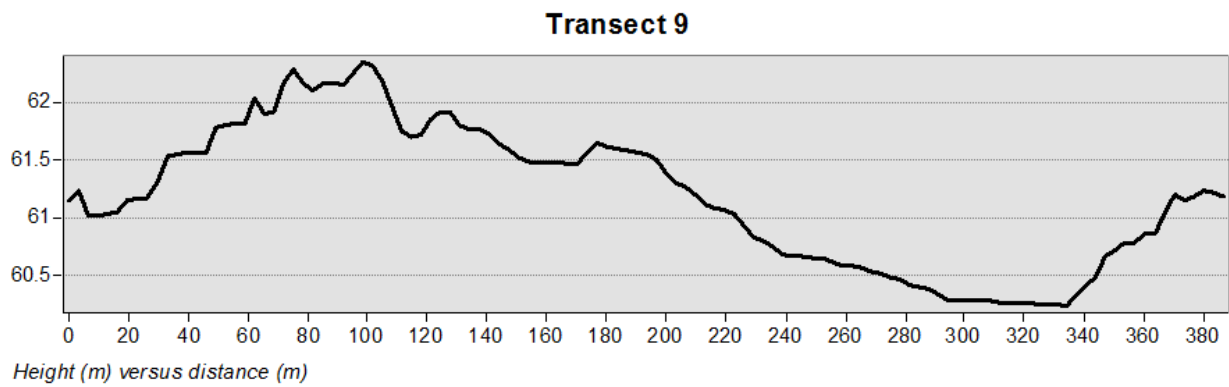
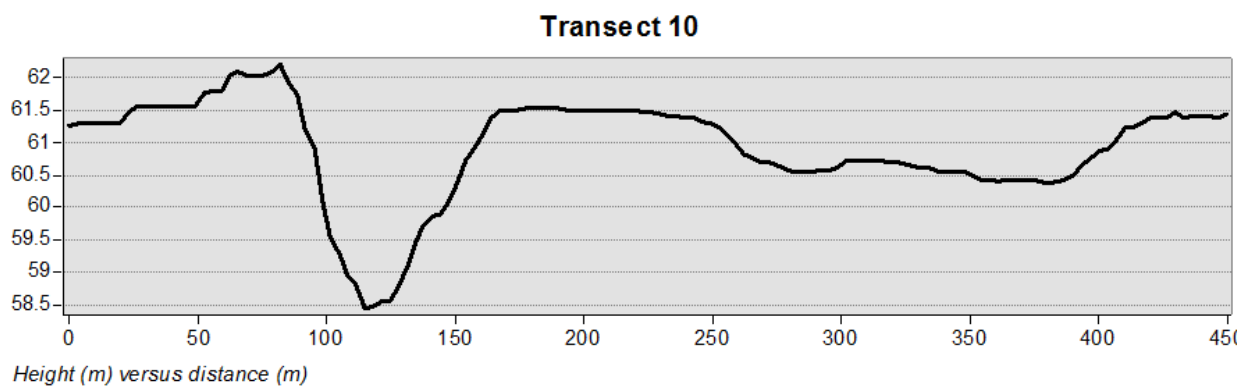
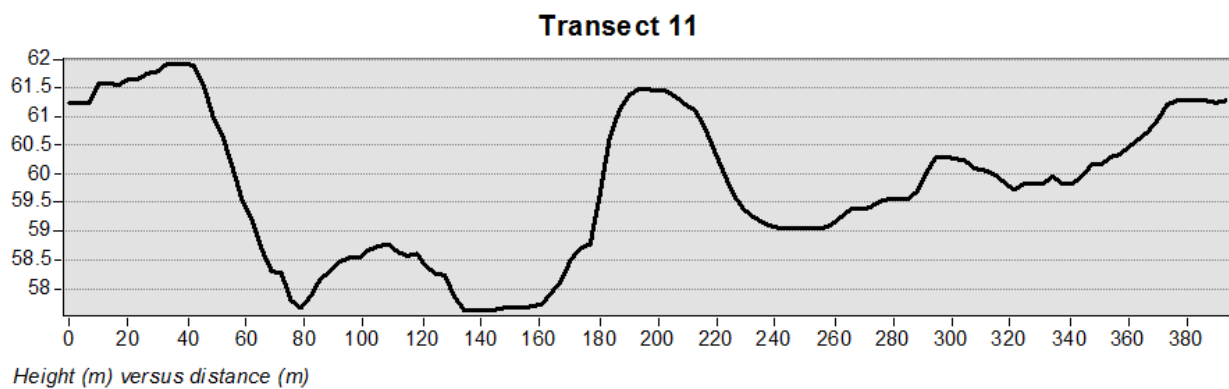
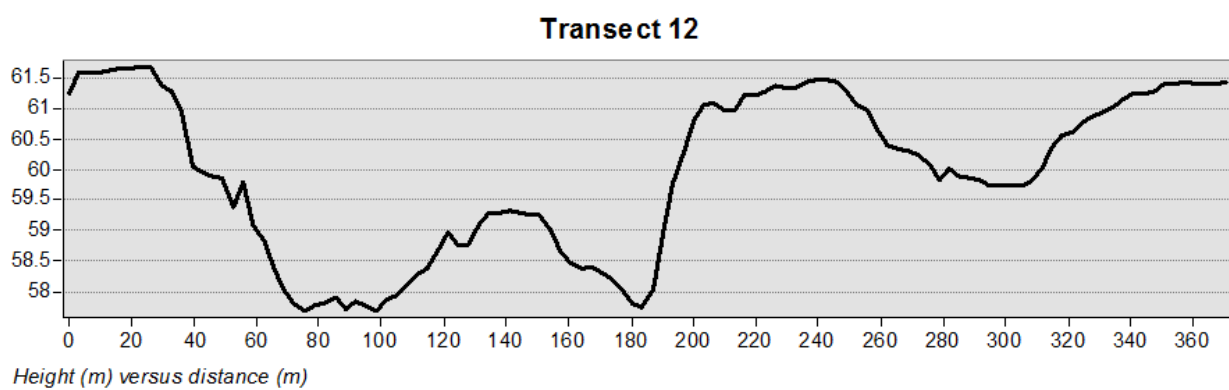




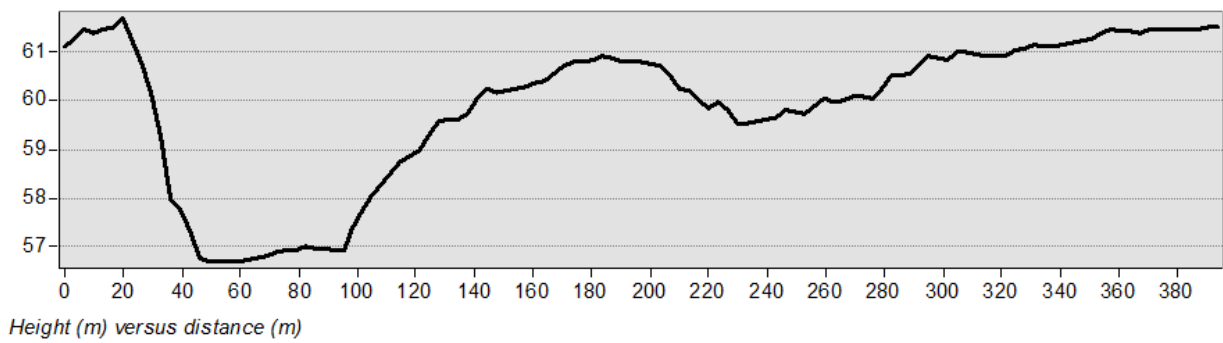
Appendix E Elevation profile for the north-south transects



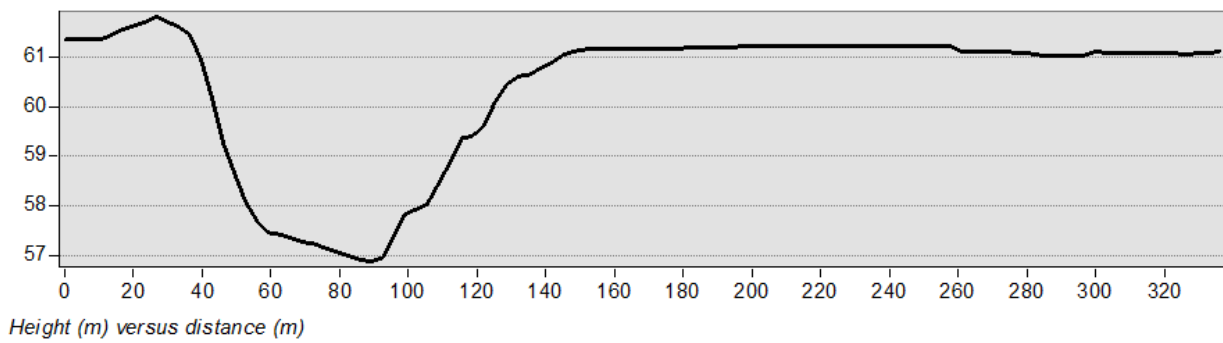




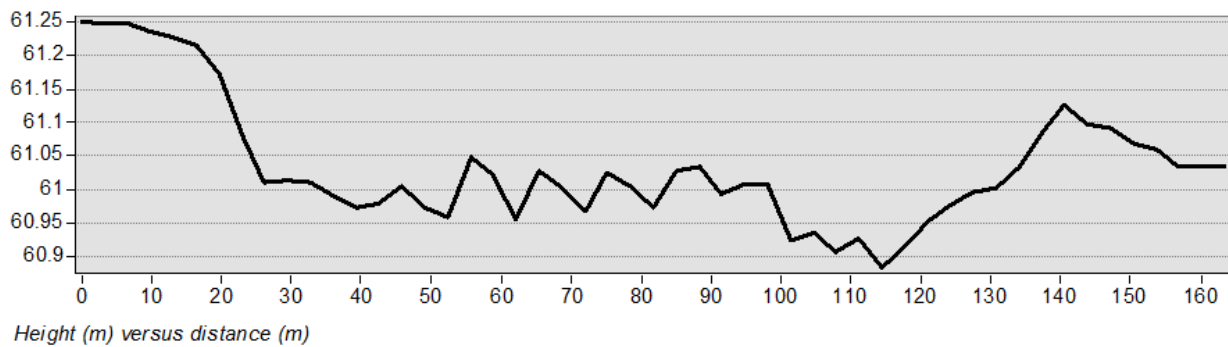
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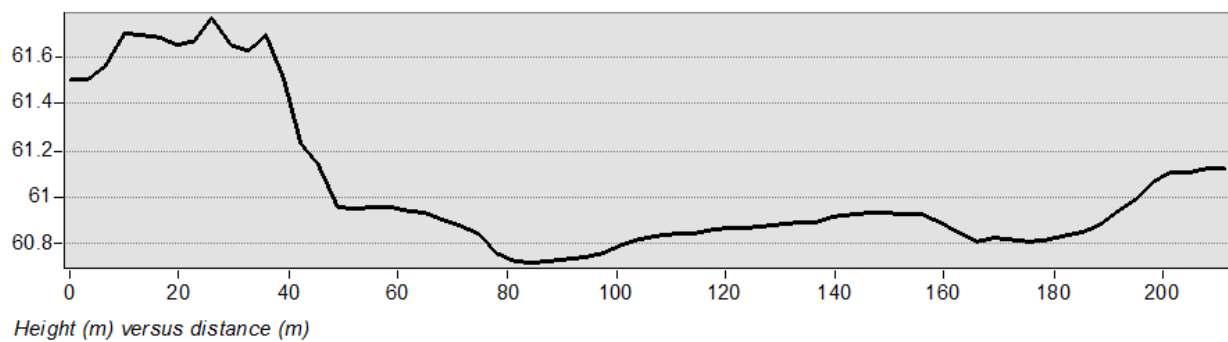
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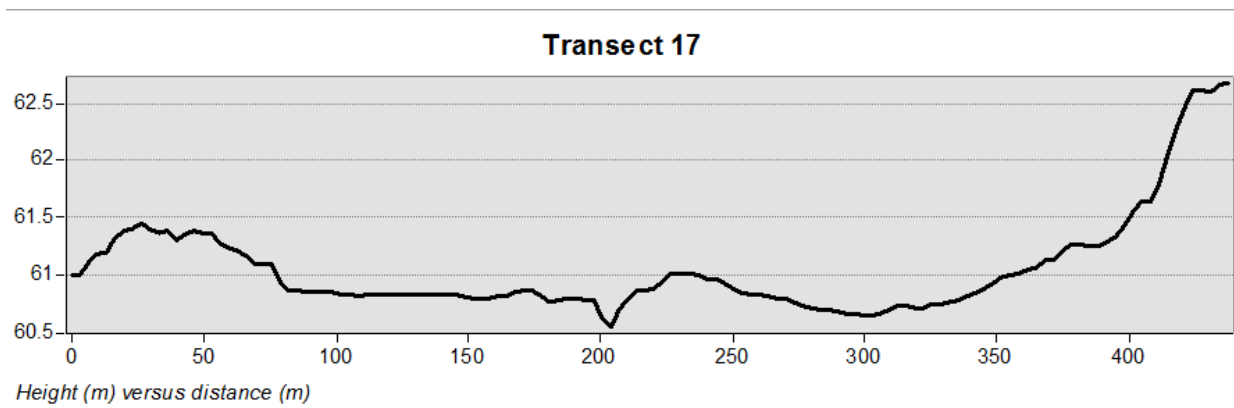
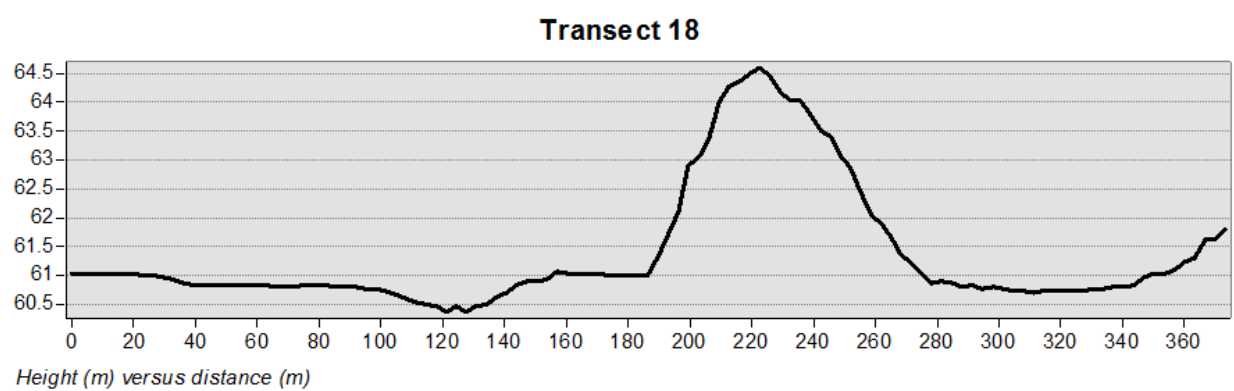
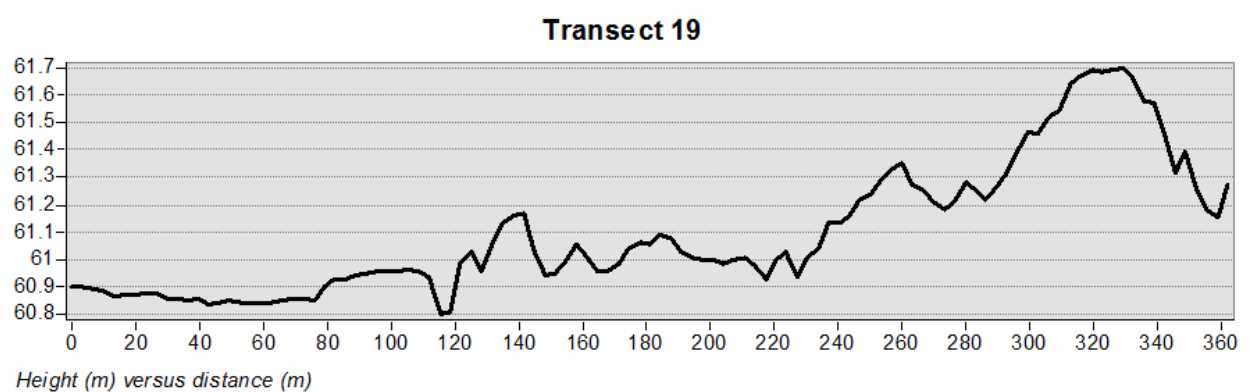
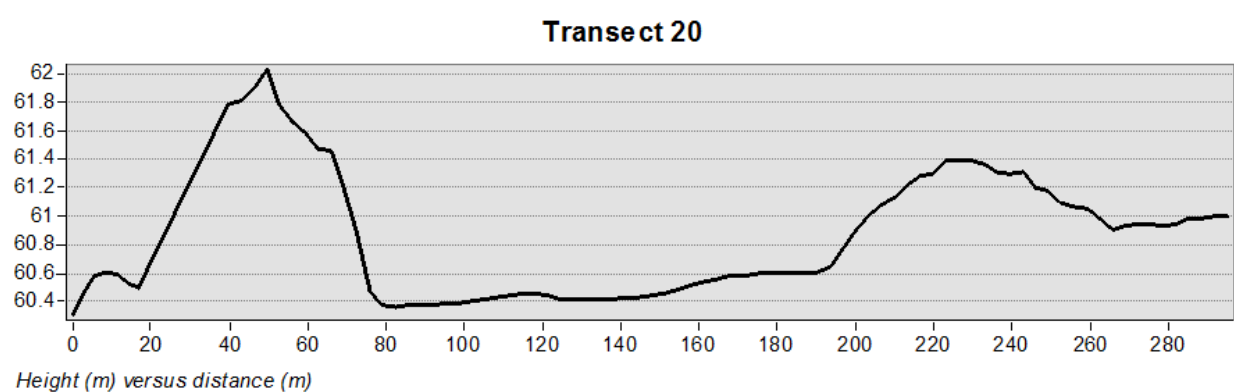


Transect 15

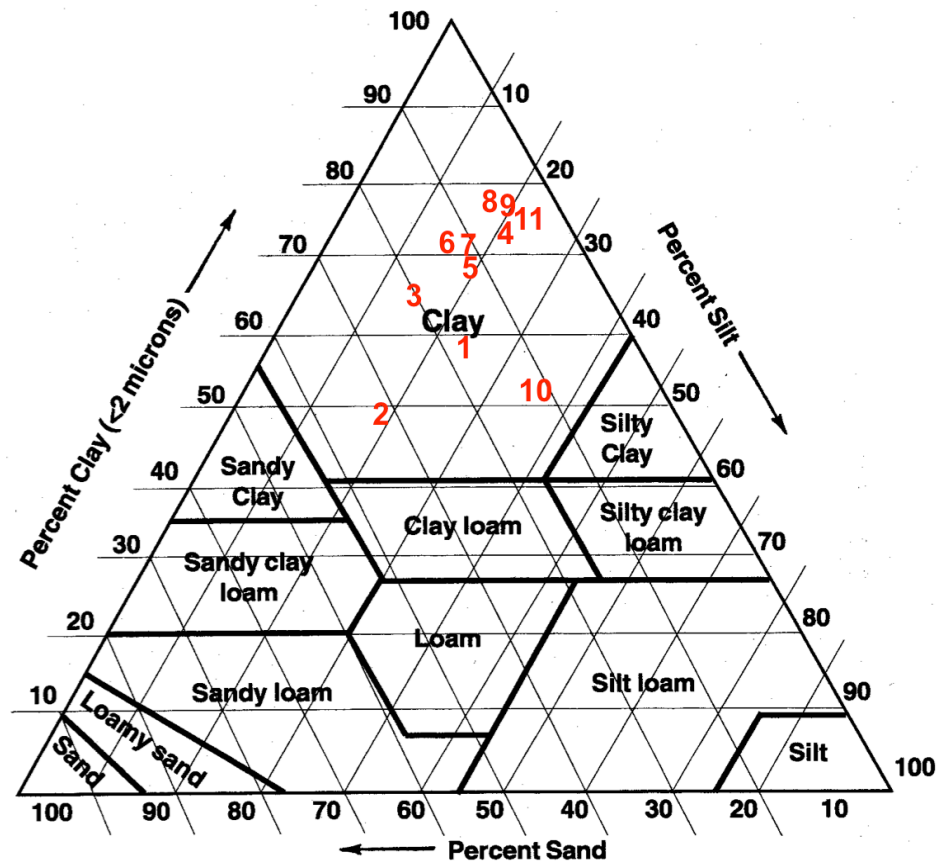


Transect 16





Appendix F Soil Texture triangle for the samples collected in the floodplain forest



Red numbers correspond to sampling points 1-11

Appendix G Vegetation species expected in the floodplain forest (Street, 2002)

A. Reedbeds: Common reed (*Phragmites australis*). Monitor will be focus into the edges of the clean water and silt lagoons where these plants will be planted.

B. Aquatic species

Amphibious bistort (*Polygonum amphibium*)
Arrowhead (*Sagittaria sagittifolia*)
Branched Bur-reed (*Sparganium erectum*)
Brooklime (*Veronica beccabunga*)
Bulrush (*Schoenoplectus lacustris*)
Flowering rush (*Butomus bellatus*)
Gipsywort (*Lycopus europaeus*)
Greater pond sedge (*Carex riparia*)
Greater spearwort (*Ranunculus lingua*)
Greater water dock (*Rumex hydrolapathum*)
Marsh marigold (*Caltha palustris*)
Purple loosestrife (*Lythrum salicaria*)
Reed grass (*Phalaris arundinacea*)
Rigid hornwort (*Ceratophyllum demersum*)

Soft rush (*Juncus effusus*)
Hard rush (*Juncus inflexus*)
Water figwort (*Scrophularia auriculata*)
Water forget-me-not (*Myosotis scorpioides*)
Water mint (*Mentha aquatica*)
Water plantain (*Alisma plantago aquatica*)
Water starworts (*Callitriche spp*)
White lily (*Nymphaea alba*)
Wild angelica (*Angelica sylvestris*)
Yellow iris (*Iris pseudacorus*)
Yellow Lily (*Nuphar lutea*)
Marsh horsetail (*Equisetum palustris*)
Watercress (*Rorippa nasturtium-aquaticum*)

C. Grassland areas

a. Species rich flood meadow

Grasses

Common bent (*Agrostis capillaris*)
Quaking grass (*Briza media*)
Crested dog's-tail (*Cynosurus cristatus*)
Red fescue (*Festuca rubra ssp commutata*)

Meadow barley (*Hordeum secalinum*)
Meadow foxtail (*Alopecurus pratensis*)
Sweet vernal-grass (*Anthoxanthum odoratum*)
Yorkshire fog (*Holcus lanatus*)

Herbs

Autumn hawkbit (*Leontodon autumnalis*)
Meadow sweet (*Filipendula ulmaria*)
Betony (*Stachys officinalis*)
Meadow vetchling (*Lathyrus pratensis*)
Bird's-foot trefoil (*Lotus corniculatus*)
Oxeye daisy (*Leucanthemum vulgare*)
Common knapweed (*Centaurea nigra*)
Pepper saxifrage (*Silaum silaus*)
Cuckoo flower (*Cardamine pratensis*)
Pignut (*Conopodium majus*)
Dropwort (*Filipendula vulgaris*)
Ribwort plantain (*Plantago lanceolata*)
Great burnet (*Sanguisorba officinalis*)
Selfheal (*Prunella vulgaris*)
Lady's bedstraw (*Galium verum*)
Yarrow (*Achillea mille folium*)

Meadow buttercup (*Ranunculus acris*)

Yellow rattle (*Rhinanthus minor*)

Meadow cranesbill (*Geranium pratense*)

b. Damp/flood pastures grassland. Same species as above, but with less wildflower rate component.

c. Tall herb/ grassland “fen” type vegetation listed below:

Cuckoo flower (*Cardamine pratensis*)

Cocksfoot (*Dactylis glomerata*)

Hemp agrimony (*Eupatorium cannabinum*)

Meadow fescue (*Festuca pratensis*)

Meadowsweet (*Filipendula ulmaria*)

Purple loosestrife (*Lythrum salicaria*)

Ragged robin (*Lychnisflos-cuculi*)

Tall fescue (*Festuca arundinacea*)

Teazel (*Dipsacus fullonum*)

Tufted Hair-grass (*Deschampsia cespitosa*)

Marsh foxtail (*Alopecurus geniculatus*)

Meadow foxtail (*Alopecurus pratensis*)

St John's wort (*Hypericum perforatum*)

Great Hairy Willowherb (*Epilobium hirsutum*)

D. Woodland areas

- a. "Dry" woodland: dominant trees would be ash, oak and field maple, with some aspen and small component of small-leaved lime.
- b. Damp woodland: still predominantly ash and oak with some maple, but bringing in small numbers of alder and downy birch, with scattered white willow, crack willow and black poplar.
- c. Winter wet/summer dry woodland: some ash, with more alder, and more white willow and crack willow, with scattered grey poplar, black poplar and downy birch, and a very few almond willow.
- d. Wet woodland: native black poplars, with white, crack, almond and osier willows and willow.

- e. Shrubs and woodland Ground Flora:

Purging buckthorn (*Rhamnus catharticus*)

Wayfaring tree (*Viburnum lantana*)

Guelder rose (*Viburnum opulus*)

Eared willow (*Salix aurita*)

Common willow (*Salix cinerea*)

Purple willow (*Salix purpurea*)

Crab apple (*Malus sylvestris*)

Blackthorn (*Prunus spinosa*)

Hawthorn (*Crataegus monogyna*)

Almond willow (*Salix triandra*)

Elder (*Sambucus nigra*)

Hazel (*Corylus avellana*)

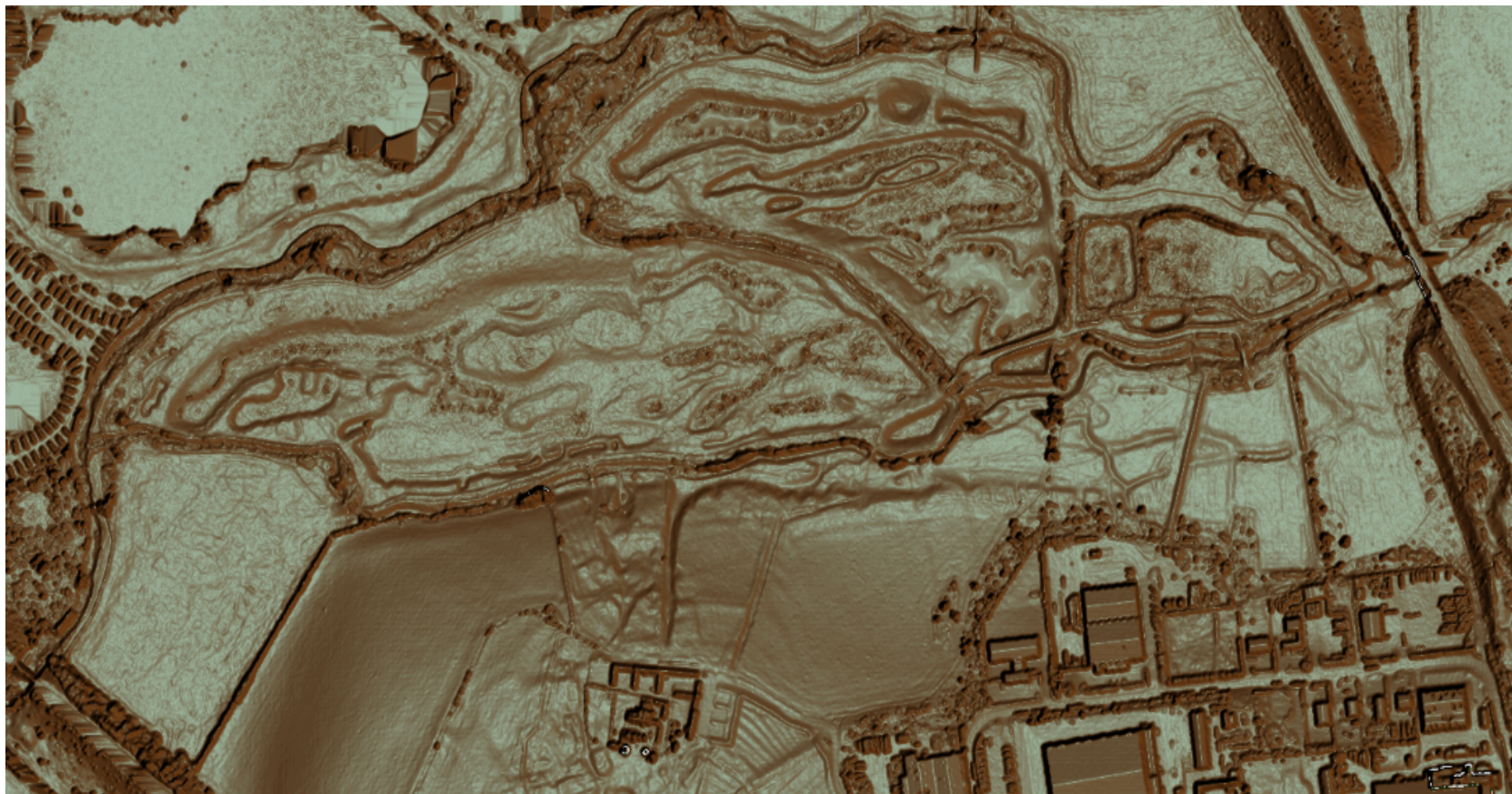
Dogwood (*Cornus sanguinea*)

Alder buckthorn (*Frangula alnus*)

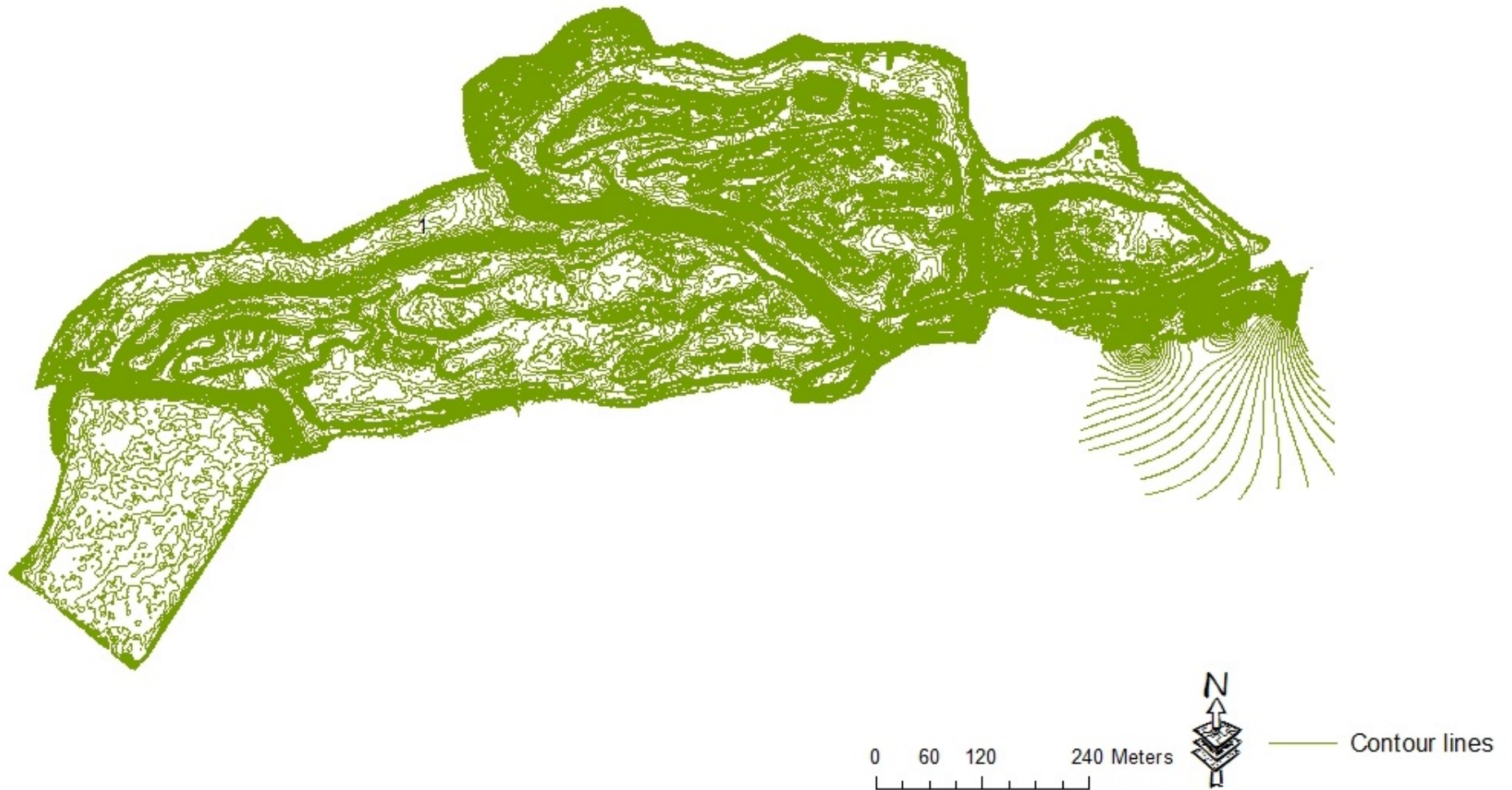
Dog rose (*Rosa canina*)

Midland Hawthorn (*Crataegus laevigata*)

Appendix H The 3D image of the floodplain forest



Appendix I Contour line map of the floodplain forest

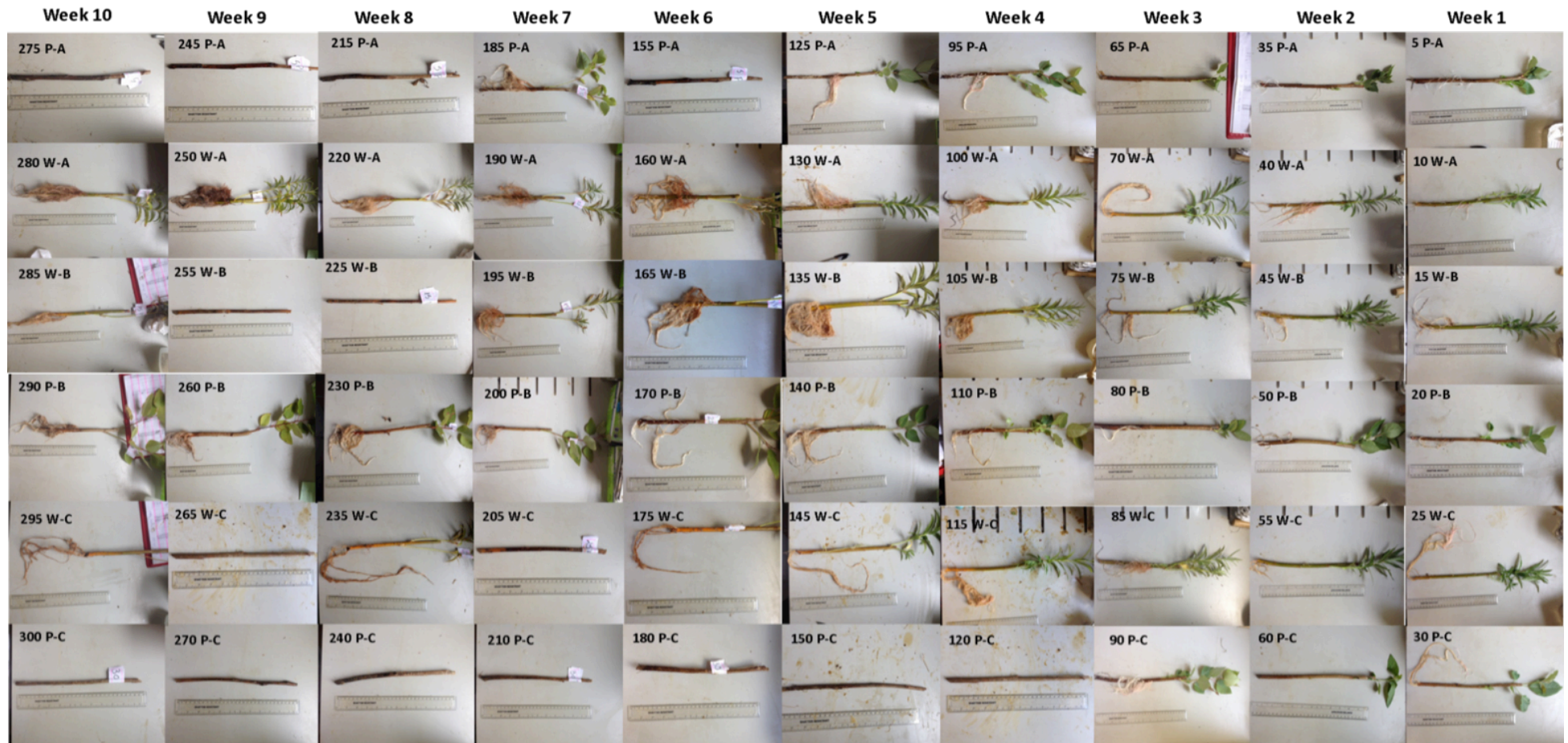


Appendix J Loggers fieldwork equipment and material inventory and description

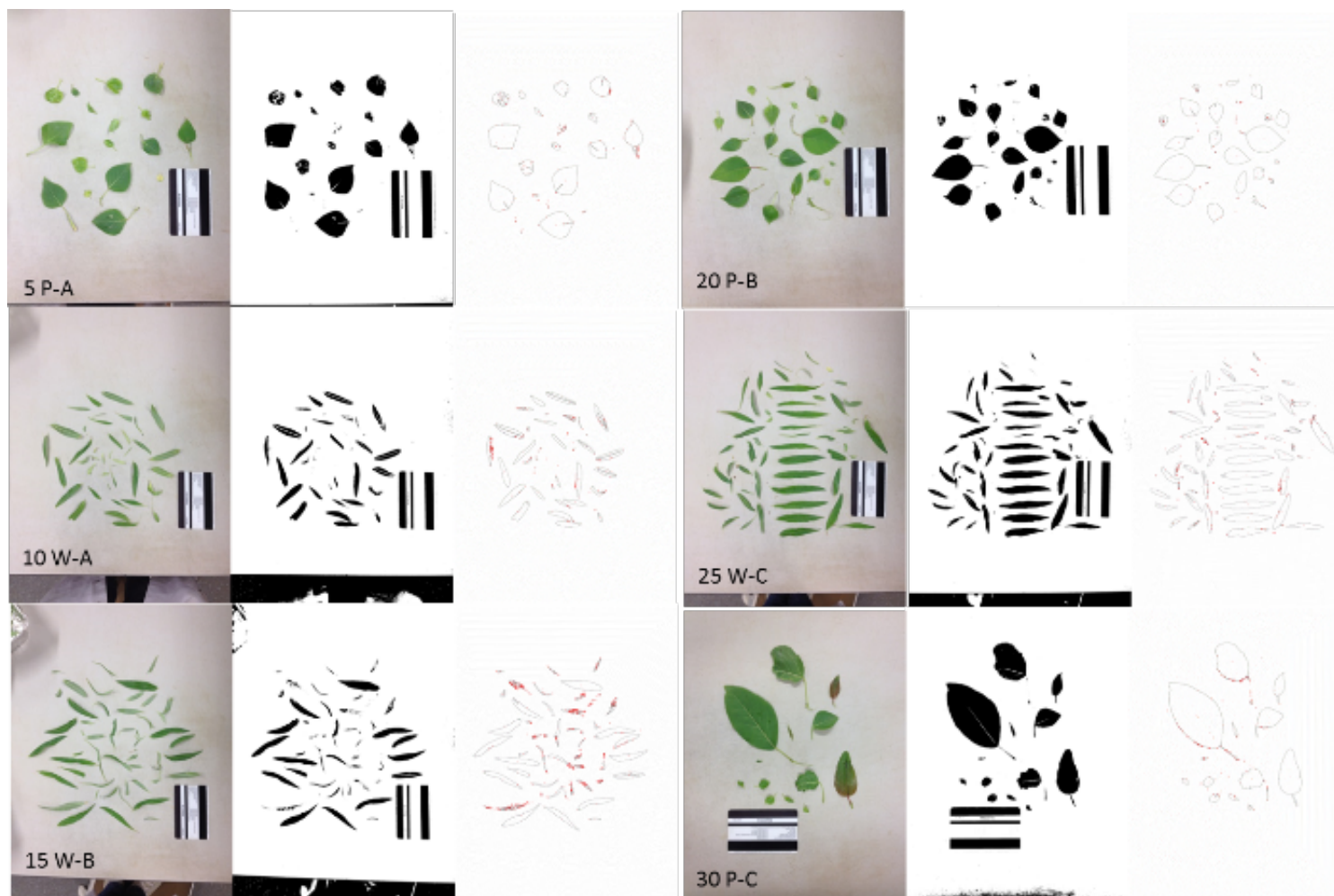
Material & Equipment	Quantity	Activity Description
Trimble unit GPS	1	This unit is used to record the coordinates of the loggers and barologger.
Spade	1	Removing the surface material (e.g. Soil in order to access the dipwell tubes).
Dipwell Lock Key	1	The key is used to open the dipwell security caps to access the level logger.
Security caps	9	To lock the dipwell tubes from the top.
Metallic squares	9	Once the logger is installed and locked with the cap, metallic squares will be put on top to ease the task find them.
Heavy Hammer	1	To nail the wood sticks into the ground.
Wood sticks	9	To find easily the Loggers coordinates when going to download the data every three months.
PPE (Personal Protective Equipment)	1	Helmet, high visibility coat, glasses, steel cap boots, gloves.
Hanson induction	1	Prior going to the quarry area. Mandatory.
Level loader	11	This unit is attached to the level logger to download the data.
Bolt croppers	1	To cut the chain in 1.5 m length.
Key rings	16	They are used as connectors
Dipwell tubes with holes	9	It will contain the logger suspended in the air. (1.5 m/7 cm diameter approximately of inner diameter)

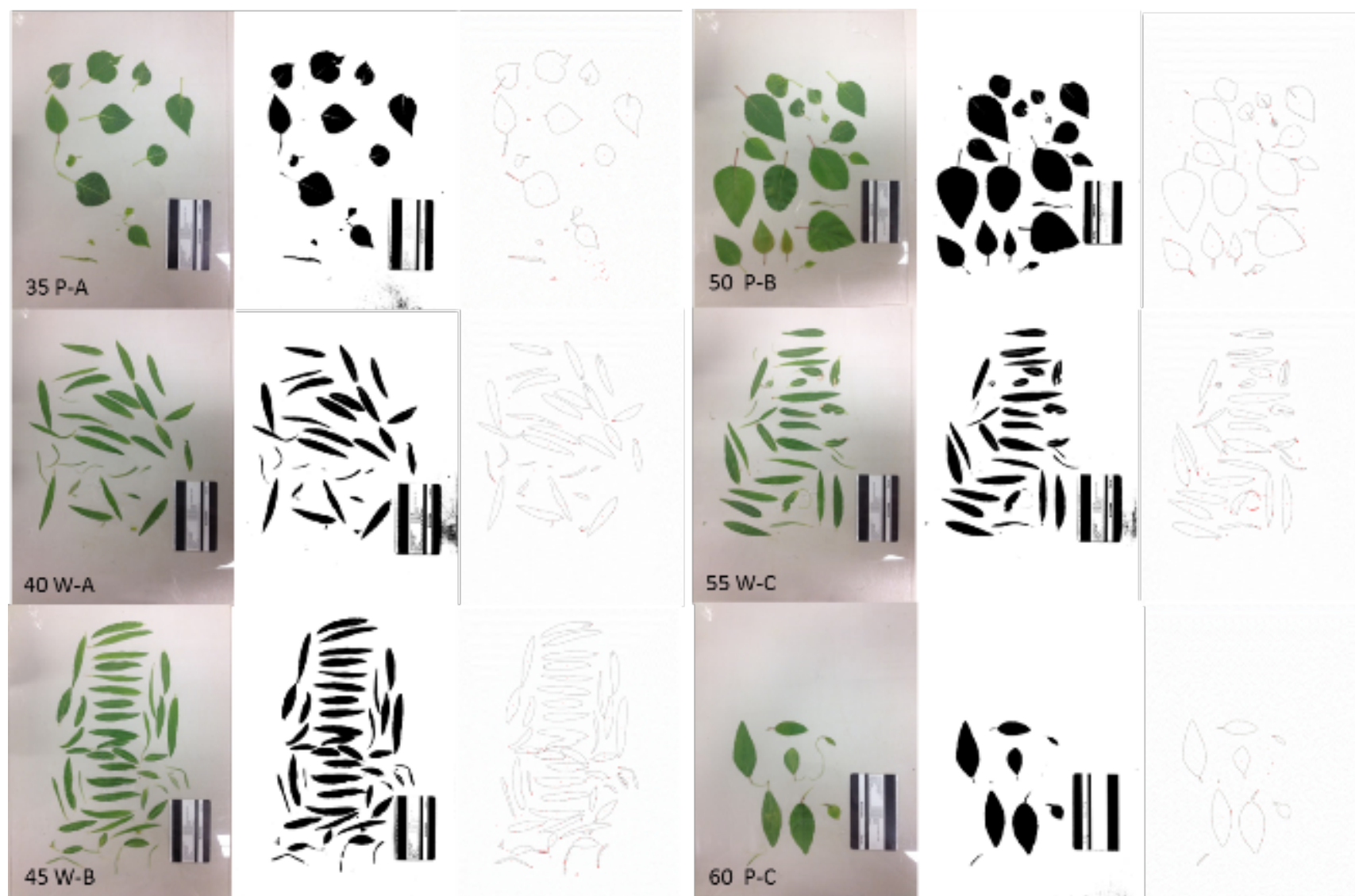
Material & Equipment	Quantity	Activity Description
Nylon sock (meshing roll)	1 roll	The nylon sock wraps the dipwell tube with holes, allowing just water is in contact with the Logger.
Measuring tape (100 m)	1	To locate sampling points according to features (it is suggested do a map to triangulate).
Chain	30 m	To join safely the Logger with the security cap.
Duct tape	1 roll	To seal the dipwell and the rubber bung at the bottom.
Scissors	1	To cut the duct tape.
Fieldwork notepad Solinst software 3.1.1 Version	1	To programme the loggers, download data and check if Loggers are working properly.
Water table level dipper	1	To measure water table in real time.
Schlumberger Optical reader	1	Allow to connect logger with the computer/laptop to download data.
Saw	1	To cut the dipwell tube if needed.
H&S/Risk Assessment	-	Prior going to the field monthly.
Rubber bungs	10	Neoprene bungs to stopper the ends of the tubes.
Maps with coordinates	1	To locate coordinates in place.
Auger+ extensions	1	To dig the holes into the ground 1.5 m depth.

Appendix K Shoot and root length outputs using ImageJ software for selected cuttings for leaf area and biomass in the glasshouse experiment



Appendix L Leaves area determination, binary images and outlines for selected cuttings in the glasshouse experiment







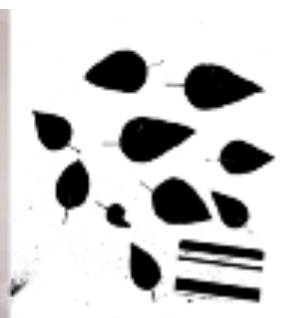




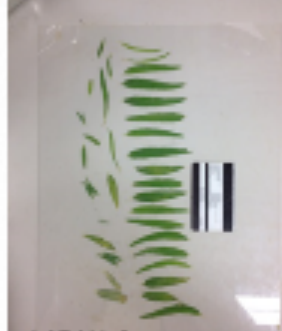
125 P-A



140 P-B



130 W-A

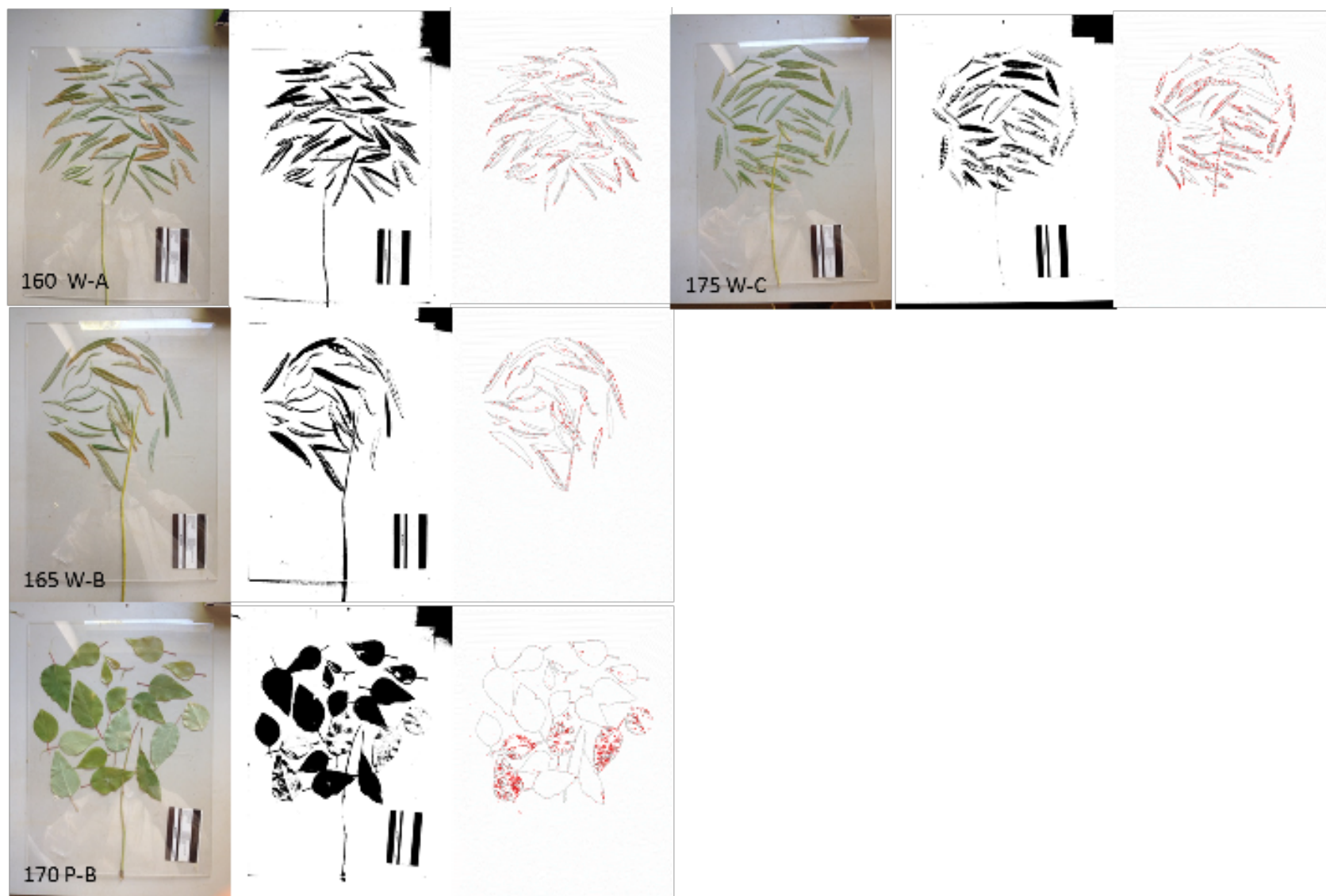


145 W-C



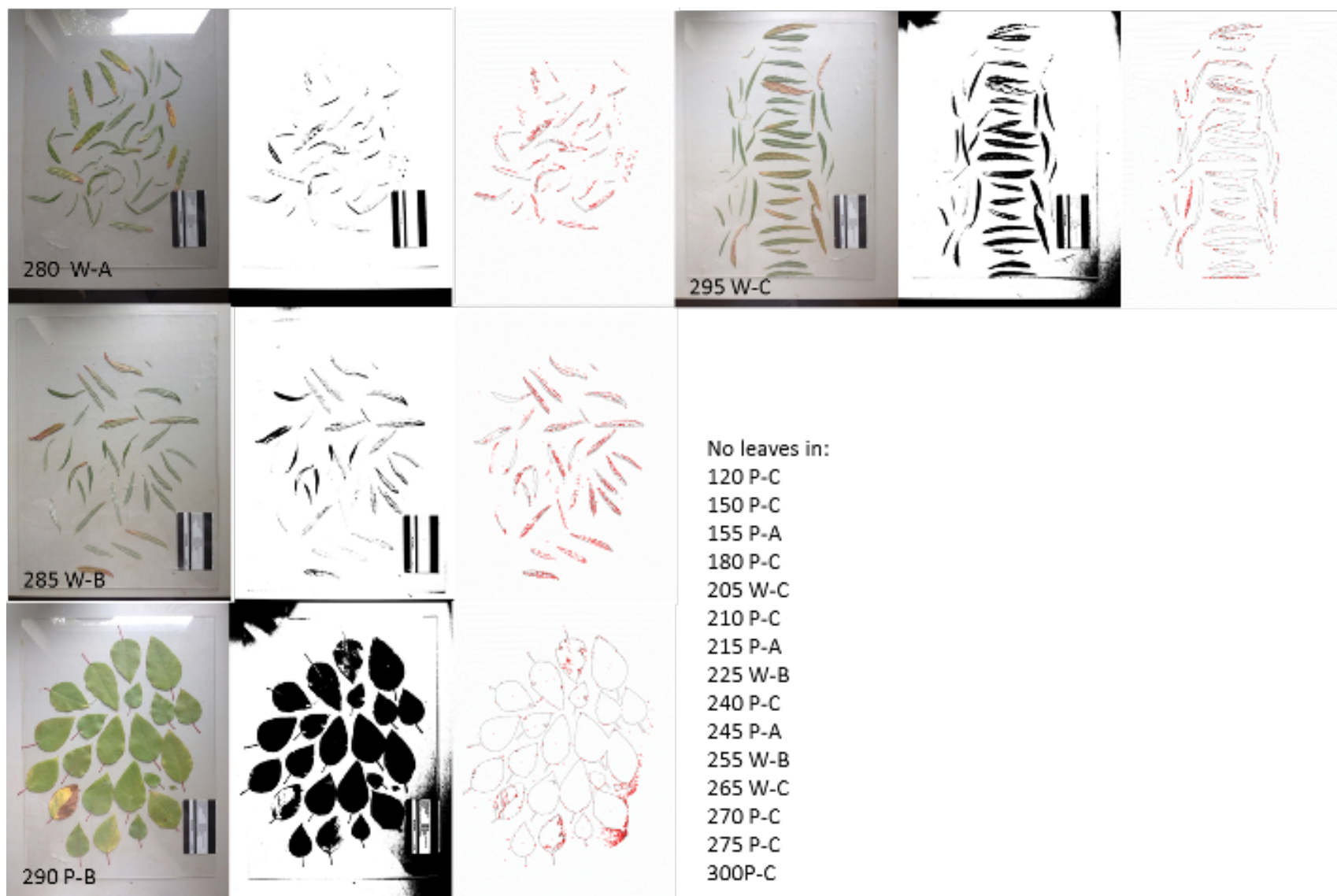
135 W-B











Appendix M Designed monitoring programme

It is important in any monitoring programme to capture the variability of the measured variable. For this purpose, replicates must be taken whenever possible. In the current case study, replication of soil samples within vegetation communities was difficult because it was yet unknown which communities were to develop and where. Therefore, if this is the case replication can only be obtained by maximising the number of samples. For water quality, replication is often not possible as conditions change quickly over time and potential replicates will never be independent - when collected at the same location and river flow it cannot be treated as an independent medium. The Environment Agency collects one sample point every 5 km of river (General Quality Assessment (GQA)) (Cranfield University, 2011). For vegetation and soil, it was envisaged to obtain high number of replicates by having a large number of samples that guarantees a minimum number of records within each vegetation community. The requirement for spatially collocated data means that for the case study of the floodplain forest, soil samples should be taken at each location where vegetation was sampled using quadrats. Water table records should be collected at several locations across the floodplain forest, but no replication was required, as one cannot assume water samples to be independent in space and time.

Note that on some occasions the target sampling locations may not be accessible depending upon site conditions. This could have an impact on the replicability of records as data may not be spatially collocated. For example, if data loggers that register water table were installed and then there was a flood event and they were under water, records will be downloaded when the flooding ceases. It is also suggested to change location of loggers if the problem repeats often. Yet, to distribute variables within each stratum to maximise the spatial coverage; each dipwell measuring the water table should be associated with the soil and vegetation sampling points within close proximity. Locations of sampling points can be identified using a GPS on site and positional markers.

Pacing out can be used to identify sampling locations (e.g. trees, scrub, elevation feature etc.) when in field during the first sampling campaign.

The research approach could include determination of erosion and deposition patterns estimated using an UAV or standard aerial photography. Aerial images obtained after overflying the floodplain could potentially help to identify erosion and deposition processes in the floodplain over time. This in turn can help to identify if new habitats communities have been created through photographic comparison over time.

Monitoring frequency

The frequency of the monitoring programme should be determined by the rate of change of each of the variables. One cannot expect soil to be monitored as frequently as vegetation or water table level variations as the speed of their response to floodplain processes are not comparable. It is suggested to carry out soil analysis at the start of a project so that baseline values are known (i.e. Nitrogen, Phosphorus and Potassium) with subsequent tests being carried out at intervals of 5-10 years, as values are unlikely to change rapidly. Within this project, it was suggested to monitor soil properties every 4-6 months (Table 1), as it was expected soil properties would change due to land movements during on-going quarry works. Once gravel extraction finished, a longer period of time could be set between soil sampling. Table 1 below shows a proposed Gantt chart with the frequency of the initial monitoring programme designed per category and per year.

Table-1. Proposed Gantt chart showing frequency of monitoring programme per key variable during a year

J	F	M	A	M	J	J	A	S	O	N	D	
*												Vegetation
												Soil
												Water quality
												Water table level

(*) Topography measurement taken yearly by using UAV.

Collection of data in the same places over the years will enable an analysis of fine-scale changes. Yet, in the floodplain forest the interest was in determining the success of species being established as much as changes in the community structure. Thus, finer time intervals were required for this purpose. It is advised to sample quadrats every 3 months (Table 1) for vegetation measurement. Vegetation sampling through remote sensing techniques if applicable (either with the UAV or from standard aerial photos) requires less frequent sampling intervals. A period of 5-year interval is suggested to be the adequate monitoring frequency to detect changes in vegetation using remote sensing techniques. For the scope of this project, remote sensing analysis for sampling topography is suggested every year during the duration of the quarry works and then afterwards. It is suggested to record manual water table levels and water quality on a monthly interval for the duration of the project (Table 1) as the Environment Agency considers as adequate the collection of 12 samples per year (Cranfield University, 2011).

Suggested field methods

This section presents the proposed field methods suggested for the designed monitoring programme. The field methods used would be subject to variability depending on external conditions (i.e. material available, equipment, budget, weather conditions etc.).

Soil

Different type of auger will be used depending on the land cover characteristics. If there is not any information available regarding soil, it is suggested to use a hand trowel to take several surface samples and make a composite sample that will be representative of the soil at the site. To avoid contamination between soil samples, it is suggested to clean the trowel between samplings. Soil particle distribution, Soil texture and structure, Soil Organic Carbon, dry matter and water content, and nutrients available for plants (Total Nitrogen, Magnesium, Potassium and Phosphorus) can be analysed.

Burgess *et al.* (2009) suggested in terms of taking soil samples for nitrogen analysis, that soil is often sampled at three depths (0-30, 30-60 and 60-90 cm) and because the soil nitrogen content can change rapidly, it is important that samples should be refrigerated immediately after sampling and the analysis should also be undertaken as soon as possible.

Vegetation

A quadrat frame is suggested to sample vegetation. The quadrat will define the sampling area. The following example parameters will be derived from sampling vegetation to characterise the abundance of species and to assess success of the restoration (Table 2). These are: density, frequency, cover, and dead/alive individual per target specie. The main purpose is to identify the habitat communities that are present in the floodplain forest and their interaction with the water table level of the floodplain forest.

Table-2. Example of quantitative characters' vegetation data collection

Vegetation categories	Density	Frequency	Cover	Dead/alive species
Reedbeds				
Aquatic sp.				
Grassland 1				
Grassland 2				
Grassland 3				
Woodland				

Aerial photography collected either with standard methods or using an UAV can be used in combination with the fixed transects to provide additional information of the vegetation communities at different scales within the floodplain forest. Note that flights need to be run over the same area where the fixed quadrats of vegetation have been collected (i.e. sampling points) to compare different outputs of the same variables by using different techniques over the same area.

Water Quality

It is suggested to collect water quality samples in channels, water bodies and along the main river (i.e. those areas where the river changes or splits). A multi-probe can be used at the site and samples will be stored in individual bottles. It is recommended to measure: Total Oxides of Nitrogen (TON) (mg/l of suspended material), Conductivity (μ S), pH, Phosphorus (μ g/l), Total Suspended Solids (TSS) (mg/l of suspended material), Phosphate-P (mg P/l) and Ammonium (mg N/l).

Water table level

It is suggested to gather water table automatically and manually. Manual measurements can be used to validate the automatic measurements (i.e. both

measurements will have to coincide in date and time with the automatic measurements). A manual dipper is used to take manual measurements. Loggers or divers are used to take the automatic measurements. It is very important to calibrate the loggers before going to the field and make sure they are working properly and run a maintenance test (i.e. check storage capacity, voltage etc.). It is advised to gather coordinates with a GPS or Leica station so sampling points could be located.

Topography

Digital Mapping have a proven track record utilising Unmanned Aerial Vehicles (UAVs) to collect and produce high quality, accurate ortho-photos and digital elevation data. UAVs consist of a remotely controlled model helicopter/aircraft with an attached camera that is able to overfly an area to get accurate pictures in real time. The resolution depends on the camera attached to the device (2-4 cm approximately). UAVs obtain more accurate aerial images under stable weather conditions: clear days, with no wind and no rain and early morning to avoid disturbance (i.e. people curiosity, walking dogs, kids playing etc.). UAV surveys use high accuracy GPS to add control points on the ground to create accuracies on all data to < 10 cm approximately (i.e. depending on the equipment). A good example is found in Woodget *et al.* (2015), where they quantified both exposed and submerged fluvial topography (i.e. associated bedforms) at the mesohabitat scale of two rivers by using images obtained with a rotary-winged Unmanned Aerial System (UAS) (i.e. Draganflyer X6). It is envisaged that frequently collected aerial images of the riverbanks and habitat communities will show changes over time. Images gathered with UAVs will help to understand the spatio-temporal dynamics of the floodplain forest through the analysis of the changes. This in turn can inform stakeholders about management decisions (i.e. where it is advisable to plant and where not, potential public footpath passages, birds' observatory etc.)

Complementing quadrats with UAV to measure vegetation is proposed. This device can overfly the floodplain forest to map vegetation communities (i.e.

emerging habitats). UAV operates better when following straight lines (Andrew Blogg, www.futureaerial.com, personal communication, December, 2014). This will enable comparison of different techniques for vegetation sampling (i.e. fixed quadrats vs. remote sensing techniques). It is suggested to overfly the floodplain forest following transects to capture all vegetation mosaics present.

Further UAV surveys are recommended in the future as vegetation patterns can be directly associated to habitat mosaics. Some advantages of using UAV are that data processing could take around 1-2 days and data could be interpreted in less than a week. The expected imagery resolution usually is quite good (4 cm approx. depending on camera used) and the obtained imagery resolution (after processing) is normally 8 cm per pixel. Some limitations found are that UAV training is required and the high cost associated per fly could reach more than several hundred pounds per day. The option of using the UAV to overfly the area needs to be considered in terms practical and financial constraints. The assessment made after post-processing information will depend on surveyor's interpretation. Battery time per flight is limited to height and camera specifications (currently in the order of several minutes) and severe weather conditions (QuestUAV, personal communication, December, 2014). Figure 1 shows proposed location of key variables sampling points and sampling zones in the floodplain forest.

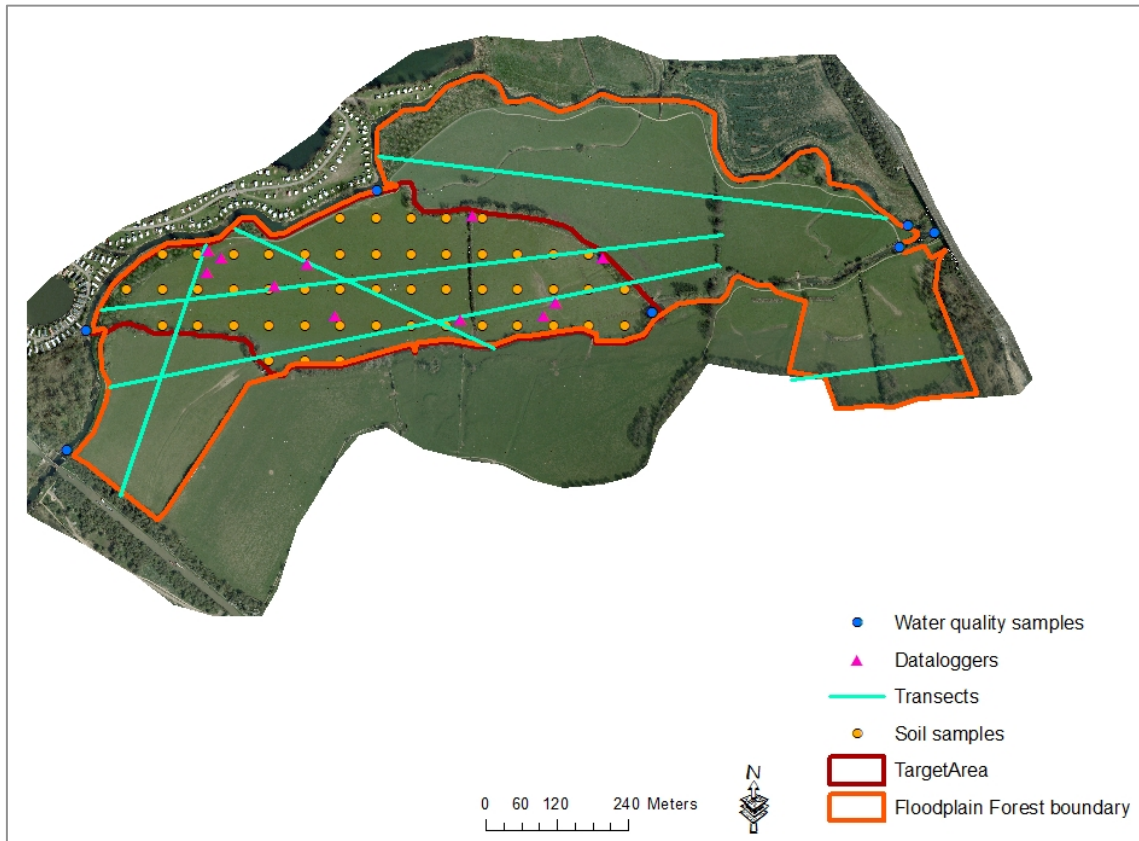


Figure 1-Proposed location of key variables sampling points and sampling zones in the floodplain forest and proposed set of transects to be collected using an UAV.

Data analysis

Data collected from site surveys are advised to be input into a database for consultation at any time of the project and for comparisons. It is recommended to collect data in the same locations over time. This will display an overall view of the data gathered and will help to analyse the changes over time.

It may be possible that the implementation of a factorial ANOVA is not practical due to a lack of records available (i.e. field conditions not allowing for an orthogonal experimental design). Similarly, it may be possible that the thresholds between strata are wrongly placed. A complementary analysis (classification tree technique) is suggested to determine the ranges of elevation and water table levels characteristic of each species. Decision Tree Classifiers

(DTCs) are applied to diverse fields (e.g. remote sensing). They have the capability to break down a complex-decision making process into a collection of simpler decisions, thus providing a solution that is often easier to interpret (Chourasia, 2013).

A set of key questions can be proposed as part of the initial monitoring programme designed. This will allow a comparison between answers of different sets of data gathered over time and to assess if change and interaction between variables have contributed to a successful restoration project. The interaction between key variables will provide the evidence of how changes in some key variables (e.g. water table) affect to others (e.g. vegetation patterns and habitat communities).

Figure 2 below proposed a radar diagram approach to assess the resulting change in key variables over time. The radar graphic representation is useful when considering the complex nature of ecosystem change and has been identified as improving clarity in research outputs to stakeholders (Gomiero and Giampietro, 2005). The key variables proposed in the radar diagram as an example were: soil, vegetation, hydrological regime, water quality, biodiversity and aesthetic contribution (i.e. ecosystem services). Each edge of the radar diagram represents a key variable and could be modified accordingly depending on the restoration case study. The larger the differences in the radar diagram, the bigger the change observed at the restored site for that period of sampling collection. With this approach is expected a different radar diagram per fieldwork. In contrast, if key variables sampled present little differences than past fieldworks then a radar diagram with similar shapes over time is expected (i.e. overlap between the red and blue lines in Figure 2).

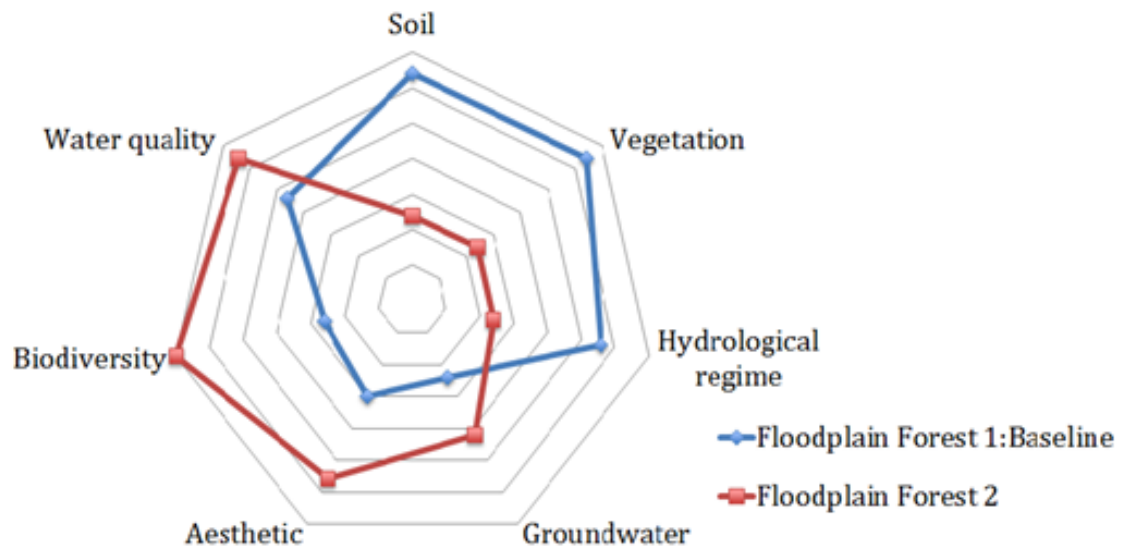


Figure 2. Proposed radar diagram example showing the distribution of the key variables values per fieldwork. Blue line corresponds to the key variables sampled in the first fieldwork (baseline) of the floodplain forest. Red line corresponds to those obtained for the second fieldwork of the floodplain forest

It is expected that restored ecosystems undergo a transition period right after restoration quarry works and evolve until they reach a dynamic equilibrium. Figure-3 shows an idealised view of the behaviour of a key variable after restoration. This will translate into changes in the radar diagram; during the initial sampling campaigns oscillations in the shape of the diagram will be more evident than at later stages when the equilibrium is being reached. Over time, key variables are expected to reach a lower variation until reaching the dynamic equilibrium. The nature of floodplain forests requires a dynamic understanding of the concept of equilibrium where variations in the functioning of the ecosystem are to be expected (Figure 3).

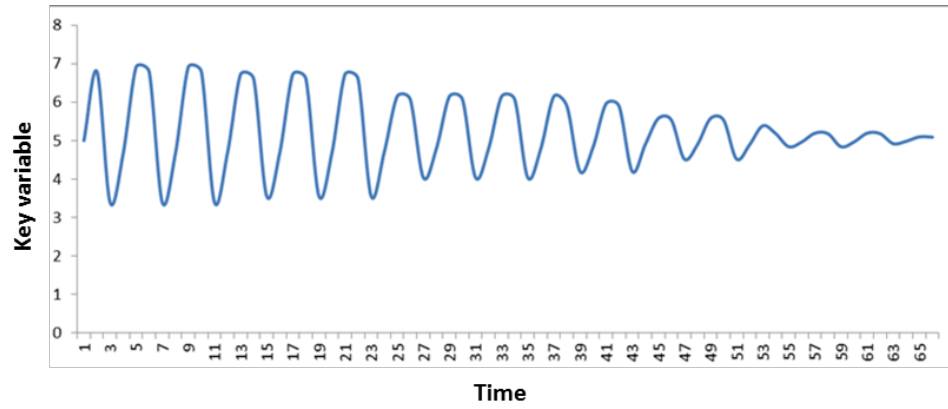


Figure 3. Proposed conceptual model showing the oscillations of a key variable in the floodplain forest over time

