Land use planning in urban areas – towards an ecosystems approach

Volume 1: Main Thesis

Peter M. Phillips

A thesis presented in fulfillment of the requirements for the degree of Doctor of Philosophy

The University of Strathclyde
Department of Civil and Environmental Engineering

2014

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed:

Date:

Acknowledgments

First and foremost, huge thanks to my supervisor Dr Elsa João for her support, guidance, encouragement and friendship throughout the whole process. I look forward to collaborating with her on many future projects. Thanks to my second supervisor Dr Richard Lord for his insightful comments and feedback on drafts.

Thanks also to Professor Zoe Shipton for encouraging me to progress from MPhil to PhD and for support accessing funding. In this regard, thanks are also due to the University of Strathclyde Department of Civil and Environmental Engineering for the financial support that made this project possible.

Important aspects of this research were undertaken in collaboration with Glasgow City Council (GCC) and thanks are due to many people who gave their time and input. Access to data and systems and peoples' various comments and insights were invaluable. Particular thanks are due to Chris Dalrymple, Heather Claridge, Cathy Johnston and David Hay.

My parents John and Clare Phillips deserve special thanks for their continued love and support, without which the completion of this thesis would have been much harder. Big thanks are also due to various other family members and my friends for their support and patience.

My colleagues at Collingwood Environmental Planning also deserve special thanks for their support during the latter stages of the project, invaluable technical insights, inspiration and comments on drafts. Particular thanks are due to Dr Bill Sheate, Jonathan Baker and Ric Eales.

A number of other people have played an invaluable role in the completion of this thesis, in particular: Phil Baarda, Ally Corbett, Trish McGregor, Dr Anna McLauchlan and Rolf Roscher.

Finally, extra special thanks are due to my wonderful wife to be Sarah Robinson for her continued love, support and incredible patience. Without a doubt she is the one person that made this thesis possible.

Abstract

Urbanisation – the demographic transition from rural to urban – can pose challenges for urban areas by increasing pressure on urban ecosystem services. In meeting these challenges, urban planning and design is increasingly looking towards techniques that work *with* rather than *against* nature. Despite this, the impact of urban land use/management on urban ecosystem services is currently little understood and urban land use planning stakeholders have limited means by which to assess the impacts of their decisions on urban ecosystem services. The overarching aim of this thesis therefore is to understand, develop, trial and evaluate new approaches to urban planning that can operationalise key aspects of the ecosystems approach.

The interdisciplinary research approach adopted had three main stages: 1) review, assessment and synthesis of technical evidence to inform the development of principles and technical guidance for ecosystems approach based urban land use planning; 2) development and trialling of new tools, models and guidance for considering ecosystem services in urban planning; and 3) evaluation of new tools, models and guidance. The research methods used are document review, rapid evidence assessment (REA), action research and semi-structured interviews. Geographic information system (GIS) technology has been used to integrate qualitative data from the evidence assessment with existing spatial datasets to develop new spatial models for urban land use planning.

This thesis has demonstrated how existing technical principles and theories from discrete natural science and social science disciplines (e.g. planning, landscape ecology and hydrology) can be combined with existing spatial datasets to produce tools, models and guidance for ecosystems approach based urban land use planning. In this regard, a new approach to urban planning has been developed comprising the following elements: 1) a suite of ecosystems approach guiding principles; 2) three new spatial models to prioritise land use/management intervention for specific urban ecosystem services; and 3) supporting technical guidance.

Table of contents

Acknowledgments iii

Abstract iv

List of appendices viii

List of tables x

List of figures xii

List of boxes xvi

List of abbreviations xvii

1. Introduction 1
  - 1.1 The problem of urbanisation 2
  - 1.2 Ecosystem services and the ecosystems approach 7
  - 1.3 Urban planning – an integrating framework to help solve urbanisation problems 13
  - 1.4 Aims, objectives and structure of the thesis 15

2. Methodology 20
  - 2.1 Research design and theoretical framework 21
    - *2.1.1 Research design 22*
    - *2.1.2 Description of the theoretical framework adopted in this research 25*
    - *2.1.3 The rationale for an interdisciplinary research approach 27*
    - *2.1.4 Choosing a pilot urban centre 28*
  - 2.2 Description of the research process 29
    - *2.2.1 Overall approach – grounded theory 29*
    - *2.2.2 Review key policy and literature and scope the research 30*
    - *2.2.3 Initial review and assessment of technical literature 31*
    - *2.2.4 Review and evaluation of existing approaches 32*
    - *2.2.5 Initial development of spatial models 33*
    - *2.2.6 Piloting of spatial models 34*
    - *2.2.7 Follow-up review and assessment of technical literature 35*
    - *2.2.8 Validate key findings through expert interviews 35*
    - *2.2.9 Refine spatial models 35*
    - *2.2.10 Develop ecosystems approach principles and technical guidance 36*
    - *2.2.11 Evaluate new theories and approaches 36*
  - 2.3 Data collection methods 37
    - *2.3.1 Document review 37*
    - *2.3.2 Rapid evidence assessment 41*
    - *2.3.3 Action research 45*
    - *2.3.4 Semi-structured interviews 47*

2.4 Data analysis methods 49
2.4.1 Analysis of qualitative data 49
2.4.2 Integrating qualitative data with existing spatial datasets in ArcGIS 51
3. Urban land use planning and the ecosystems approach 56
3.1 Urban land use planning – frameworks and opportunities in Scotland 57
3.1.1 The land use planning system in Scotland 58
3.1.2 The LDP-development process 63
3.1.3 Urban land use, openspace and green infrastructure 67
3.1.4 Getting the best from our land – Scotland's land use strategy 73
3.2 Ecosystems, ecosystem services and the ecosystems approach 76
3.2.1 Ecosystems and environmental limits 77
3.2.2 Ecosystem services – a generic typology 83
3.2.3 Ecosystem services and their potential role in decision-making 87
3.2.4 Key principles of the ecosystems approach 90
3.2.5 Prioritising ecosystem services for consideration in this thesis 95
4. Urban land use planning and water management 99
4.1 Urbanisation, drainage, climate change and flooding 101
4.2 A catchment based approach to sustainable flood risk management 105
4.3 Flood risk assessment (FRA) – the fundamentals 108
4.4 Key principles of hydraulics for urban land use planning and water management 112
4.5 River restoration 116
4.5.1 Problems caused by river modification 117
4.5.2 Key morphology pressures affecting small urban watercourses 118
4.5.3 River modification and ecosystem services 120
4.6 Floodplain/riparian zone woodland planting and restoration 122
4.6.1 The hydrological and hydraulic properties of trees and woodland 123
4.6.2 Constraints and opportunities for floodplain woodland planting in urban areas 125
4.6.3 Strengths and weaknesses of floodplain woodland for FRM 126
4.7 Land use/management measures for reducing runoff at source 131
4.7.1 The hydrological cycle and its relationship with land use/management 132
4.7.2 Land use/management based measures for reducing runoff at source 134
4.7.3 SuDS measures for reducing runoff at source and providing storm water storage 141
5. Urban land use planning, landscape ecology and habitat networks 149
5.1 The key principles of landscape ecology 150
5.1.1 Landscape and landscape scale 152
5.1.2 Measurement and evaluation of landscape function 154

5.2 Habitat networks and habitat network modelling 155

5.2.1 Habitat networks – structural and functional connectivity 155

5.2.2 Habitat network modelling and data 157

5.3 The multiple benefits of urban habitat networks 162

6. Evaluating existing examples of ecosystems approach based land use planning frameworks – strengths, weaknesses and lessons for wider practice 167

6.1 THESAURUS ecosystem services assessment and mapping project 169

6.1.1 Evaluation of the THESAURUS approach 169

6.1.2 The THESAURUS approach – key innovations... 172

6.2 EERA environmental limits mapping project 178

6.2.1 Evaluation of the EERA approach... 179

6.2.2 The EERA approach – key innovations 182

6.3 Glasgow and Clyde Valley (GCV) green network opportunities mapping....................... 186

6.3.1 Evaluation of the green network opportunities mapping approach 188

6.3.2 The green network opportunities mapping approach – key innovations...................... 191

6.4 Synthesis of key findings from the example approaches 196

6.4.1 Have the example approaches considered the CDB ecosystems approach principles? 197

6.4.2 What types of method/approach have been used? 201

6.4.3 What are the main strengths and weaknesses of the example approaches?................ 205

7. Developing new spatial models for urban planning: how do we know where urban ecosystem services are required? 209

7.1 Overall approach to the new spatial models for urban planning...................................... 210

7.2 The flood control model – where are flood storage services required? 212

7.2.1 Step 1 – is the catchment subject to significant flood risk? 215

7.2.2 Step 2 – what is the distribution of flood risk areas across the catchment?................ 216

7.2.3 Step 3 – are there significant areas of openspace within the floodplain? 217

7.2.4 Step 4 – is the watercourse subject to morphology pressures? 220

7.2.5 Step 5 – is there potential for significant areas of floodplain woodland and wetland? 225

7.2.6 Step 6 – identify sites where opportunities are greatest and constraints minimal........ 230

7.2.7 Step 7 – topographical analysis to identify further constraints/viability of measures.. 240

7.2.8 Step 8 – scenario development 244

7.3 The hydrological cycle model – where are runoff reduction services required? 250

7.3.1 Hydrological cycle model stage 1 – slope analysis 254

7.3.2 Hydrological cycle model stage 2 – catchment analysis 260

7.3.3 Hydrological cycle model stage 3 – integration analysis.. 266

7.4 The habitat network model – where are ecological connectivity services required? 270

7.4.1 Habitat network model Stage 1 – analysis of ecological potential.............................. 273

7.4.2 Habitat network model Stage 2 – identify prime sites 276

8. Integrating spatial models: how do we know where multiple urban ecosystem services are required?... 281

8.1 Introduction to the new ecosystems approach guiding principles and technical guidance 282

8.1.1 Analysis approach 282

8.1.2 Structure of the new guiding principles and technical guidance................................. 283

8.2 Combined use of the new spatial models and technical guidance to inform the development of integrated urban land use/management strategies 286

8.2.1 Identifying priority areas for multifunctional land use 286

8.2.2 Combined use of new spatial models/technical guidance: worked example 288

8.3 Integrating model outputs with the Local Development Plan (LDP) process.................. 291

9. Conclusions and recommendations.. 296

9.1 Methodology evaluation 297

9.2 Summary of key findings... 297

9.2.1 Land use planning in urban areas – towards an ecosystems approach 298

9.2.2 Important ecosystem services for northern European urban centres........................... 302

9.2.3 The impact of urban land use/management on urban ecosystem services 302

9.2.4 Lessons from existing ecosystems approach based urban planning frameworks......... 304

9.3 Recommendations for future research 305

9.3.1 The need for a proof of concept study 306

9.3.2 The need for better data 306

9.3.3 Enhancing the scope of the new approaches.. 307

9.4 Recommendations for future practice... 308

9.4.1 Recommendations for urban land use planning stakeholders of general applicability internationally/in northern Europe 309

9.4.2 Recommendations for urban land use planning stakeholders in Scotland 309

References.. 311

List of appendices

Appendix 1 Literature map

Appendix 2 Interview schedule and data from expert interviews

Appendix 3 A new suite of guiding principles for ecosystems approach based urban land use planning

Appendix 4 Guidance for interpreting and acting on flood control model outputs in the development of integrated urban land use/management strategies

Appendix 5 Guidance for interpreting and acting on hydrological cycle model outputs

in the development of integrated urban land use/management strategies
Appendix 6 Guidance for interpreting and acting on habitat network model outputs in the development of integrated urban land use/management strategies
Appendix 7 Evaluation of existing ecosystems approach based land use planning frameworks
Appendix 8 Flood control model step-by-step instructions and example outputs
Appendix 9 Hydrological cycle model step-by-step instructions and example outputs
Appendix 10 Habitat network model step-by-step instructions and example outputs
Appendix 11 Evaluation of new ecosystems approach based land use planning framework developed through this research
Appendix 12 Example application of the new approaches in the Glasgow 2014 Multifunctional Greenspace Project (MGP)

List of tables

Table 2.1 Research process summary 29
Table 2.2 Documents considered in the Step 1 document review 39
Table 2.3 Evaluation criteria for the Step 3 document review 40
Table 2.4 Data collation protocol for Step 3 document review 41
Table 2.5 Research questions addressed in the Rapid Evidence Assessment (REA) 42
Table 2.6 Literature interrogation and data collation protocol for Steps 2 and 6 43
Table 2.7 Interview protocol for Step 7 47
Table 2.8 Step 7 expert interviews – interviewee expertise 48
Table 2.9 Causal variables and spatial datasets used in the new spatial models 52
Table 3.1 Types of development plan in the Scottish planning system 59
Table 3.2 Details of the Scottish Government planning series 60
Table 3.3 Statutory provisions for inclusion in LDP Main Issues Reports (MIR) 66
Table 3.4 PAN65 openspace typology 70
Table 3.5 Scotland’s Land Use Strategy – principles for sustainable land use 75
Table 3.6 General applications/benefits of ecosystem services for decision-making 89
Table 3.7 Ecosystems approach considerations in key EU, UK and Scottish policy 92
Table 3.8 International, UK and Scottish principles for the ecosystems approach 94
Table 4.1 Natural drainage processes 103
Table 4.2 Scotland’s guidance on sustainable Flood Risk Management (FRM) – key outcomes and links with urban land use/management planning 106
Table 4.3 Definitions of pluvial and fluvial flooding 108
Table 4.4 Scottish Planning Policy (SPP) three tiered risk framework for flooding 111
Table 4.5 Key pressures on the morphology of river watercourses 117
Table 4.6 Potential relationships between natural drainage processes and land use/management 136
Table 4.7 PAN65 openspace typology ordered by potential hydraulic roughness 138
Table 4.8 Key SuDS components – advantages/disadvantages and FRM performance 145
Table 5.1 Broad habitat types and sub-categories as defined in the UK National Ecosystem Assessment (UKNEA) and UK Biodiversity Action Plan (UKBAP) 165
Table 5.2 Relationship between broad habitats and ecosystem services 166
Table 6.1 THESAURUS – causal variables and data sources for key ecosystem services . 176
Table 6.2 Glasgow and Clyde Valley (GCV) green network components 187
Table 6.3 Green network opportunities mapping – spatial queries, layers and datasets 191
Table 6.4 Evaluation of case study ecosystems approach based land use planning frameworks – qualitative summary 202
Table 6.5 Summary of the main strengths and weaknesses of example ecosystems approach based land use planning frameworks 206
Table 7.1 Ecosystem services/causal variables considered in the spatial models 211
Table 7.2 Flood control model – description of key stages 214
Table 7.3 Where are individual NFM measures considered in the flood control model?.... 215
Table 7.4 Flood control model Step 3 – schedule of model outputs 220
Table 7.5 Flood control model Step 4 – schedule of model outputs 225
Table 7.6 Flood control model Step 5, Task 5.3 – example model output 228
Table 7.7 Flood control model Step 5 – schedule of model outputs 229

Table 7.8 Flood control model Step 6, Tasks 6.2 and 6.3 - example schedules of potential natural flood management (NFM) measures 235
Table 7.9 Flood control model Step 6, Task 6.4 – natural flood management (NFM) measures considered in multi criteria analysis (MCA) evaluation 237
Table 7.10 Flood control model Step 7, Task 7.3 – example model output 243
Table 7.11 Categorisation of potential gradient constraint on floodplain NFM measures .. 244
Table 7.12 Hydrological cycle model – summary description of key stages....................... 252
Table 7.13 Habitat network model – summary description of key stages 272
Table 8.1 Extract from the new set of guiding principles for ecosystems approach based urban land use planning 285
Table 8.2 Example schedule of objectives and relevant technical guidance for a scoped-in multifunctional priority area (MPA) 290
Table 8.3 Expert interview Question 4.7 results – other than LDP policy, what other key mechanisms are there for delivering natural environment and ecosystem service enhancements through urban land use planning/management? 294

List of figures

Figure 1.1 Extent and location of urban areas in Europe in 2010 3
Figure 1.2 Trends in urban population by major geographical region as a percentage of total population 4
Figure 1.3 The Millennium Ecosystem Assessment (MEA) ecosystem service typology showing linkages between services and human wellbeing 9
Figure 1.4 Trends in ecosystem service flows from UK broad habitats since 1990 11
Figure 1.5 Geographical location of Glasgow in Europe 17
Figure 2.1 The theoretical framework and sub-theories adopted in this research 27
Figure 2.2 Schematic summary of the research process 31
Figure 2.3 Overall action research approach in the testing of spatial models – Step 5 46
Figure 2.4 Initial codes allocated during data collection at Steps 2, 3 and 6 50
Figure 2.5 Analysis approach – integrating qualitative data with existing spatial datasets in ArcGIS 54
Figure 3.1 Expert interview Question 4.4 results – to your mind, what are the five most important land use delivery mechanisms for integrating the natural environment and ecosystem services into urban planning? 61
Figure 3.2 The statutory Local Development Plan (LDP) development process and integration with strategic environmental assessment (SEA) 63
Figure 3.3 Example LDP spatial strategy – an extract from the Perth and Kinross LDP Proposed Plan showing land use in Perth 69
Figure 3.4 The role green infrastructure at different scales 72
Figure 3.5 Green infrastructure planning/design at different scales 73
Figure 3.6 Overall conceptual framework adopted in the UKNEA 78
Figure 3.7 Identification of limits and thresholds in natural systems 81
Figure 3.8 Ecosystem processes, services, goods and values used in the UK National Ecosystem Assessment (UKNEA) 85
Figure 3.9 Forest ecosystem services and management for specific goods 86
Figure 3.10 Expert interview Question 3.5 results – which services from the following list do you think the urban natural environment provides? 96
Figure 3.11 Expert interview Question 3.6 results – of the services you have identified, which three do you consider to be most important? 97
Figure 4.1 Predicted change in winter mean precipitation rate (%) in Scotland under high a emissions scenario by the 2080s 102
Figure 4.2 Relationship between likelihood, consequences and risk of flooding 103
Figure 4.3 A catchment based approach to sustainable flood risk management 104
Figure 4.4 Flood extent for Tollcross Burn – short return period rainfall event 109
Figure 4.5 Flood extent for Tollcross Burn – long return period rainfall event 110
Figure 4.6 Potential hydraulic influences of riparian vegetation during overbank flows 115
Figure 4.7 Section through a formerly culverted stretch of watercourse showing restored channel and floodplain – low flows 118
Figure 4.8 Section through a formerly culverted stretch of watercourse showing restored channel and floodplain – high flows 120
Figure 4.9 Impact of tree species choice and management on floodplain hydraulics 124

Figure 4.10 Literature examples of floodplain woodland impact on flood storage – flood extent and depth at Ings Bridge (base case) 128
Figure 4.11 Literature examples of floodplain woodland impact on flood storage – flood extent and depth at Ings Bridge (with woodland planting) 129
Figure 4.12 Literature examples of floodplain woodland impact on flood storage – impact of woodland planting on flood depth at Ings Bridge 129
Figure 4.13 Literature examples of floodplain woodland impact on flood storage – impact of woodland planting on flood flow velocity at Ings Bridge 130
Figure 4.14 Drainage processes in natural catchments and urban catchments 133
Figure 4.15 Managing PAN65 sites for hydraulic benefits 141
Figure 4.16 The SuDS triangle 142
Figure 4.17 The SuDS management train 143
Figure 5.1 Defining an urban landscape in terms of its structural elements 153
Figure 5.2 Contrast between structural and functional connectivity of habitat patches 156
Figure 5.3 Modelling functional connectivity in habitat networks 157
Figure 5.4 Illustration of the principle of least-cost habitat network modelling 159
Figure 5.5 Influence of dispersal ability on functional connectivity of habitat networks 160
Figure 6.1 THESAURUS – summary of evaluation against Convention on Biological Diversity (CBD) ecosystems approach principles 170
Figure 6.2 THESAURUS – overview of methodological approach 172
Figure 6.3 THESAURUS – flood regulation/storage ecosystem service map 175
Figure 6.4 EERA – summary of evaluation against Convention on Biological Diversity (CBD) ecosystems approach principles 181
Figure 6.5 EERA environmental capacity project – land based flora and fauna environmental limits map 183
Figure 6.6 EERA environmental capacity project – composite environmental limits map . 184
Figure 6.7 Green network opportunities – summary of evaluation against Convention on Biological Diversity (CBD) ecosystems approach principles 189
Figure 6.8 Green network opportunities – methodology schematic 193
Figure 6.9 Extract from green network opportunities map raster overlay 194
Figure 6.10 Degree to which CBD ecosystems approach principles have been considered – percentage of instances across all case studies 197
Figure 6.11 Degree to which individual case studies have considered the CBD ecosystems approach principles 198
Figure 6.12 Degree to which individual CBD ecosystems approach principles have been considered – number of instances across the three case studies 199
Figure 7.1 Overall structure of the flood control model 213
Figure 7.2 Flood control model Step 1, Tasks 1.1 and 1.2 – example model output 216
Figure 7.3 Flood control model Step 3 – example model output 218
Figure 7.4 Flood control model Step 4, Task 4.1 – example model output 222
Figure 7.5 Flood control model Step 4, Task 4.2 – example model output 223
Figure 7.6 Flood control model Step 4, Task 4.3 – example model output 224
Figure 7.7 Flood control model Step 5, Task 5.2 habitat patches and habitat networks in the floodplain – example model output 226

Figure 7.8 Flood control model Step 5, Task 5.2 floodplain woodland opportunity areas – example model output 227
Figure 7.9 Flood control model Step 6, Task 6.1 – example model output 232
Figure 7.10 Flood control model Step 6, Task 6.2 – example model output 234
Figure 7.11 Flood control model Step 6, Task 6.4 – example multi criteria analysis (MCA): low cost site/weighting scenario 1 238
Figure 7.12 Flood control model Step 6, Task 6.4 – example multi criteria analysis (MCA): low cost site/weighting scenario 2 239
Figure 7.13 Flood control model Step 7, Task 7.1 – example model output 241
Figure 7.14 Flood control model Step 8, Task 8.3 – example model output 248
Figure 7.15 Flood control model Step 8, Task 8.6 – typical model output 249
Figure 7.16 Overall structure of the hydrological cycle model... 251
Figure 7.17 Hydrological cycle model – Stage 1 geoprocessing operations (Steps 1 – 8) .. 254
Figure 7.18 Hydrological cycle model Steps 2 and 3 – example outputs 255
Figure 7.19 Hydrological cycle model Steps 4 and 5 – example outputs 257
Figure 7.20 Hydrological cycle model Steps 6 and 7 – example outputs 258
Figure 7.21 Hydrological cycle model Step 8 – example outputs 259
Figure 7.22 Hydrological cycle model – Stage 2 geoprocessing operations (Steps 9 – 15) 261
Figure 7.23 Hydrological cycle model Steps 10 and 11 – example outputs 262
Figure 7.24 Hydrological cycle model Steps 12 and 15 – example outputs 264
Figure 7.25 Hydrological cycle model – Stage 3 geoprocessing operations (Steps 16 – 21) 267
Figure 7.26 Hydrological cycle model Stage 1 (Step 8) and Stage 3 (step 19) – example outputs.. 268
Figure 7.27 Hydrological cycle model Stage 1 (Step 8) and Stage 3 (step 17) – example outputs.. 269
Figure 7.28 Overall structure of the habitat network model 271
Figure 7.29 Habitat network model – Stage 1 geoprocessing operations 274
Figure 7.30 Habitat network model Stage 1 (Step 2) – example outputs............................ 275
Figure 7.31 Habitat network model Stage 1 (step 3) – example output.............................. 276
Figure 7.32 Habitat network model – Stage 2 geoprocessing operations 277
Figure 7.33 Habitat network model Stage 1 (Step 2) and Stage 2 (step 4) – example outputs 279
Figure 8.1 Overall structure of the new guiding principles and technical guidance for ecosystems approach based urban land use planning 284
Figure 8.2 Integrating individual spatial model outputs to identify priority areas for multifunctional land use – schematic representation of GIS overlay process...................... 287
Figure 8.3 Example overlay of hydrological cycle model and habitat network model outputs showing two potential multifunctional priority areas (MPAs) 288
Figure 8.4 Developing broad-brush land use/management intervention proposals for scoped-in multifunctional priority areas (MPAs)... 289
Figure 8.5 Proposed process for integrating the new tools, models and guidance with the statutory Local Development Plan (LDP) process.. 293

Figure 9.1 Performance of the new approach proposed in this thesis against the Convention on Biological Diversity (CBD) ecosystems approach principles – qualitative comparison with example urban land use planning frameworks evaluated in Chapter 6........................ 299
Figure 9.2 Performance of the new approach proposed in this thesis against the Convention on Biological Diversity (CBD) ecosystems approach principles – quantitative comparison with example urban land use planning frameworks evaluated in Chapter 6........................ 300

List of boxes

Box 1.1 Key findings from the UKNEA 10

Box 1.2 Research objectives 16

List of abbreviations

APA	American Planning Association
BEETLE	Biological and Environmental Evaluation Tools for Landscape Ecology
CAP	Common Agricultural Policy
CBD	Convention on Biological Diversity
CEP	Collingwood Environmental Planning
CIWEM	Chartered Institution of Water and Environmental Management
COP	Conference Of the Parties
CSGN	Central Scotland Green Network
DCLG	Department for Communities and Local Government
DEFRA	Department for Environment Food and Rural Affairs
DEM	Digital Elevation Model
DM	Development Management
EA	Environment Agency
EC	European Commission
EEA	European Environment Agency
EERA	East of England Regional Assembly
EIA	Environmental Impact Assessment
EsA	Ecosystems Approach
EU	European Union
FCS	Forestry Commission Scotland
FEH	Flood Estimation Handbook
FRA	Flood Risk Assessment
FRM	Flood Risk Management
GCC	Glasgow City Council
GCV	Glasgow and Clyde Valley
GCVGNP	Glasgow and Clyde Valley Green Network Partnership
GCVSDP	Glasgow and Clyde Valley Strategic Development Plan
GCVSDPA	Glasgow and Clyde Valley Strategic Development Planning Authority
GCPH	Glasgow Centre for Population Health
GFS	Generic Focal Species
GI	Green Infrastructure
GIS	Geographic Information System
GNOM	Green Network Opportunities Mapping

IALE	International Association for Landscape Ecology
IGI	Integrated Green Infrastructure
IHN	Integrated Habitat Network
KTGG	Kent Thameside Green Grid
LBAP	Local Biodiversity Action Plan
LDF	Local Development Framework
LDP	Local Development Plan
LiDAR	Light Detection and Ranging
LUC	Land Use Consultants
LUS	Land Use Strategy
LWD	Large Woody Debris
MA	Millennium Ecosystem Assessment
MCA	Multi Criteria Analysis
MGSDP	Metropolitan Glasgow Strategic Drainage Partnership
MIR	Main Issues Report
MPA	Multifunctional Priority Area
NFM	Natural Flood Management
NFRA	National Flood Risk Assessment
NPF	National Planning Framework
NPPF	National Planning Policy Framework
OSMM	Ordnance Survey Master Map
PAN	Planning Advice Note
P-GIS	Participatory Geographic Information System
RBMP	River Basin Management Plan
RDP	Rural Development Programme
REA	Rapid Evidence Assessment
RRC	River Restoration Centre
SCCIP	Scottish Climate Change Impacts Partnership
SDP	Strategic Development Plan
SEA	Strategic Environmental Assessment
SEPA	Scottish Environment Protection Agency
SEPM	Spatially Explicit Population Model
SFRA	Strategic Flood Risk Assessment
SNH	Scottish Natural Heritage
SNIFFER	Scotland and Northern Ireland Forum for Environmental Research

SPP	Scottish Planning Policy
SPRI	Source Pathway Receptor Impact
SQL	Structured Query Language
SSSI	Site of Special Scientific Interest
SuDS	Sustainable Drainage Systems
SWT	Scottish Wildlife Trust
TEEB	The Economics of Ecosystems and Biodiversity
THESAURUS	Thames Gateway Ecosystem Services Assessment Using Green Grids and Decision Support Tools for Sustainability
UK	United Kingdom
UKBAP	United Kingdom Biodiversity Action Plan
UKNEA	United Kingdom National Ecosystem Assessment
UKTAG	United Kingdom Technical Advisory Group
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
WFD	Water Framework Directive
WHO	World Health Organisation

1. Introduction

For the first time in history, more than half of the world's population now lives in urban areas, a trend predicted to continue as global population growth is sustained during the 21st century (UN, 2012; WHO, 2013). This process of urbanisation – the demographic transition from rural to urban – creates both challenges and opportunities for urban areas. Urbanisation can result in increased pressure on urban services and systems (EEA, 2010a; Mostafavi, 2010) such as transport, water supply, waste management, protection against natural disasters, education, greenspaces and recreational opportunities. Conversely, urbanisation can drive innovation and economic growth and support increased vitality and cultural diversity (ibid). This thesis explores a specific urbanisation problem concerning the way in which urban land is used and managed for the provision of key land based urban services *or* urban 'ecosystem services' (MA, 2005; Davies et al, 2011; Mace et al, 2011; Scottish Government, 2011c; UKNEA, 2011).

The impact of urban land use/management on urban ecosystem services is currently little understood. Also, urban land use planning stakeholders currently have limited means by which to assess the impact of their decisions on urban ecosystems and the services that they provide. These are the key gaps this thesis addressed.

This Chapter is structured as follows: Section 1.1 defines urbanisation and characterises the urbanisation problem that remains to be tackled. Section 1.2 discusses how the concept of ecosystem services can be a means of framing the urban natural environment as a help rather than a hindrance to sustainable urbanisation. Section 1.3 argues that urban planning could provide a possible framework for operationalising ecosystem services thinking. Finally section 1.4 defines the aims, objectives and purpose of this thesis including an outline of its overall structure.

1.1 The problem of urbanisation

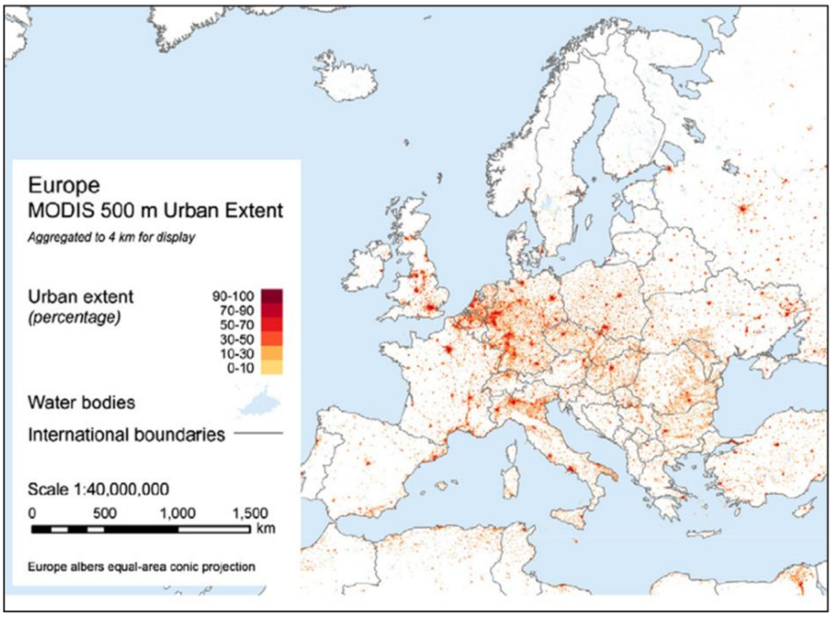
> **urbanisation** / noun: **1** the demographic transition from rural to urban. **2** the social process whereby cities grow and societies become more urban

More than half of the world's population now lives in urban areas – that is, our cities, towns and other settlements (UN, 2012; WHO, 2013). Numerically, this equates to some 3.6 billion people or 52.1% of the world's total population (UN, 2012). This phenomenon is particularly pronounced in the developed world – in North American, European and Oceanic countries, a majority of people have lived in urban areas since the 1950s and 77.7% of people in these regions are currently classed as urban dwellers (ibid).

In land terms, urban areas[1] occupy 0.5% of the world's total land area (EC, 2010; Schneider et al, 2009) meaning, therefore, that most of the world's population lives on only one two hundredth of its land. This phenomenon is illustrated on Figure 1.1 using Europe as an example. Furthermore, the number of people living in urban areas is predicted to increase significantly (UN, 2012) as people move to towns and cities in search of a better quality of life. Indeed by the middle of the 21st century it is anticipated that the global urban population will almost double, increasing to approximately 6.4 billion by 2050 (WHO, 2013). Projected trends in urban population growth by major geographical region are indicated on Figure 1.2.

---

[1] Defined by Schneider et al (2009 p.2) as *"places dominated by the built environment"* that are greater than 1km^2 including cities, towns and other settlements



Globally, urban areas occupy 0.5% of the world's land area

In Europe, approximately 72.5% of the population currently lives in urban areas (2010 data)

By 2050, it is anticipated that approximately 82% of Europe's population will live in urban areas

The map to the left shows the current (2010) extent and location of urban areas in Europe

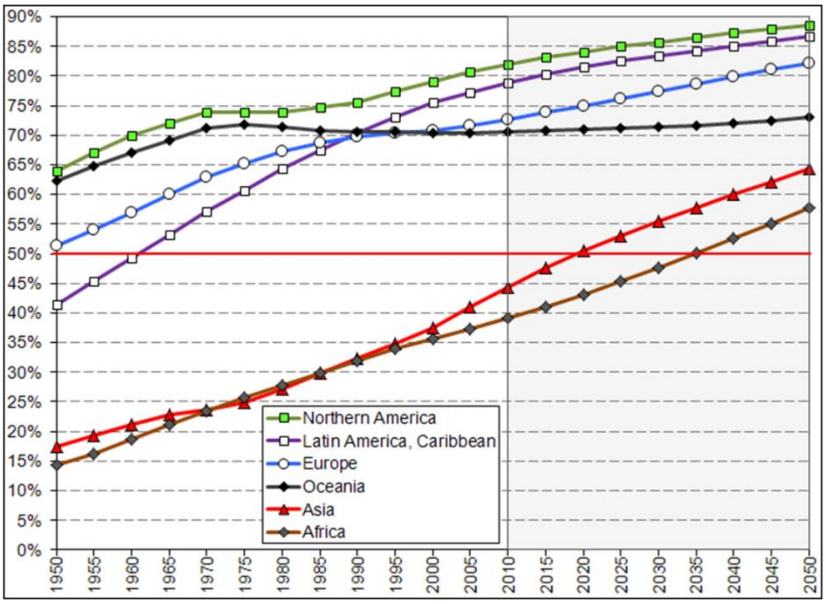
This is the land area where 72.5% of Europeans make their home

Figure 1.1 Extent and location of urban areas in Europe in 2010

(Adapted from Schneider et al, 2009; UN, 2012)

Combining these two metrics, population density provides a measure of the number of people per unit area of land. High population densities occur where large numbers of people live together in the same place. For example, the population density of London (UK) is 5,163 people/km^2 (London Councils, 2013), in Shanghai (China) there are 3,700 people/km^2 (Shanghai Municipal Population and Family Planning Commission, 2012) and in New York (US) there are 10,640 people/km^2 (US Census Bureau, 2008). This is in contrast to more rural/remote areas where population densities are generally much lower – the average population density in the Sutherland area of the Scottish Highlands (UK) for example is only 1.1 people/km^2 (The Highland Council, 2013).

Wherever population densities are high and large numbers of people live together in the same place, there will inevitably be high demand for the goods and services on which those people rely – from food, housing and education to transport, jobs and recreation. In densely populated urban areas (such as the global examples listed above), this issue can be particularly pronounced in relation to the 'urban sprawl' effect (Hasse and Lathrop, 2003; Kumar Jat et al, 2008; Schneider et al, 2009) whereby demand for land resources can increase pressure on the ecosystem services that urban land provides (TEEB, 2011; UK NEA, 2011). Furthermore, many of these land based ecosystem services cannot readily be substituted by technology and often have to be provided at the locus of the demand e.g. biodiversity and protection against natural hazards like floods and landslides (ibid).



A majority of people in developed countries (Northern America, Europe and Oceania) have lived in urban areas since the 1950s

By 2035, it is anticipated that the majority of people from all regions of the world will live in urban areas

North America has the highest percentage of people living in urban areas

Latin America is anticipated to show the greatest rate of urbanisation up to 2050

Figure 1.2 Trends in urban population by major geographical region as a percentage of total population

(Adapted from UN, 2012)

Compounding these issues, the world's urban centres have historically been (and in many cases still are) subjected to unplanned and unregulated development that has acted to degrade the land and disrupt and damage many of the natural processes that underpin the ecosystem services it provides (Davies et al, 2011; UKNEA, 2011; Scottish Government, 2013a). In modern terms, we would now describe this form of development as being 'unsustainable' whereby the consideration of environmental[2] issues has been absent from decision-making, contributing to environmental/land degradation. Indeed Stock and Burton (2011) highlight how many 'real-world' sustainability problems occur at the 'interface' of human and natural systems.

Whilst urbanisation can create problems, it is important to recognise that there can also be substantial benefits associated with urban areas – not least the

---

[2] And potentially a range of social and human development issues also e.g. access to education, access to healthcare, provision of safe and accessible neighbourhoods etc

economies of scale associated with utilities and other essential services which can be delivered much more efficiently in large urban areas than in more remote, rural areas (Davies et al, 2011 p.364). There are also pro-urbanisation arguments centred around the advantages of concentrating intensive human impacts in one place (Mills, 2007; Schneider et al, 2009) as opposed to more dispersed models of urbanisation that would see many smaller, diffuse impacts distributed across the land. In reality, many of these more diffuse impacts may occur anyway as rural land based enterprises (e.g. agriculture, forestry, energy production, extractive industries etc) are fundamental for the production of goods and services consumed in urban areas. A key challenge therefore is to increase the efficiency of urban service delivery, thereby reducing urban demand for goods and services. In line with this, Mills (2007 p.1849) describes cities as "both the chief cause of and solution to anthropogenic global changes".

As these global trends of urbanisation play out over the coming decades, there will inevitably be increased pressure on the world's urban areas. Furthermore, we will have to develop and choose between a range of potential governance, planning, design and engineering strategies in our response to these pressures – for example, do we accept increased urban sprawl, whereby the extent of urban areas increases, or do we endeavour to make more effective use of the urban land resource that we have? This research seeks to help answer some of these questions by improving our practical understanding of how urban land use/management decisions can impact urban ecosystems and ecosystem services. This is achieved in part by exploring new ways of planning, designing and delivering key land based urban services – ecosystem services – that can work *with* rather than *against* natural systems – this is the essence of the ecosystems approach which is described in further detail at sections 1.2 and 3.2.

Regardless of the specific mix of urbanisation problems experienced in towns and cities at any one time, there are a growing number of external, global pressures that can act to shock or stress urban systems and, in doing so, act to aggravate locally felt urbanisation problems. As we have seen above, urbanisation occurs when people move from rural to urban areas, when towns and cities grow and when societies become more urban. Regardless of the model of urbanisation followed, urban areas will always have higher population densities than more rural areas and therefore demand for goods and services will be higher. Under these conditions, the introduction of uncertain external pressures can act to shock or stress the delicate balance of urban systems, especially when these systems have not been designed with flexibility and resilience in mind (Leichenko, 2020; Olsson et al, 2012).

One of the most significant external pressures affecting urban areas today is global climate change and its locally felt impacts (Emmanuel and Kruger, 2012; Leichenko, 2010; Olsson et al, 2012; Scottish Government, 2011a; Scottish Government, 2013a; Wamsler et al, 2013). Climate change is a highly complex problem – although it is environmental in nature, it impacts or is impacted by a broad range of global issues including poverty, economic development, biodiversity, population growth, sustainable development and resource management (UNFCCC, 2013). Furthermore, the specific nature of climate changes and therefore the impacts of climate change are not evenly distributed around the world. For example, anticipated climate change in Sub-Saharan Africa is likely to result in less rainfall and increased average temperatures (Kotir, 2010). In terms of impacts, this is predicted to cause increased drought, decreased agricultural production and multiple human health problems including malnutrition and higher incidences of infant mortality (ibid). On the other hand, climate change in Scotland is forecasted to result in warmer, wetter weather with increased incidences of extreme weather events including heavy downpours and very strong winds (Scottish Government, 2013b). Key impacts of climate change in Scotland therefore are flooding and storm damage to property and infrastructure (as well as potentially positive impacts such as longer growing seasons and less demand for heating in winter months).

Leichenko (2010 p.164) reports how the concept of resilience is gaining increasing prominence within the literature on cites and climate change and goes on to describe how references “generally refer to the ability of a city or urban system to withstand a wide array of shocks or stresses”. Furthermore, Leichenko (ibid) suggests that there are four categories within urban climate change resilience literature and practice: 1) urban ecological resilience; 2) urban hazards and disaster risk reduction; 3) resilience of urban and regional economies; and 4) promotion of resilience through urban governance and institutions. In this regard, climate change and urban climate resilience should arguably be key considerations in the development of integrated, forward looking urban land use/management strategies.

1.2 Ecosystem services and the ecosystems approach

As described in section 1.1, there are many potential problems associated with increased urbanisation. Compounding this, major external pressures (especially global climate change) can act to shock and stress the often delicate balance of urban systems, potentially impacting the delivery of key urban services, including ecosystem services. In terms of the urban land resource in particular, urbanisation and urban sprawl can constrain the availability and impact the quality of many urban ecosystem services such as flood storage, micro-climate regulation, semi-natural habitats, biodiversity, recreational space, habitat networks and urban agriculture (EEA, 2006; EEA, 2010a; EEA, 2010b). Crucially, this includes the ‘green’ and ‘natural environment’ type land uses within towns and cities that provide a backbone of greenspace and semi-natural habitats, supporting urban ecosystem function (EEA, 2006). As mentioned in section 1.1, many urban ecosystem services are also context specific in nature and need to be provided at or near to the locus of demand (TEEB, 2011; UKNEA, 2011). For example, flood storage services cannot just be provided in one catchment, rather, they need to be provided on a catchment by catchment basis. Similarly, the recreation services provided by urban parks and other greenspaces cannot just be provided in one neighbourhood – they need to be provided throughout the urban area to meet the needs of local communities.

Despite the importance of urban ecosystem services, their consideration in urban planning decision-making, as in more rural sectors such as agriculture and forestry, has often been absent or over-looked (MA, 2005; UKNEA, 2011) and “nature has sometimes been taken for granted and undervalued” (Defra, 2011 p.3). Globally, patterns of human development over the latter half of the 20th century have resulted in more rapid and extensive changes to ecosystems than in any other comparable period of human history and these changes, whilst contributing to net gains in human wellbeing and prosperity, have resulted in the degradation of many services provided by ecosystems (MA, 2005; UKNEA, 2011). Crucially, there is concern that the ability of future generations to obtain benefits from ecosystems will be diminished unless ecosystem degradation is halted (ibid). In an urban context, these are the issues and challenges that this thesis seeks to address.

In recent years however there has been growing recognition of the natural environment's vital role supporting societal wellbeing and prosperity (CBD Secretariat, 1992; CDB Secretariat 2013; EC, 2011a; Defra, 2011; Scottish Government, 2011c; UKNEA, 2011; EC, 2013a; Scottish Government, 2013g). This recognition has crystallised around the concept of ecosystem services (ibid). Crucially, the ecosystem services concept recognises that a healthy natural environment, through its constituent landscapes, ecosystems and habitats, provides a range of *advantages* or *benefits* that are essential for societal wellbeing and prosperity (MA, 2005; Haines-Young and Potschin, 2008; Hughes and Brooks, 2009; Defra, 2011; Scottish Government, 2011c; UKNEA, 2011; Baker et al, 2013). This notion of the natural environment providing advantages or benefits supporting human wellbeing is the definition of ecosystem services adopted in this thesis.

The central premise of the ecosystem services concept is the protection and enhancement of biodiversity[3], the logic being that by emphasising the natural environment's role supporting human wellbeing and prosperity (see Figure 1.3), governments, corporations, private individuals and other stakeholders will be driven to take action to protect and enhance the natural environment (CBD Secretariat, 1992; CDB Secretariat 2013a). There are however wider, more operationally focussed benefits of considering ecosystem services in planning and decision-making processes that set the context and rationale for much of this research. These issues are discussed in further detail at section 3.2.

The Millennium Ecosystem Assessment (MA) was called for in 2000 by the then United Nations (UN) Secretary-General Kofi Annan (Brown et al, 2011). The MA assessed the consequences of ecosystem change for human wellbeing (ibid) and the conceptual framework established through the MA process has formed the basis for much of the subsequent development in ecosystem services science and policy

---

[3] The ecosystem services concept originates from the UN Convention on Biological Diversity (CBD) which is premised on the notion of biodiversity underpinning all ecosystem services. By this logic therefore the protection and enhancement of biodiversity is of central importance to human wellbeing and prosperity. The ecosystems approach is cited as the primary framework for action under the Convention: https://www.cbd.int/ecosystem/default.shtml [accessed 02/01/14]

(Baker et al, 2013). In particular, the MA established the now widely accepted framework for ecosystem services that links the natural environment and ecosystem services with constituents of human wellbeing (MA, 2005; UKNEA, 2011; Brown et al, 2011) as indicated on Figure 1.3.

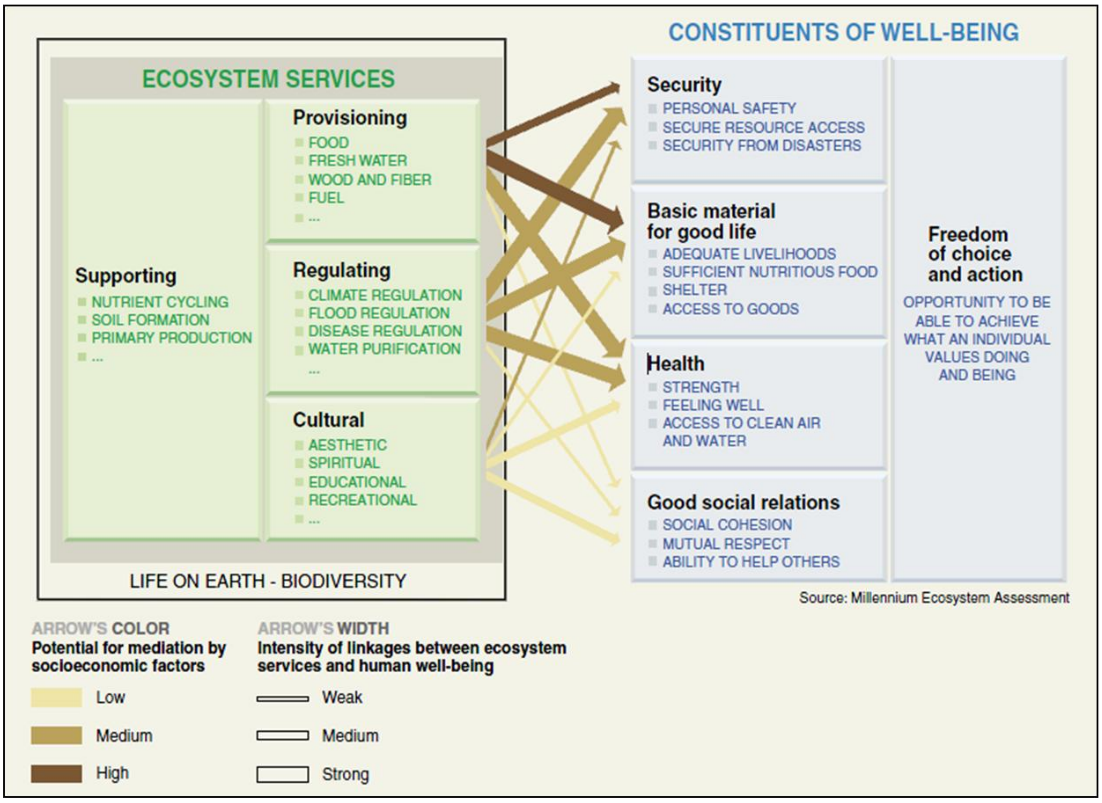


Figure 1.3 The Millennium Ecosystem Assessment (MEA) ecosystem service typology showing linkages between services and human wellbeing

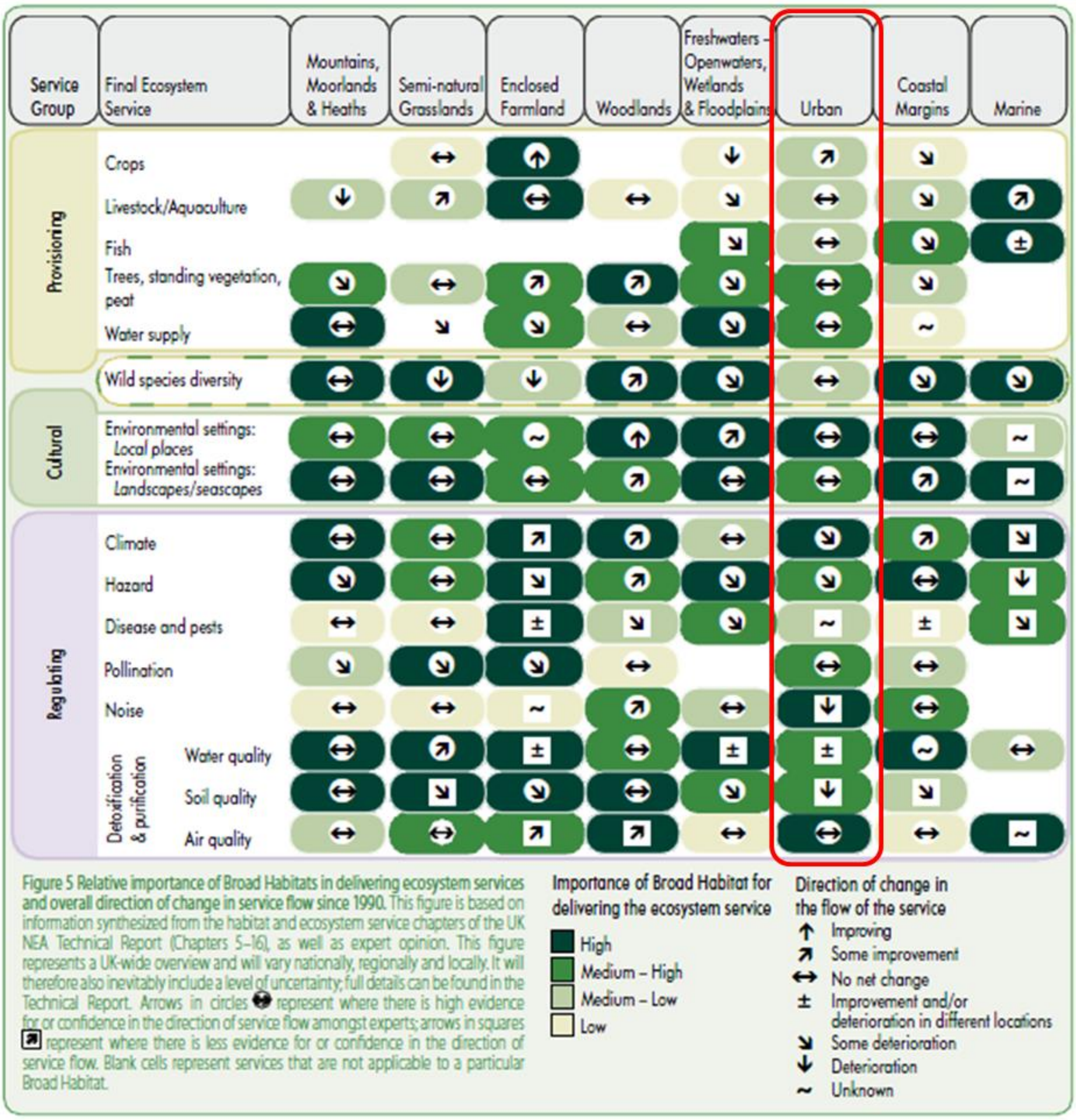
(Source: MA, 2005)

The UK National Ecosystem Assessment (the UKNEA) was a direct response to the 2000 MA, in particular the House of Commons Environmental Audit Committee recommended in 2007 the undertaking of a full MA-style assessment for the UK to enable the identification and development of effective policy responses to ecosystem service degradation (House of Commons Environmental Audit Committee, 2007). The UKNEA drew on the best available evidence and most up-to-date conceptual thinking and analytical tools to develop and improve the MA assessment methodology (Brown et al, 2011). Given the UK based focus of this thesis (see sections 1.4 and 2.1.4), the UKNEA and its post-MA theoretical and methodological developments are of particular relevance and are discussed more fully at section 3.2. In summary however, the findings of the UKNEA raise stark concerns for the health and integrity of the UK's natural environment and ecosystem services. Key findings from the UKNEA are shown in Box 1.1 and on Figure 1.5.

Box 1.1 Key findings from the UKNEA
(Source: UKNEA, 2011a p.5)

- "The natural environment, its biodiversity and its constituent ecosystems are critically important to our wellbeing and economic prosperity but are constantly undervalued in conventional economic analyses and decision-making;
- Ecosystems and ecosystem services have changed markedly in the past 60 years driven by changes in society;
- The UK's ecosystems are currently delivering some services well, but others are in long-term decline;
- The UK population will continue to grow, and its demands and expectations continue to evolve. This is likely to increase pressures on ecosystem services in a future where climate change will have an accelerating impact both here and in the world at large; and
- Actions taken and decisions made now will have consequences far into the future for ecosystems, ecosystem services and human well-being. It is important that these are understood, so that we can make the best possible choices, not just for society now but also for future generations"

As is evident from Box 1.1 and Figure 1.5, there is clearly a pressing need to address ecosystem service degradation in order to safeguard their integrity and availability for future generations. Of particular relevance to this research, population growth and urbanisation both raise concerns over the management of urban ecosystems for key urban ecosystem services (especially those that cannot readily be substituted by technology – see section 1.1), an issue that is compounded by future uncertainty (UKNEA, 2011) and the absence of comprehensive tools to support strategic planning for urban ecosystems and ecosystem services. In particular, Figure 1.5 highlights the importance of urban ecosystems providing key cultural and regulating services – especially environmental settings (local places) and climate, hazard, noise and air quality regulation.



Service Group	Final Ecosystem Service	Mountains, Moorlands & Heaths	Semi-natural Grasslands	Enclosed Farmland	Woodlands	Freshwaters – Openwaters, Wetlands & Floodplains	Urban	Coastal Margins	Marine
Provisioning	Crops		↔	↑		↓	↗	↘	
	Livestock/Aquaculture	↓	↗	↔	↔	↘	↔	↘	↗
	Fish					↘	↔	↘	±
	Trees, standing vegetation, peat	↘	↔	↗	↗	↘	↔	↘	
	Water supply	↔	↘	↘	↔	↘	↔	~	
	Wild species diversity	↔	↓	↓	↗	↘	↔	↘	↘
Cultural	Environmental settings: Local places	↔	↔	~	↑	↗	↔	↔	~
	Environmental settings: Landscapes/seascapes	↔	↔	↔	↗	↔	↔	↗	~
Regulating	Climate	↔	↔	↗	↗	↔	↘	↗	↘
	Hazard	↘	↔	↘	↗	↘	↘	↔	↓
	Disease and pests	↔	↔	±	↘	↘	~	±	↘
	Pollination	↘	↘	↘	↔		↔	↔	
	Noise	↔	↔	~	↗	↔	↓	↔	
	Detoxification & purification: Water quality	↔	↗	±	↔	±	±	~	↔
	Detoxification & purification: Soil quality	↔	↘	↘	↔	↘	↓	↘	
	Detoxification & purification: Air quality	↔	↔	↗	↗	↔	↔	↔	~

Figure 5 Relative importance of Broad Habitats in delivering ecosystem services and overall direction of change in service flow since 1990. This figure is based on information synthesized from the habitat and ecosystem service chapters of the UK NEA Technical Report (Chapters 5–16), as well as expert opinion. This figure represents a UK-wide overview and will vary nationally, regionally and locally. It will therefore also inevitably include a level of uncertainty; full details can be found in the Technical Report. Arrows in circles represent where there is high evidence for or confidence in the direction of service flow amongst experts; arrows in squares represent where there is less evidence for or confidence in the direction of service flow. Blank cells represent services that are not applicable to a particular Broad Habitat.

Importance of Broad Habitat for delivering the ecosystem service
- ■ High
- ■ Medium – High
- ■ Medium – Low
- ☐ Low

Direction of change in the flow of the service
- ↑ Improving
- ↗ Some improvement
- ↔ No net change
- ± Improvement and/or deterioration in different locations
- ↘ Some deterioration
- ↓ Deterioration
- ~ Unknown

Figure 1.4 Trends in ecosystem service flows from UK broad habitats since 1990

(Source: UKNEA, 2011)

Note: The UKNEA is based on eight recognised broad habitats found within the UK. UKNEA (2011) recognise that the classification of ecosystems is distinctly overlapping with that of habitats, meaning therefore that the eight broad habitats above can be considered synonymous with ecosystems. The Figure depicts the relative importance of these broad habitats in delivering ecosystem services (dark green cells indicate greater importance) as well as trends in the flow of ecosystem services from these habitats since 1990. Although many services provided by the broad habitats are described as having shown ‘some improvement’ or ‘no net change’, many services have been assessed as showing deterioration. Crucially, many services provided by urban areas (highlighted in red) are deteriorating, especially key regulating services including climate, hazard (encompassing flood storage) and noise regulation as well as soil quality.

These are key challenges and issues that this thesis seeks to help address. In particular, this thesis argues that a pressing ‘real-world’ urban sustainability issue

(Stock and Burton, 2011) is the impact of inappropriate land use/management on the functioning of urban ecosystems and the ecosystem services that they are able to provide (EEA, 2010a; Davies et al, 2011; UKNEA, 2011). Adopting an ecosystems approach to urban land use planning may provide part of the solution. This sort of approach is predicated on a subtle shift in emphasis – from viewing the land, the natural environment and ecosystems merely as a backdrop to absorb the impacts of development to something that provides a range of tangible services that can support development and human wellbeing objectives (Baker, 2010; Baker et al, 2013).

The ecosystems approach is described as "a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way" (CBD Secretariat, 1992). More recent interpretations have framed the ecosystems approach as a means of working with nature for the delivery of multiple benefits (Scottish Government, 2011c; SNH, 2012). There is now a wide range of literature (e.g. Davies et al, 2011; UKNEA, 2011; Sheate et al, 2012; Baker et al, 2013; Gore et al, 2013; Helming et al, 2013; Partidario and Gomes, 2013) and policy (e.g. EC, 2011a; EC, 2011c; Defra, 2011; EC, 2013; Scottish Government, 2011c; Scottish Government, 2013d) supporting the assertion that the ecosystems approach can be used, in a variety of decision-making and planning contexts, to help protect and enhance biodiversity whilst simultaneously identifying complementarity and opportunities for the delivery of multiple benefits, thereby helping to drive down the costs of infrastructure and service delivery. The aim of this thesis is to identify practical ways of operationalising the ecosystems approach in urban land use planning.

The potential application of the ecosystems approach within urban planning and design has been discussed within the literature (Chan et al, 2006; Defra, 2008; Davies et al, 2011; Sheate et al, 2012; Gaston et al, 2013; Labiosa et al, 2013). At the project scale, urban design is increasingly looking towards techniques that work with rather than against the natural processes that underpin urban ecosystem function. This is the case for design issues such as resilient buildings, zero waste systems and water sensitive design (Susdrain, 2012; Gret-Regamey et al, 2013). In particular, the use of more traditional engineered interventions to address problems of urban sustainability (e.g. air conditioning, flood defence, drainage etc) is increasingly being questioned due to cost, environmental impact and lack of flexibility, especially with respect to future uncertainty (CIWEM, 2007; Wild et al, 2010; Scottish Government, 2011a; Susdrain, 2012; Scottish Government, 2013a).

What is often found to be lacking however are practical tools, techniques and modelling/scenario evaluation frameworks that allow urban planners and designers to take a more strategic view of their town or city in order to better understand and plan for the impact of urban land use/management options on whole ecosystems and the goods and services that they provide (Chan et al, 2006; Gret-Regamey et al, 2013; Labiosa et al, 2013). This specific gap is what this thesis seeks to address.

1.3 Urban planning – an integrating framework to help solve urbanisation problems

Although there is no one recognised definition of urban planning, its central purpose is arguably to support better decision-making about the future use of land in urban areas. In this manner, effective urban planning can be used to discuss, rationalise, plan for and help to address urbanisation problems described at section 1.1.

The American Planning Association (2013) describe urban planning as a means of improving the welfare of people and communities by creating more convenient, equitable, healthy, efficient and attractive places for present and future generations. The APA (ibid) go on to describe how the role of planners is to "…help create broad visions for towns and cities through the use of research, technical analyses, consultation with stakeholders, design and the production of a plan". The plan sets out the vision and objectives for the area and also the strategies that will be put in place to deliver the vision and achieve the objectives.

In England, the National Planning Policy Framework – the NPPF – (DCLG, 2012) describes how the purpose of planning (including urban planning) is to achieve sustainable development in the built, natural and historic environments, for the benefit of economic and social progress. The NPPF includes a suite of policies covering a range of planning issues – from town centres, transport and the green belt to healthy communities, flooding and climate change – that must be taken into account in the preparation of local plans (ibid). Local plans are required to set out the strategic priorities for the plan area over an appropriate timescale[4] including *inter alia* broad locations for strategic developments, land use designations, site allocations to promote development and the flexible use of land, identification of land that is inappropriate for development and a clear strategy for enhancing the natural, built and historic environments (ibid).

The Scottish Government (2013c) describes how the planning system makes decisions about the future development and use of land in towns, cities and the countryside. The planning system "considers where development should happen, where it should not and how development affects its surroundings. It balances competing demands to make sure that land is used and developed in the public's long-term interest" (ibid). Similarly to the US and English[5] systems, the Scottish planning system is also 'plan-led' and is based on a hierarchy of development plans at different scales – national, regional and local. Development plans in Scotland "…set out how places should change and what they could be like in the future. They say what type of development should take place where, and which areas should not be developed. They set out the best locations for new homes and businesses and protect places of value to people or wildlife" (Scottish Government, 2013d).

Reflecting on the above, key tenets of urban planning in the US, England and Scotland include: 1) using urban planning to help balance competing objectives/demands on land use; and 2) the use of a plan to convey an agreed vision, objectives and strategy for future land use and development within the urban area. Furthermore, the plan is not simply a document that sits on a shelf. In Scotland and England for example, the process of deciding whether or not to grant or refuse planning permission (the consent required by a proponent in order to legally progress a development) is made in accordance with the extant development plan which is a statutory document underpinned by relevant primary legislation (DCLG, 2013; Scottish Government, 2013e). In this manner, the development plan is also a key mechanism for delivering the agreed land use and development strategy for the urban

---

[4] DCLG (2012) suggests that an appropriate timescale is 15 years

[5] The Scottish and English planning system share the same overarching legislative framework – the Town and Country Planning Act 1990, http://www.legislation.gov.uk/ukpga/1990/8/contents [accessed 21/09/13]

area including provision for the protection[6] and enhancement[7] of 'green' and 'natural environment' type land uses and the ecosystem services they provide.

Crucially therefore, legislative frameworks for urban planning, such as those in place for England and Scotland, can provide the legal basis *or* 'teeth' for progressing the urban sustainability agenda in relation to land use/management and impacts on urban ecosystem services. By virtue of their design, legislative frameworks are often very broad, setting out objectives and targets for what must be achieved but without providing much in the way of guidance or instruction for how. The delivery of statutory objectives and targets is then supported through research, guidance, best-practice and also the expertise of the professionals whose job it is to implement the legislation. In the case of planning (including urban planning) in Scotland for example, there is an extensive portfolio of statutory planning guidance covering many policy issues including flooding (Scottish Executive, 2004), openspace (Scottish Government, 2008), green infrastructure (Scottish Government, 2011b) and environmental impact assessment (Scottish Government, 2013f). Accordingly, there is always an opportunity to improve urban planning practice and process through the development, testing and adoption of new approaches, guidance and practice. This is an opportunity that this thesis seeks to exploit through the development of practical tools, techniques and modelling/scenario evaluation frameworks that can feed into and inform urban planning practice.

1.4 Aims, objectives and structure of the thesis

As outlined in the sub-sections above, the key problem addressed by this research is urbanisation and the pressure that urbanisation can place on urban land and the urban ecosystem services it can provide (see section 1.1). This problem needs to be investigated because there is currently a limited practical understanding of how urban land use/management decisions can impact urban ecosystem services (see section 1.2). Furthermore, although urban planning may potentially provide a useful integrating framework for addressing urbanisation problems (see section 1.3), there

---

[6] e.g. through the use of Tree Preservation Orders (TPOs) and Conservation Areas http://www.legislation.gov.uk/ukpga/1990/8/part/VIII/chapter/I/crossheading/tree-preservation-orders and http://www.legislation.gov.uk/ukpga/1990/9/contents [accessed 21/09/13]

[7] e.g. through the use of Section 106 agreements http://www.legislation.gov.uk/ukpga/1990/8/section/106 [accessed 21/09/13]

is a need for better tools, techniques and modelling/scenario evaluation frameworks to help urban land use planners consider the impacts of their decisions on urban ecosystems and ecosystem services (see section 1.2). As such, the overarching aim of this research is:

To understand, develop, trial and evaluate new approaches to urban planning that can operationalise key aspects of the ecosystems approach

This overarching aim is supported by five more detailed objectives as per Box 1.2.

Box 1.2 Research Objectives

1. To **identify** urban ecosystem services that are particularly important to urban centres in northern Europe
2. To **understand** how urban land use/management can impact the functioning of urban ecosystems and the provision of certain urban ecosystem services
3. To **identify** existing approaches to urban planning that may have potential to operationalise the ecosystems approach and to evaluate their utility in this regard
4. To **develop** new approaches to urban planning that can operationalise key aspects of the ecosystems approach and inform practical urban land use/management decision-making and green infrastructure project design
5. To **evaluate** the appropriateness and utility of the new approaches with respect to their adoption in urban planning practice

This research has adopted a qualitative approach, based on grounded theory, which has sought to develop an improved understanding of the relationship between urban land use/management and certain urban ecosystem services. Qualitative data collected and analysed through this research has then been integrated with existing spatial datasets in a Geographic Information System (GIS) to develop new spatial models for urban land use planning, based on the principles of the ecosystems approach. Ecosystem services – the central concept in this research – can be defined as the advantages or benefits provided by a healthy natural environment that are essential for societal wellbeing and prosperity (see section 1.2).

Figure 1.5 Geographical location of Glasgow in Europe

(Source: EC, 2013c)

The research has purposefully focussed on three specific urban ecosystem services – 1) flood storage; 2) runoff reduction; and 3) ecological connectivity – and a specific study site which, in this instance, is a specific urban centre – Glasgow (see Figure 1.5). The rationale for the selection of these ecosystem services and study site is explained at sections 2.1.4 and 3.2.5. The selection of specific ecosystem services and study site has influenced the scope and parameters of this research, especially in relation to the participants in the study. Participants in this regard include: 1) land use/management planning experts; 2) a group of land use/management planning stakeholders from Glasgow City Council (GCC) constituting a ‘social setting’ in the terms of one of the research methods used; and 3) the various documents and literature reviewed as part of the evidence assessment method.

The subsequent Chapter of this thesis – Chapter 2 – describes the methodology adopted in this research including the overall research design, the theoretical framework and the specific data collection and analysis methods adopted. As outlined in sections 2.2.3, 2.2.7 and 2.3.2, a Rapid Evidence Assessment (REA) methodology has been used to collate, analyse and synthesise technical data from existing literature on the impact of urban land use/management on the three specific urban ecosystem services considered in this research. In this regard, a key aspect of the data collection methodology adopted in this research is focussed on the REA (a literature review type approach), the outputs of which are documented in three 'evidence assessment' Chapters (see Chapters 3 – 5). As such, this thesis does not include a formal literature review Chapter given the literature-based focus of a key part of the methodology (see section 2.3.2). As part of the research, a literature map has been developed (see Appendix 1) to develop an understanding of the relationships between different categories of literature. This has been particularly important given the interdisciplinary nature of the research and the literature considered (see section 2.1.3).

Chapter 3 is the first of the four evidence assessment Chapters in the thesis. It analyses the urban land use planning system in Scotland, highlights key opportunities for consideration of urban ecosystem services and characterises the urban natural environment for the purposes of ecosystems approach based urban land use planning. It then goes on to introduce and explain the theory and science of ecosystem services and the ecosystems approach that has underpinned this research, thereby arguing the case for the use of these concepts in urban land use planning. Chapter 3 also explains why certain urban ecosystem services have been focussed on in this research.

Chapter 4 is the second of the four evidence assessment Chapters. It provides the technical basis for the two water management related ecosystem services – flood storage and runoff reduction – that have been considered in this research in the development of new tools and techniques for urban land use planning. It discusses the catchment based approach to sustainable Flood Risk Management (FRM) as well as the key hydraulic and hydrological principles that provide the technical basis for later Chapters in the thesis. It then provides an analysis of four key approaches to natural flood management (NFM) that can be used in urban catchments and that have been integrated with the new tools and techniques developed through this research.

Chapter 5 is the third of the four evidence assessment Chapters. It provides the technical basis for the ecological connectivity ecosystem services that have been considered in this research in the development of new tools and techniques for urban land use planning. It explains the theory of landscape ecology and landscape metrics before exploring the principles, tools and techniques available for modelling landscape connectivity. It then discusses the key principles of conservation management before arguing the case for the use and management of urban habitat networks for the provision of multiple benefits.

Chapter 6 is the last of the four evidence assessment Chapters. It documents the review and evaluation of existing ecosystems approach based urban land use planning frameworks. This includes an evaluation of each approach and a synthesis of the main findings. It also highlights where and how the strengths, weaknesses and key methodological innovations identified from existing practice have informed the development of the new tools and techniques as part of this research.

Chapter 7 describes the new spatial models that have been developed in this research to help urban land use planners better consider the impacts of their land use/management decisions on urban ecosystems and ecosystem services. This includes a summary explanation of the structure, process and function of the new models, thereby arguing the case for their wider use in urban land use planning practice elsewhere. Crucially, the development of the new spatial models has been directly informed by the evidence assessment described in Chapters 3 – 6.

Chapter 8 introduces the new guiding principles and technical guidance for ecosystems approach based urban land use planning that have been developed through this research. This includes an explanation of the specific data analysis approach used in this case. Crucially, Chapter 8 then goes on to explain how the new spatial models (see Chapter 7), guiding principles and technical guidance can be used to inform the development of integrated urban land use/management strategies. This includes a newly developed process for integrating model outputs with key stages of the Local Development Plan (LDP) process, in line with the Planning etc (Scotland) Act 2006. Finally, Chapter 9 presents the conclusions of the thesis including a summary of key findings and recommendations for future research and for future practice.

2. Methodology

As described at Chapter 1, the overarching aim of this thesis is "to understand, develop, trial and evaluate new approaches to urban planning that can operationalise key aspects of the ecosystems approach". In essence, this is a sustainability research project focussed on improving institutional responses to natural environment challenges by combining research on the ecological and social components (Stock and Burton, 2011) of urban systems, including policies and institutions (i.e. urban land use plans and local authorities). As such, the research has adopted an interdisciplinary approach drawing on qualitative research methods from the social sciences in conjunction with theories from the natural sciences.

Box 1.2 identified the five Research Objectives that this thesis has set out to achieve. Cresswell (2009) describes how in qualitative studies, research questions are used instead of objectives or hypotheses which are used more commonly in quantitative or mixed methods studies. Although this research uses purely qualitative research methods (see sections 2.3 and 2.4), defining clear objectives was an important part of the overall framing of the research, especially given the pressing need for sustainability research to contribute to effective, practical outcomes (Stock and Burton, 2011). In addition however, Research Objectives Nos. 1, 2 and 3 (i.e. the three objectives that relate specifically to the collation of qualitative data – see sections 2.2 and 2.3) have been framed as Research Questions to help guide the use of key qualitative methods in the research (e.g. helping to clarify the relationship between data requirements, research methods and the overall aim and objectives of the research). As such, the three headline Research Questions are:

1. Which ecosystem services are particularly important for urban centres in northern Europe?
2. How does urban land use/management impact the functioning of urban ecosystems and the provision of certain urban ecosystem services?
3. What can be learnt from existing ecosystems approach based urban land use planning frameworks?

The remainder of this Chapter describes the overall methodological approach adopted in this research including the research design, specific use of theories and an explanation of the interdisciplinary nature of the approach (section 2.1), the overall research process followed in terms of the individual steps and the sequence of events therein (section 2.2), the specific data collection methods adopted (section 2.3) and the approach adopted in the analysis of the various data produced throughout the research (section 2.4).

2.1 Research design and theoretical framework

Cresswell (2009 p.3) defines research designs as “plans and procedures for research […] informed by the nature of the research problem being addressed, the researcher’s personal experiences and the audiences for the study”. The remainder of this section outlines the specific research design adopted in this thesis (section 2.1.1), describes the theoretical framework used (section 2.1.2), explains the rationale for the interdisciplinary nature of the research (section 2.1.3) and describes how a pilot urban centre was selected for the study (section 2.1.4).

2.1.1 Research design

Cresswell (2009) identifies three main types of research design in the human and social sciences: 1) qualitative; 2) quantitative; and 3) mixed methods. Within these three broad approaches, Cresswell (ibid) highlights how the researcher then needs to consider and make decisions about the worldview assumptions they bring to the study, the selection of an appropriate procedure of enquiry (or research strategy) and specific methods of data collection, analysis and interpretation. Although this research has adopted an interdisciplinary approach (see section 2.1.3), only qualitative methods have been used. As such, a qualitative research design was considered appropriate. The different elements of the research design are discussed further below. Firstly however it is important to understand the rationale behind the use of a qualitative approach.

The nature of the research problem under investigation has a key influence over research design choice. As outlined in Chapter 1, the research problem investigated in this thesis is urban sustainability with a particular focus on the relationship between urban land use/management, the provision of certain urban ecosystem services and the need for better tools, techniques and modelling/scenario evaluation frameworks to support urban land use planning in this regard. As such, a key characteristic of this research problem is the need to better understand a concept or phenomenon because little research has been done on it (Cresswell, 2009) – i.e. how urban land use/management can impact the provision of urban ecosystem services and then how this information might be framed within new tools and techniques for urban land use planning. In this regard, a qualitative approach is considered to be most appropriate given its more exploratory nature and the flexibility it affords for the consideration of multiple variables (Cresswell, 2009; Bryman, 2012). This is in contrast to a quantitative approach for example which will generally feature a smaller number of defined variables (ibid). Another key factor influencing research design choice is the personal experiences of the researcher. The author comes from a qualitative background (environmental and sustainability policy and assessment) and regularly uses qualitative techniques in his professional work including strategic environmental assessment (SEA) practice and research (e.g. Phillips and Sheate, 2010; Sheate and Phillips, 2014) and social research for central government (e.g. Phillips et al, 2014). As such, qualitative techniques were the obvious choice in this regard due to their familiarity and the benefits of this familiarity for research efficacy, quality and deliverability. This latter issue was particularly pertinent as this PhD research was undertaken alongside fulltime professional work at Glasgow City Council (GCC) and then Collingwood Environmental Planning (CEP) Ltd (see section 2.3.3).

As discussed at the start of this sub-section, there are three main components of research design: 1) philosophical worldview; 2) strategies of enquiry; and 3) research methods (Cresswell, 2009). Cresswell (ibid) highlights how philosophical ideas can have an important influence on research practice, even though they are often largely hidden within research outputs. In this regard, the researcher is advised to make explicit the philosophical ideas they espouse given the implications of these for other aspects of research design – i.e. they can be seen as a "general orientation about the world and the nature of research that a researcher holds" (Cresswell, 2009 p.6). As such, this study is approached through a pragmatic worldview. Crucially, pragmatism arises out of "actions, situations and consequences rather than antecedent conditions [and it has] a concern with applications – what works – and solutions to problems" (Cresswell, 2009 p.10). Given this, pragmatism can be seen as having a keen focus on the pressing problems of the day, an issue that is particularly important in the field of sustainability research where effective research outcomes are essential – i.e. identifying practical solutions to 'real world' system problems (Stock and Burton, 2011).

Arguably, there are also close parallels between pragmatism and the adoption of interdisciplinary approaches as per this research (see section 2.1.3). In particular, interdisciplinary approaches are considered vital for sustainability research which itself is focussed on addressing the practical 'real world' problems faced by humanity (ibid). From a personal stance, the author is undoubtedly a pragmatist – working at the interface of research and practice, the resolution of real world sustainability problems are the focus of his professional work[8]. Most notably, pragmatism has influenced the research approach in terms of its keen focus on

---

[8] The author is a senior consultant at CEP Ltd, an independent consultancy specialising in strategic and practical sustainability issues: http://www.cep.co.uk/What_we_do.html [accessed 18/04/14]

finding solutions to the urban sustainability problems outlined above and in Chapter 1. In particular, the emphasis has been on identifying workable solutions now that can be improved upon in the future – i.e. demonstrating the overall efficacy of new theories and approaches has been more of a priority than debating the minutiae.

Cresswell (2009 p.11) defines strategies of enquiry as “the types of qualitative, quantitative and mixed methods designs or models that provide specific direction for procedures in a research design”. The specific strategy of enquiry adopted in this research however is harder to align directly with the social research methods literature. In particular, the interdisciplinary nature of the research (see section 2.1.3) means that it is hard to pin it down to particular epistemological and ontological orientations (indeed this has been identified as a challenge of interdisciplinary research more generally including the potential for epistemological and ontological incompatibilities – see Stock and Burton, 2011). This issue is compounded by the fact that most interdisciplinary research (including this research) deals with environmental or natural resource issues (including land) where the interaction between human systems and ecosystems is the focus of investigation (ibid). In terms of epistemological considerations for example, this research draws on commonly held theories from the natural sciences (see section 2.1.2) to develop new urban planning tools and techniques, designed for integration with institutional and policy frameworks, that are themselves predicated on social action (e.g. engagement of stakeholders and the public in policy formulation).

The resolution of these issues comes back to the pragmatic worldview described above. In essence, this research recognises how practical, interdisciplinary sustainability research is needed to address ‘real world’ sustainability problems, such as population growth, urbanisation and urban sprawl (see section 1.1). As such, this thesis argues for interdisciplinary research methodologies that can incorporate the practices and norms of the natural science model whilst recognising the need to emphasise how individuals interact with their social world (Bryman, 2012), including with institutions and policy-development processes. This, in essence, is the ecosystems approach – i.e. the overarching theoretical framework adopted in this research (see section 2.1.2).

Given this, the strategy of enquiry that aligns best to the approach adopted in this research is grounded theory. Grounded theory is considered to be the most widely used framework for analysing qualitative data (Bryman, 2012) and can be used to derive "general, abstract theories of a process, action or interaction" (Cresswell, 2009 p.13). A grounded theory strategy is predicated on the use of multiple stages of data collection and refinement to identify themes, concepts, categories, hypotheses and, ultimately, formal theories (Cresswell, 2009; Bryman, 2012). Whilst the overall thrust of grounded theory is based on an inductive approach – i.e. using observations and findings to develop theories – there is inevitably a degree of iteration between data, extant theories and any new theories that the research may propose (Bryman, 2012). This sort of iterative approach has been adopted in this research as described at section 2.2.

The final component of Cresswell's (2009) framework for research design is the specific research methods used for data collection, analysis and interpretation. Section 2.3 provides a more detailed explanation of the data collection methods used and section 2.4 outlines the specific data analysis and interpretation approaches utilised. In summary however a grounded theory approach has been used for data analysis and interpretation and specific data collection methods are as follows:

- Document review
- Rapid evidence assessment (REA)
- Action research
- Semi-structured interviews

2.1.2 Description of the theoretical framework adopted in this research

As mentioned at the start of this Chapter, this research draws on extant theories from the natural sciences in order to develop improved institutional responses to natural environment challenges and urban sustainability problems. As such, the research has been approached with a distinct theoretical lens or perspective (Cresswell, 2009) that has provided an overall theoretical framework on which the research design has been based (see section 2.1.1). Bryman (2012) describes how theory is normally something that emerges from the collection and analysis of qualitative data yet he also highlights how qualitative data can be used to test extant theories as well. In this regard, whilst this research has developed new theories for urban land use planning, the collection, analysis and interpretation of qualitative data underpinning the new theories has been undertaken within a framework of existing theories, primarily from the natural sciences (i.e. there are elements of both an inductive and deductive approach).

Ecosystem services provide the overarching theoretical framework adopted in this research. The theory of ecosystem services is based around the processes that link human societies and their wellbeing with the natural environment (MA, 2005; Mace et al, 2011), emphasising "the role of ecosystems in providing services that bring improvements in wellbeing to people" (Mace et al, 2011 p.2). As discussed briefly at section 2.1.1, many of the 'real world' problems faced by humanity today are located at the interface of human and natural systems (Stock and Burton, 2011). In this regard, ecosystem services can provide a common framework within which different disciplines can align through interdisciplinary approaches (ibid).

This research argues that the use of ecosystem services as a theoretical framework has the potential to bring focus to 'real world' problems through common objectives. This sentiment is echoed by Stock and Burton (2011 p.1096) who describe how interdisciplinary studies into 'real world' problems "force participants from a variety of unrelated disciplines to cross boundaries to create new knowledge" (Stock and Burton, 2011 p.1096). Given this, although ecosystem services can be regarded as a theoretical framework in its own right, a key strength of the theory lies in its integrated nature (Baker et al, 2013). In practice, this means that the overarching ecosystem services theoretical framework is underpinned and supported by many other theories from discrete disciplines, supporting interdisciplinarity.

This includes theories from the social as well as natural sciences. For example feminist perspectives, critical theory and racialised discourses (Cresswell, 2009) are arguably considered within the ecosystems approach which includes key principles on considering all forms of relevant information (including indigenous and local knowledge) and involving all relevant sectors of society in decision-making (CBD Secretariat, 2013a). Although the theory of ecosystem services is underpinned by discrete theories from many separate disciplines, this research has a finite scope (informed by findings under Research Question No.1 – see section 2.2.2) and therefore a finite consideration of related theories. This is indicated on Figure 2.1.

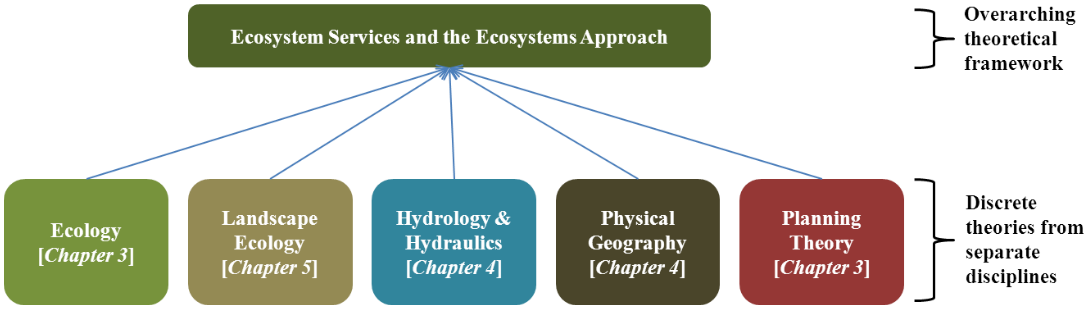


Figure 2.1 The theoretical framework and sub-theories adopted in this research

Note: The Figure depicts the relationship between the overarching theoretical framework adopted in the research and the discrete theories from separate disciplines that support and underpin this framework. The Figure also indicates where the discrete theories from separate disciplines are treated elsewhere in this thesis – i.e. the three main evidence assessment Chapters that have underpinned the development of the new theories for urban land use planning.

2.1.3 The rationale for an interdisciplinary research approach

Stock and Burton (2011 p.1091) describe integrated research as “all categories of sustainability research involving integrated multiple disciplines”. As discussed in sections 2.1.1 and 2.1.2, this type of approach can be particularly useful for addressing ‘real world’ problems at the interface of human and natural systems. The problem addressed in this research – i.e. urban sustainability with a particular focus on the relationship between urban land use/management, the provision of certain urban ecosystem services and the need for better tools and techniques to support urban land use planning in this regard – falls within this category and, as such, the adoption of an integrated research approach has been considered appropriate.

Stock and Burton (ibid) define three broad categories of integrated research: 1) multidisciplinary; 2) interdisciplinary; and 3) transdisciplinary. The approaches are considered within a hierarchy whereby multidisciplinary approaches are the least integrated and transdisciplinary the most. Stock and Burton (ibid) characterise interdisciplinary research approaches variously though key characteristics include the use of an iterative research process (section 2.2), a problem solving focus (section 2.1.1), the involvement of multiple disciplines and the crossing of epistemological boundaries (section 2.1.1). These key characteristics and others have helped to shape the approach adopted in this research as outlined in sections 2.1.1, 2.1.2 and 2.2. In particular, this research focuses on close integration and cooperation in order to bridge disciplinary viewpoints. As described at section 2.1.2 and shown on Figure 2.1, this approach has been framed within the overarching theoretical framework of ecosystem services which, by its very nature, is an integrating concept. Chapter 3 includes a detailed discussion of ecosystem services theory as it relates to the aims, objectives and questions posed by this research.

2.1.4 Choosing a pilot urban centre

As described at section 1.4, a key part of the overall aim of this research is the development, trialling and evaluation of new approaches to urban planning that can operationalise the ecosystems approach (see Research Objectives Nos. 4 and 5 in Box 1.2). As explained at section 2.1.1, this research has been approached through a pragmatic worldview whereby the intention has always been for the research to help identify practical solutions to 'real world' urban sustainability problems (see Chapter 1). In this regard, key aspects of the research have focussed on a pilot urban centre whereby the new approaches developed in this research have been tested in one location to understand their applicability in other contexts as well. In this regard, the research process has been influenced by policy, legislation, institutions, data availability and stakeholders of relevance to the specific pilot urban centre. This has influenced various aspects of research design including the choice of methods and the scope of data collection. The focus on a pilot urban centre will undoubtedly influence the scope and wider applicability of the research findings and conclusions. This is discussed at section 9.4.

As outlined at section 1.4, Glasgow (Scotland, UK) has been used as the pilot urban centre. Cresswell (2009) describes how the researcher's personal experiences are one of the criteria for selecting a research design (including the location, situation or context where the research will take place). The author's professional career to date has focussed on Scotland and Glasgow, including three years working for Glasgow City Council (2010 – 2013) as an environmental planner/strategic environmental assessment (SEA) officer. As such, the author's experience and familiarity with relevant Scottish legislation, policy, research, data and stakeholders made Glasgow an obvious choice for a pilot urban centre. Access to stakeholders and data (especially at GCC) was seen as a particular strength in this regard.

2.2 Description of the research process

Section 2.1 describes the overall research design and theoretical framework that has underpinned this research. Section 2.2 builds on this, describing the overall research process adopted in terms of the individual steps and the interaction therein. Each step is described individually including the following information: 1) links to specific Research Objectives; 2) links to specific data collection and/or analysis methods used; and 3) cross-references to later Chapters of the thesis where relevant results and/or analysis are documented. The overall process followed in this research is indicated on Figure 2.2 and summarised in Table 2.1.

Table 2.1 Research process summary

Research step	Research Objectives	Data collection and/or analysis method(s)	Relevant thesis Chapter(s)
Step 1: Review key policy and literature and scope the research	1	Document review	Evidence assessment – Chapter 3
Step 2: Initial review and assessment of technical literature	2	REA; Coding; and Integrative diagrams	Evidence assessment – Chapters 3, 4 and 5
Step 3: Review and evaluation of existing approaches	3	Document review; and Criteria based evaluation	Evidence assessment – Chapter 6
Step 4: Initial development of spatial models	4	Use of ArcGIS	Spatial models – Chapters 7 and 8
Step 5: Pilot spatial models	4	Action research; and Use of ArcGIS	Spatial models – Chapters 7 and 8
Step 6: Follow-up review and assessment of technical literature	2	REA; Coding; and Integrative diagrams	Evidence assessment – Chapters 3, 4 and 5
Step 7: Validate key findings through expert interviews	All objectives	Semi-structured interviews; and Coding	Evidence assessment – Chapters 3, 4 and 5
Step 8: Refine spatial models	4	Use of ArcGIS	Spatial models – Chapters 7 and 8
Step 9: Develop ecosystems approach principles and technical guidance	4	Coding; and Integrative diagrams	Spatial models – Chapter 8
Step 10: Evaluate new theories and approaches	5	Criteria based evaluation	Conclusions – Chapter 9

2.2.1 *Overall approach – grounded theory*

As described at section 2.1.2, this research has adopted a strategy of enquiry loosely based on grounded theory. A grounded theory approach derives general abstract theories from multiple stages of data collection and analysis to understand relationships between emerging categories (Cresswell, 2009; Bryman, 2012; Dick, 2012). In practical terms, this research has used a grounded theory type approach to develop an understanding of the relationship between urban land use/management and the provision of certain ecosystem services (broadly akin to ‘concepts’ and ‘categories’ in terms of grounded theory literature). This understanding has then been used to develop and trial new approaches to urban land use planning that integrate the principles of the ecosystems approach (broadly similar to ‘hypotheses’ and ‘theories’ in terms of grounded theory literature). Within this thesis, the ‘understanding’ aspect has been framed as an evidence assessment (see Chapters 3 – 6) that provides the technical basis for developing the new ‘approaches’ (see Chapters 7 and 8). Where relevant, the sub-sections below align the process followed in this research to the process and outcomes of a grounded theory approach.

2.2.2 Review key policy and literature and scope the research

Step 1 collected and analysed data that directly supported Research Objective/Question No.1. The main purpose of Step 1 was to identify ecosystem services that are particularly important for the sustainability of urban centres located in northern Europe. In essence, Step 1 acted as a scoping exercise, identifying the key urban ecosystem services that then became the thematic focus of the research in subsequent data collection and analysis steps (e.g. which aspects of the literature to focus on as part of the REA in Steps 2 and 6 and what questions to pose to the experts in Step 7). The focus on northern Europe reflects the use of Glasgow as a pilot urban centre (see section 2.1.4).

Step 1 used a document review methodology to analyse key European Union (EU) and Scottish Government policies and reports to form a view on the challenges facing northern European urban centres (and Glasgow/Scotland) and therefore the urban ecosystem services that could potentially help to address these challenges. In this regard, Step 1 can be considered as an initial data collection stage within a grounded theory approach – i.e. it identified ‘coarse’ outline themes in terms of the ecosystem services that focussed subsequent stages of the research. In terms of grounded theory therefore, Step 1 produced outputs that can be considered broadly similar to ‘concepts’, which are defined as the “building blocks of theory” (Bryman, 2012 p.570). The methodology adopted in Step 1 is described at section 2.3.1. The results of Step 1 are outlined at section 3.2.5.

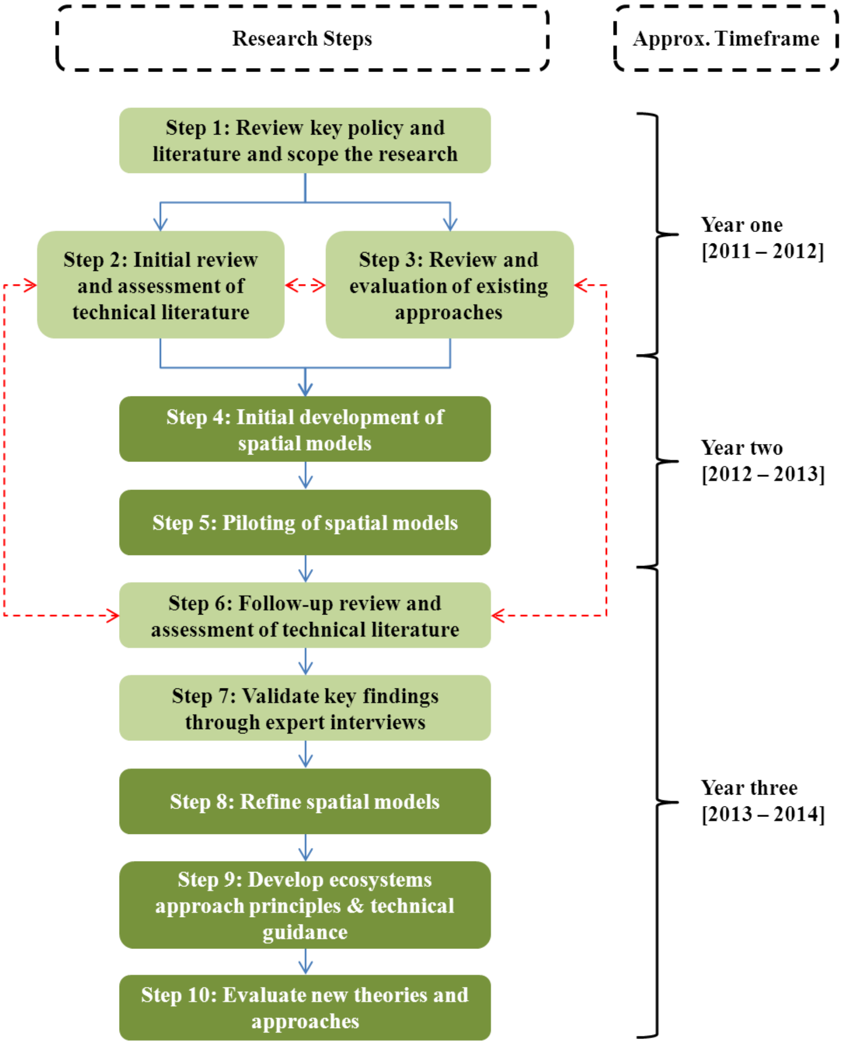


Figure 2.2 Schematic summary of the research process

Note: The Figure depicts the overall process followed in this research in terms of individual research steps and the interactions therein. Research steps that were particularly iterative are illustrated with red dashed lines. The Figure also provides an approximate indication of when individual research steps took place within the three year programme (2011 – 2014).

Key

Data collection
Data analysis & interpretation

2.2.3 *Initial review and assessment of technical literature*

Step 2 collected and analysed data that directly supported Research Objective/Question No.2. The main purpose of Step 2 was to collate initial data around the Step 1 themes to form an outline view of how urban land use/management might contribute to the enhancement and protection of the urban ecosystem services identified at Step 1. Crucially therefore Step 2 needed to identify the relevant disciplines and theories that could be investigated, through the relevant literature, in order to develop an understanding of how urban land use/management can impact the urban ecosystem services identified at Step 1. This is discussed at section 2.1.3.

Step 2 adopted a methodology based on the UK Government's Rapid Evidence Assessment (REA) approach (REA Toolkit Government Social Research website, undated). In practice this involved the identification and assessment of key literature relevant to the disciplines that provide the theoretical framing for the ecosystem services considered in the research[9] (see Figure 2.1). As such, this data provided the initial basis for thinking about hypotheses and potential new theories for ecosystems approach based urban land use planning. In terms of grounded theory therefore, Step 2 was an integrated data collection, coding and constant comparison process (Bryman, 2012; Dick, 2012) producing outputs that can be considered broadly similar to 'categories', defined as "concepts that have been elaborated so that they can be regarded as representing real-world phenomena" (Bryman, 2012 p.570). In particular, Step 2 took the coarse themes/ecosystem services identified at Step 1 and developed an initial understanding of how these can be influenced, in an urban context, through practical land use/management action on the ground – i.e. the translation of broad themes identified in strategic policy into more practical themes that can be understood in specific 'real-world' urban planning contexts. The methodology adopted in Step 1 is described at section 2.3.2. The results of Step 2 are integrated with the results of Step 6 in Chapters 3, 4 and 5.

2.2.4 Review and evaluation of existing approaches

Step 3 collected and analysed data that directly supported Research Objective/Question No.3. Step 3 recognised that examples of urban land use planning frameworks adopting the ecosystems approach were likely to be available

---

[9] An REA is different from a systematic review of literature as it is more defined in terms of its scope (e.g. there is less potential for 'snowballing'). This is explained further at section 2.3.2.

for study. The main purpose of Step 3 therefore was to identify and evaluate existing approaches, highlighting relevant lessons from existing practice – i.e. the identification of possible extant theories that could be considered in conjunction with data produced through other research steps, to help formulate hypotheses and new theories for urban land use planning. In this regard, Step 3 was undertaken in parallel with Step 2, supporting the integrated analysis of data and potential hypotheses and theories. Step 3 used a document review methodology to evaluate key documents relating to the existing land use planning frameworks considered (three examples). In this instance, the Convention on Biological Diversity (CDB) ecosystems approach principles (CBD Secretariat, 2013a) were used as criteria for the document review and evaluation to provide a focus on the key issues that mattered for the research – i.e. how were ecosystem services and the ecosystems approach being considered and what could be learnt for wider practice? Similarly to Step 2 therefore, Step 3 produced outputs that can be considered broadly similar to 'categories' in terms of grounded theory. The methodology adopted in Step 3 is described at section 2.3.1. The results of Step 3 are described at Chapter 6.

2.2.5 Initial development of spatial models

Step 4 was an integrated data analysis step that directly supported Research Objective No.4. In practical terms, the main purpose of Step 4 was to link the initial understanding of urban land use/management's potential impact on key urban ecosystem services (Steps 1 – 3) to existing spatial datasets and spatial analysis techniques that could be used to develop practical tools, techniques and modelling/scenario evaluation frameworks to support urban land use planning. In terms of grounded theory, Step 4 explored the 'concepts' and 'categories' identified through Steps 1 – 3, in an integrated manner, to scope initial 'hypotheses' and 'theories' for ecosystems approach based urban land use planning. Hypotheses are defined as "initial hunches about relationships between concepts" and theories as "a set of well-developed categories that are systematically related through statements of relationship to form a theoretical framework that explains some relevant phenomenon" (Bryman, 2012 p.570). In essence, Step 4 provided the space to explore the relationships between the 'concepts' and 'categories' identified at Steps 1

– 3. In practice, this exploration was facilitated through the integrated use of ArcGIS software, relevant existing spatial datasets, the suite of ArcGIS geoprocessing tools and ArcGIS ModelBuilder. In this manner, qualitative data from Steps 1 – 3 was integrated with spatial analysis in the GIS through the development of initial spatial models[10]. The specific analysis methodology adopted in Step 4 is described at section 2.4.1. The results of Step 4 analysis are integrated with the results of Step 8 in Chapters 7 and 8.

2.2.6 Piloting of spatial models

Step 5 collected and analysed data that directly supported Research Objective No.4. The main purpose of Step 5 was to provide a platform for testing the initial ‘hypotheses’ and ‘theories’ for ecosystems approach based urban land use planning developed at Step 4 (i.e. the initial spatial models). In practice, the Step 4 spatial models were piloted in live projects whilst the researcher was employed at Glasgow City Council (GCC). In this regard, an action research based approach was used whereby the researcher and members of a social setting (i.e. relevant urban land use planning stakeholders) collaborated to further develop the problem diagnosis (Steps 1 – 3) and to refine the potential solutions to this problem (Bryman, 2012; Dick, 2013) – i.e. the new ‘hypotheses’ and ‘theories’ for urban land use planning. An additional objective was to develop knowledge and understanding, as part of practice, within the social setting (Dick, 2013) – i.e. relevant urban land use planning stakeholders in Glasgow. A key outcome from Step 5 was an improved understanding of information needs in terms of ecosystem service inputs to land use planning decision-making processes. In terms of grounded theory, Step 5 further explored the ‘concepts’ and ‘categories’ (Steps 1 – 3) and helped to refine the initial ‘hypotheses’ and ‘theories’ for ecosystems approach based urban land use planning (Step 4). The specific data collection and analysis methodology adopted in Step 5 is described at section 2.3.4. The results of Step 5 are integrated with the results of Steps 4 and 8 in Chapters 7 and 8.

---

[10] In this regard, although the methodology adopted in this research is primarily qualitative, there is a small element of mixed methods given the use of quantitative spatial datasets (e.g. habitats, elevation).

2.2.7 Follow-up review and assessment of technical literature

Step 6 collected and analysed data that directly supported Research Objective/Question No.2. As indicated on Figure 2.2, Step 6 was iterative with Steps 2 and 3. The main purpose of Step 6 therefore was to develop and refine data collection from Steps 2 and 3 in response to the analysis at Steps 4 and 5, thereby addressing data deficiencies/gaps highlighted by the pilot phase at Step 5. Step 6 adopted the same data collection methodology as Step 2 (see section 2.3.2). In terms of grounded theory therefore, Step 6 can be regarded as a further iteration of the data collection, coding and constant comparison processes (Bryman, 2012; Dick, 2012) undertaken at Step 2. In Step 6 however, a key objective was to saturate the ‘categories’ (ibid) identified at Steps 2 and 3 to provide a robust basis for developing the initial ‘hypotheses’ and ‘theories’ from Steps 4 and 5 into more substantive theories. In practical terms, the saturation of ‘categories’ directly informed the scope and structure of the three evidence assessment Chapters – 3, 4 and 5.

2.2.8 Validate key findings through expert interviews

Step 7 collected data that supported all five Research Objectives. The main purpose of Step 7 was to engage land use/management planning experts, through a semi-structured interview process, in order to validate key findings from the preceding Steps, especially those that informed the evidence assessment – i.e. Steps 1, 2, 3 and 6. In this regard, Step 7 gathered expert views on the initial hypotheses and theories that underpinned the initial development of spatial models at Steps 4 and 5. In terms of grounded theory therefore, Step 7 can be regarded as an additional data collection process that contributed to the further saturation of categories and, crucially, the testing of hypotheses (Bryman, 2012; Dick, 2012). The specific data collection methodology adopted in Step 7 is described at section 2.3.3. The results of Step 7 are integrated with the three evidence assessment Chapters – 3, 4 and 5 and the conclusions at Chapter 9.

2.2.9 Refine spatial models

Step 8 was an integrated data analysis step that directly supported Research Objective No.4. Step 8 involved a similar process to Step 4 although it was based on refined ‘categories’ and ‘hypotheses’ following input from Steps 5, 6 and 7. The specific analysis methodology adopted in Step 8 is described at section 2.4.2. The results of Step 8 analysis are integrated with the results of Step 4 in Chapters 7 and 8.

2.2.10 Develop ecosystems approach principles and technical guidance

Step 9 was a further integrated data analysis step that directly supported Research Objective No.4. The main purpose of Step 9 was to review all data collected, analysed and documented as part of the evidence assessment (Chapters 3, 4, 5 and 6) as a final refinement of the new hypotheses and theories for urban land use planning developed through all preceding steps. In practice, Step 9 resulted in the development of the following: 1) an overarching set of guiding principles for ecosystems approach based urban land use planning; and 2) technical guidance to support stakeholders to interpret and act on spatial model outputs (see Step 8) in the development of integrated urban land use/management strategies. In terms of grounded theory therefore, Step 9 was a final further refinement of hypotheses testing and checking that resulted in the development of theory (Bryman, 2012). This thesis argues that the theories/theoretical framework developed through this research – i.e. the new tools, models and guidance for ecosystems approach based urban land use planning – can be considered ‘formal’ as per Bryman (ibid). In effect, the new theories developed through this research are based, in part, on existing theory and research as per the theoretical framework outlined at section 2.1.3 and Figure 2.1. The specific analysis methodology adopted in Step 9 is described at section 2.4.1. The results of Step 9 analysis are integrated with the results of Step 4 and 8 in Chapters 7 and 8.

2.2.11 Evaluate new theories and approaches

Step 10 was an analysis step that directly supported Research Objective No.5. The main purpose of Step 10 was to evaluate the new theories and approaches developed through the preceding steps. In practice, Step 10 adopted the same approach as Step 3 – i.e. using the CBD ecosystems approach principles as evaluation criteria to form a view on the degree to which the new theories and approaches might support an ecosystems approach to urban land use planning. The specific analysis methodology adopted in Step 10 is described at section 2.4.1. The results of Step 10 are described in Chapter 9.

2.3 Data collection methods

This section describes the four key data collection methods adopted in this research including the rationale behind their use. Cresswell (2009) describes how qualitative research must purposefully select the participants, sites and documents that will help the researcher understand the research problem. This includes specifying the type of data that will be collected and protocols for recording data. Where relevant, the sub-sections below provide this information.

2.3.1 Document review

Bryman (2012) highlights how existing documents can be a useful source of data though cautions that data collection in this regard must be undertaken in a structured manner to ensure that the meaning of the material uncovered can be understood. A document review methodology was adopted in Steps 1 (section 2.2.2) and 3 (section 2.2.4). Key methodological issues were: 1) the choice of documents to review; and 2) the selection of criteria with which to review the documents.

In Step 1, EU and Scottish Government policies and official reports were reviewed to scope urban ecosystem services for consideration in subsequent steps of the research (see section 2.2.2). In terms of Bryman's (ibid) categorisation of documents, EU and Scottish Government policies and official reports would be described as official state documents. In this regard, the documents reviewed in Step 1 are considered to be authentic, credible and representative (ibid). Documents were identified for review initially on the basis of the researcher's existing knowledge[11] of EU and UK/Scottish Government policy on urban land use, sustainability, climate change, natural environment and ecosystem services. These documents are highlighted in Table 2.2. Additional relevant documents were identified from the initial list and reviewed also (see Table 2.2). The review was undertaken on the basis of broad review criteria to identify urban ecosystem services that might be particularly relevant in northern European urban centres:

- **Geography**

---

[11] Based on seven years' professional experience in the fields of environmental and sustainability policy and assessment.

  - Does the document refer specifically to urban centres in northern Europe/the UK/Scotland?
- **Urban nature**
  - Does the document refer to urban nature/the natural environment?
  - Does it discuss the benefits of urban nature?
- **Urban challenges**
  - Does the document discuss pressures/challenges facing urban areas?
  - Does it outline green infrastructure/ecosystem service/nature based responses to these challenges?
- **Ecosystem services**
  - Does the document refer explicitly to urban ecosystem services?

In Step 3, documents relating to example ecosystems approach based land use planning frameworks were reviewed to identify possible lessons for wider practice. Three example approaches for the review were identified on the basis of the author's knowledge and awareness[12] of UK based practice and through informal discussions with colleagues and associates. As such, it is important to stress that Step 3 was intended to be illustrative rather than exhaustive – i.e. it was intended to identify possible broad lessons for wider practice as opposed to specific hypotheses or theories (see section 2.2.4). In this regard, two of the three examples reviewed were known to the researcher – this was seen as pragmatic in terms of ensuring access to relevant documents for the review.

Once the three examples had been identified, documents were identified for review through: 1) internet searches; 2) reviewing organisation websites; and 3) contacting named/known individuals. All three examples were in the public sector. As such, the reports reviewed would be described as official state reports in terms of Bryman's (2012) categorisation of documents. In this regard, the documents reviewed in Step 3 are considered to be authentic, credible and representative (ibid). Documents were collated and then reviewed using review criteria – the CBD ecosystems approach principles were framed as criteria in this regard (see Table 2.3).

---

[12] Ibid

A simple data collection protocol was used to store document review data for analysis at a later stage (see Table 2.4).

Table 2.2 Documents considered in the Step 1 document review

	Review criteria			
Document	**Geography**	**Urban nature**	**Urban challenges**	**Ecosystem services**
Documents identified on the basis of the researcher's existing knowledge				
The European Environment State and Outlook 2010: Urban Environment (EEA, 2010a)	Y	Y	Y	Y
Adapting to Climate Change: Towards a European Framework for Action (EC, 2009)	N	Y/N	Y/N	Y/N
Europe 2020: a Strategy for Smart, Sustainable and Inclusive Growth (EC, 2010)	N	N	Y	Y/N
Our Life Insurance, Our Natural Capital: an EU Biodiversity Strategy to 2020 (EC, 2011)	N	N	N	Y/N
Getting the Best From our Land – a Land Use Strategy for Scotland (Scottish Government, 2011d)	Y	Y	Y	Y
UK National Ecosystem Assessment Urban Chapter (Davies et al, 2011)	Y	Y	Y	Y
Flood Risk Management (Scotland) Act 2009: Delivering Sustainable Flood Risk Management (Scottish Government, 2011a)	Y	Y	Y	Y
Additional documents identified through the initial review				
The European Environment State and Outlook 2010: Land Use (EEA, 2010b)	Y	Y/N	Y	Y/N
Scottish Climate Change Information: UKCP09 Compendium (SCCIP, 2009)	Y	N	Y	N
Scotland's Climate Change Adaptation Framework (Scottish Government, 2009c)	Y	N	Y	Y/N
Scottish Planning Policy (Scottish Government, 2010b)	Y	Y	Y/N	N

Note: The Table indicates where the review criteria were met in each of the documents reviewed. Y = criteria met; N = criteria not met; and Y/N = criteria met to a degree (e.g. urban nature was discussed but not in terms of the benefits that it can provide).

The overall review in Step 3 was guided by the use of specific research questions. These informed the development of the review criteria (see Table 2.3) and the overall focus of the review. The findings of the Step 3 review, as documented in Chapter 6, have also been framed in terms of the research questions which are:

- To what degree have the CBD ecosystems approach principles been considered in the example land use planning frameworks? Which principles have been considered?
- What types of method/approach have the example land use planning frameworks used to consider the CBD principles in their land use/management planning?
- What are the main strengths and weaknesses of the example land use planning frameworks in terms of how they have considered the CBD principles?

Table 2.3 Evaluation criteria for the Step 3 document review

(Adapted from CBD Secretariat, 2013a; Phillips et al, 2014)

CBD ecosystems approach principle	Evaluation criteria for Step 3 document review
EsA1	1. Does the approach define ecosystems or landscapes? 2. Does the approach operate at a spatial scale such that it is likely to encompass multiple ecosystems? 3. Does the approach consider the effects of land use/management on adjacent ecosystems, either implicitly or explicitly?
EsA2	1. Does the approach discuss ecosystem processes/intermediate services? 2. Does the approach discuss ecosystem structure? 3. Does the approach include specific methodologies for evaluating land use/management impacts on ecosystem structure and function?
EsA3	1. Does the approach refer to environmental limits? 2. Does the approach define specific environmental limits (e.g. for environmental state or ecosystem service indicators)? 3. Does the approach include specific methodologies for evaluating land use/management impacts on environmental limits?
EsA4	1. Does the approach work at the ecosystem or landscape scale? 2. What is the rationale for spatial delineation of the area of land encompassed by the approach (e.g. based on administrative boundaries or natural features)? 3. Is the temporal scope of the approach sufficient such that ecosystem restoration projects can be planned and delivered effectively?
EsA5	1. Does the approach set long term objectives (e.g. >10 years)? 2. Does the approach discuss the varying temporal scales and lag effects that characterise ecosystem processes and their restoration?
EsA6	1. Does the approach recognise the dynamic nature of landscapes and ecosystems? 2. Does the approach discuss how change is inevitable?
EsA7	1. Does the approach discuss the costs and benefits associated with land management for different objectives? 2. Does the approach attempt to integrate non-market values of ecosystem services with decision-making? 3. Does the approach consider how grants, incentives and regulation can be used to influence land use/management objectives (including private objectives)?

CBD ecosystems approach principle	Evaluation criteria for Step 3 document review
EsA8	1. Does the approach have an overarching objective on the conservation of biodiversity? 2. Does the approach seek to balance the use and conservation of biodiversity? 3. Does the approach employ a specific mechanism in place to help balance the conservation and use of biodiversity?
EsA9	1. Does the approach seek to engage the public and affected communities in land use/management decision-making? 2. Does the approach employ specific consultation and engagement techniques?
EsA10	1. What steps does the approach take to decentralise land use/management planning to local levels? 2. Is there evidence of decentralisation of land use/management decision-making happening in practice?
EsA11	1. What steps does the approach take to glean knowledge and ideas from all sectors of society to inform land use/management decision-making? 2. Is there evidence of diverse information, innovation and practice informing decision-making?
EsA12	• As per EsA11

Note: See Table 3.8 for full details of the CBD ecosystems approach principles.

Table 2.4 Data collation protocol for Step 3 document review

Document reference		Notes	Relevant evaluation criteria
Title/Author/ Year		• *Brief notes outlining how the specific reference supports or works against ecosystems approach principles as informed by the evaluation criteria* • *Brief notes on methods/approaches evidenced that may be useful in other land use planning contexts*	*List the criteria from Table 2.3 to which the note/reference applies*
Page number			
Paragraph number			

2.3.2 *Rapid evidence assessment*

The overall approach to this research is loosely based on grounded theory (see section 2.2.1). In this regard, data has been collected and analysed to inform the development of new hypotheses and theories for urban land use planning. In practical terms, this involved developing an understanding of the relationship between urban land use/management and the provision of certain[13] urban ecosystem services to then develop new tools, techniques and modelling/scenario evaluation frameworks for urban land use planning (see sections 1.4 and 2.1.1). The 'understanding' component of this approach was predicated on the collection of qualitative data from key technical literature relating to the ecosystem services under consideration[14],

---

[13] The research focussed on specific urban ecosystem services as defined through Step 1 of the research – see sections 2.2.2, 2.3.1 and 3.2.5

[14] Ibid

especially Scottish Government policy, guidance documents and other official reports, articles from peer reviewed academic journals and relevant gray literature.

Table 2.5 Research questions addressed in the Rapid Evidence Assessment (REA)

Overarching question	**Detailed research questions**
How does urban land use/management impact the functioning of urban ecosystems and the provision of certain urban ecosystem services?	**Urban land use planning and ecosystems approach questions**
	1. What opportunities are there to integrate consideration of the natural environment and ecosystem services into urban land use planning in Scotland? 2. How can the urban natural environment be characterised and defined for the purposes of ecosystems approach based urban land use planning? 3. What is the relationship between ecosystem health/function and ecosystem services? How can ecosystems be managed for the provision of specific ecosystem services? 4. Which ecosystem services can the urban natural environment provide? Which services are particularly important for northern European urban centres? 5. What are the key principles of the ecosystems approach and how can they be operationalised in decision-making processes?
	Urban land use planning and water management questions
	1. What are the key natural processes that influence the hydrology of urban catchments? 2. How can the management and use of urban land influence the provision of water management related ecosystem services in urban areas? 3. What are the main techniques available for land use/management based urban water management?
	Urban land use planning, landscape ecology and habitat network questions
	1. What factors influence species movements in urban areas? 2. How can the management and use of urban land influence the provision of ecological connectivity related ecosystem services in urban areas? 3. What are the potential multiple benefits of natural/semi-natural habitats and habitat networks in urban areas?

Note: The overarching question shown above relates directly to Research Objective No.2 as outlined at the start of this Chapter. The REA research questions were framed in terms of the key ecosystem services identified through Step 1 of the research (see sections 2.2.2 and 3.2.5).

Given the broad scope of theories underpinning the ecosystem services considered in this research (e.g. from landscape ecology and hydrology to urban planning/design and physical geography – see Figure 2.1), it was considered necessary to adopt a fairly streamlined approach to the review of technical literature and collection of data from this literature (reflecting the researcher’s pragmatic worldview – see section 2.1.1). In this regard, a full systematic review (Bryman, 2012) of literature was considered to be too unwieldy. Instead, an approach based loosely on the UK Government’s Rapid Evidence Assessment (REA) approach was used (REA Toolkit Government Social Research website, undated; Twigger-Ross et al, 2014). REAs can be used to provide a balanced assessment of what is already known about a policy or practical issue (e.g. ecosystems approach based urban land use planning) through the use a systematic review methodology to search and then critically appraise existing research (ibid). This level of detail was considered appropriate to provide a broad understanding that could underpin the development of new urban planning approaches.

Table 2.6 Literature interrogation and data collation protocol for Steps 2 and 6

(Adapted from: Public Health Resource Unit, 2006; Twigger-Ross et al, 2014)

<table>
<tr><td colspan="6">**Screening protocol – review the abstract/executive summary**</td></tr>
<tr><td>*Are the findings, scope, objectives relevant?*</td><td>Yes</td><td>No</td><td rowspan="2">*Should the reference be retained for detailed interrogation?*</td><td rowspan="2">Yes</td><td rowspan="2">No</td></tr>
<tr><td>*Is the approach adopted thorough, rigorous and appropriate?*</td><td>Yes</td><td>No</td></tr>
<tr><td colspan="6">**Reference categorisation protocol**</td></tr>
<tr><td colspan="3">*Which of the scoped in ecosystem services from Step1 is the reference relevant to?*</td><td colspan="3">*Tick all that apply*
• Flood storage
• Runoff reduction
• Habitat networks</td></tr>
<tr><td colspan="3">*Which of the detailed research questions (see Table 2.5) is the reference relevant to?*</td><td colspan="3">*List all that apply*</td></tr>
<tr><td colspan="6">**Technical review and data collation protocol**</td></tr>
<tr><td colspan="6">**Theory:** Identify, record and reference all relevant information that can support the theoretical basis and understanding of the research across the following disciplines:
• Ecology
• Landscape ecology
• Hydrology
• Hydraulics
• Physical geography
• Planning</td></tr>
<tr><td colspan="6">**Policy:** Identify, record and reference all relevant information that can support an understanding of the policy framework for ecosystems approach based urban land use planning. This should focus on the key ecosystem services considered in the research and cover the following:
• European Union (EU) policy
• UK Government policy
• Scottish Government policy</td></tr>
<tr><td colspan="6">**Technical information:** Identify, record and reference all relevant technical information:
• Example approaches, for example
○ SuDS use in specific contexts
○ River restoration strategies/approaches for specific contexts
• Technical principles that can be applied in a range of contexts, for example
○ Principles of conservation management
○ Influence of land use on natural drainage processes
○ Factors influencing the hydraulic properties of the floodplain
○ Factors influencing runoff generation
Note: Technical principles are potential parameters for spatial models and/or can help to scope data requirements for models. Example approaches provide guidance for interpreting and acting on model outputs in the development of integrated urban land use/management strategies.</td></tr>
</table>

The data collection component of the REA type approach adopted in this research involved three main stages: 1) defining the research questions; 2) developing the search strategy; and 3) data/evidence gathering. Data analysis methods are outlined at section 2.4.1. A question-led approach can help provide a clear statement that can be investigated and acts as the driver for all data collection from the literature (REA Toolkit Government Social Research website, undated; Twigger-Ross et al, 2014). The research questions considered are shown at Table 2.5. The questions were framed in terms of the key ecosystem services identified through Step 1 (see sections 2.2.2 and 3.2.5).

In terms of search strategy, literature was identified initially on the basis of the researcher's existing knowledge of the field (see section 2.3.1). This was supplemented with literature recommended by colleagues, associates and experts. For example, key Scottish Government policy and guidance on Flood Risk Management (FRM) were made known to the researcher by the Principal FRM Engineer at Glasgow City Council (GCC). Additional relevant literature was identified from the initial list also. This initial approach to search strategy can therefore be considered as 'expert-led' (Twigger-Ross et al, 2014). Following this, relevant databases were interrogated using defined key words for each research question identified at Table 2.5. For example, the question – *what are the key natural processes that influence the hydrology of urban catchments* – was searched on using the following key words and search strategy: **hydrological processes** AND **urban** AND **catchment**. A similar approach was adopted for each research question using the following databases:

- Abstracts in New Technology and Engineering
- Civil Engineering Abstracts
- Engineering Village
    - Compendex
    - Inspec
    - GEOBASE
- Ecology Abstracts

- Environmental Engineering Abstracts
- Sustainability Science Abstracts

Based on an initial review of the literature and the key ecosystem service themes identified through Step 1 of the research (see section 2.2.2), a draft literature map was developed to provide a visual summary of relevant research done by others (Cresswell, 2009) as well as government policy and guidance in this instance. This helped to organise the literature before it was interrogated systematically as part of data/evidence gathering. A final map of the literature considered in this part of the research is provided at Appendix 1. Once the literature had been organised in this manner, it was then interrogated as per the protocol outlined at Table 2.6. Data collated through this process was kept in note format – the synthesis of the REA type process adopted in this research is documented in Chapters 3, 4 and 5.

2.3.3 Action research

Year 2 of the research (see Figure 2.2) was undertaken while the researcher was employed at Glasgow City Council (GCC) as an environmental planner/strategic environmental assessment (SEA) technical officer. The research problem under investigation was highly relevant to GCC who were in the process of preparing their Local Development Plan (LDP) Main Issues Report (MIR) at the time (see section 3.1). As such, it was considered useful for both parties if key aspects of the research were undertaken collaboratively with GCC. In this regard an action research approach was adopted in Step 5 of the research (see section 2.2.6) while the researcher had ready access to urban land use/management planning stakeholders constituting a 'social setting' in terms of the literature (Bryman, 2012).

Dick (2013) highlights how an action research approach can be useful where there is a wish to involve people in the system being researched (i.e. urban land use planning) and/or a wish to bring about change at the same time as the research. Both of these characteristics applied in this instance. Firstly, it was considered useful and appropriate to involve land use/management planning stakeholders in order gather their views on the initial spatial models developed at Step 4 (see section 2.2.5) and to develop an understanding of stakeholder's practical information needs in terms of ecosystem service inputs to urban land use planning processes. Secondly, land use/management stakeholders in GCC had expressed a wish to learn more about ecosystem services and the ecosystems approach, particularly in relation to informing proposals within the LDP MIR that was being developed at the time.

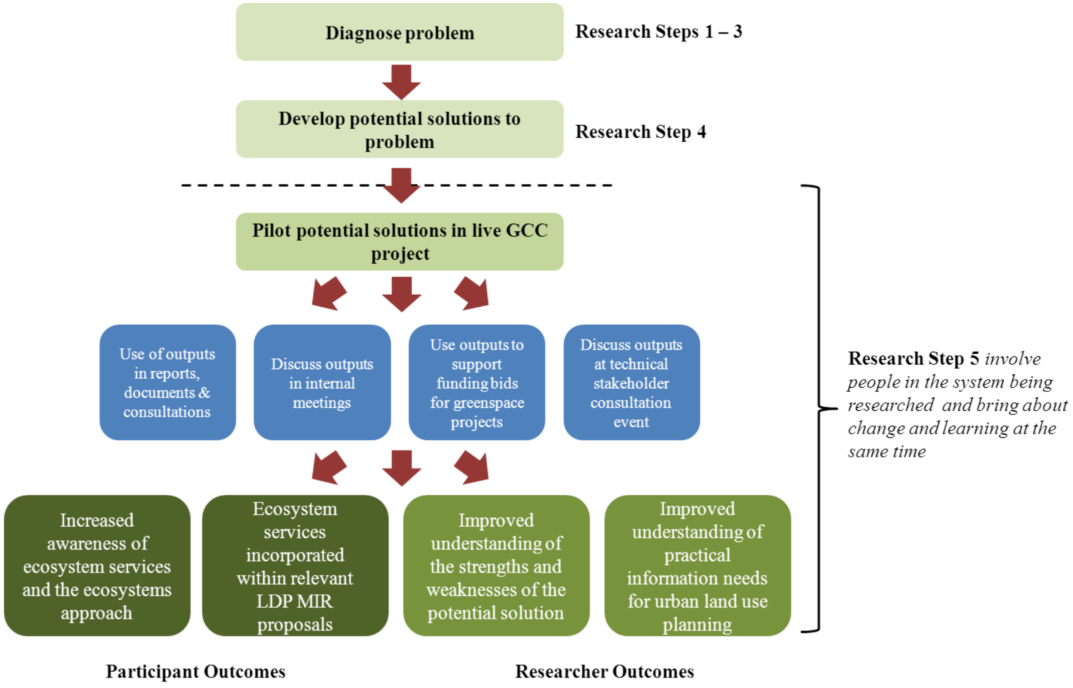


Figure 2.3 Overall action research approach in the testing of spatial models – Step 5

(Adapted from: Bryman, 2012; Dick, 2013)

Note: The dashed line indicates the start of the action research based approach in Step 5. Blue boxes indicate how participants were involved in the action research – i.e. improving the potential solutions to the problem identified at Step 4. The boxes at the bottom indicate the outcomes of action research for the participants (left-hand side) and the researcher (right-hand side).

Figure 2.3 provides a schematic representation of the action research methodology adopted in Step 5. In this instance, the process of diagnosing the problem and developing a potential solution to the problem (Bryman, 2012) had been undertaken by the researcher independently of the participants in Steps 1 – 4 of the research (see section 2.2). In this regard, participant input was used to reflect on and improve the potential solution (i.e. the new spatial models developed at Step 4) which was tested through a live GCC project[15]. The involvement of participants was facilitated through a variety of means as indicated by the blue boxes on Figure 2.3 e.g. discussing outputs in internal meetings and using outputs in reports, documents and consultations. Appendix 12 provides an example report detailing how the initial spatial models informed practical land use/management decision-making at GCC through their application scoping sites in a live project – the Glasgow 2014 Multifunctional Greenspace Project (MGP)[16]. The report at Appendix 12 demonstrates the applied application and success of the spatial models informing decision-making and supporting funding bid applications (see section 9.2.1 also).

2.3.4 Semi-structured interviews

Semi-structured interviews with experts were undertaken at Step 7 to validate and refine the evidence assessment undertaken at Steps 2, 3 and 6. The interviews also provided key data that helped to shape the hypotheses and theories developed in the research, especially the development of ecosystems approach principles and technical guidance at Step 9 (see section 2.2.10). An outline interview schedule was developed comprising mostly open-ended questions and some multiple choice questions. The questions were general in their frame and the interview protocol (see Table 2.7) allowed further questions to be asked as the interview progressed (Bryman, 2012). A full interview schedule is included at Appendix 2.

Table 2.7 Interview protocol for Step 7

(Adapted from: Cresswell, 2009; Bryman, 2012; University of Strathclyde, 2013)

Introducing the interview
• Introduce the research
○ The researcher – who I am
○ The university and the department
○ Interviewees provided with a copy of the research framework: 1) title; 2) aims; and 3) objectives
• Introduce the interview
○ Structure

---

[15] The initial spatial models were used to identify sites and potential interventions as part of the Glasgow 2014 Multifunctional Greenspace Project (the MGP) – one of nineteen 'greener theme' legacy projects being developed as part of the Glasgow 2014 Commonwealth Games. Further information on the MGP and the use of the spatial models in this regard is provided at Appendix 12. http://www.glasgow.gov.uk/index.aspx?articleid=11143 [accessed 20/04/14]

[16] Ibid

Introducing the interview

  - How the data will be recorded
- Outline how the interview data will be collated and used
- Outline the ethical considerations
  - Chatham House rules – no attributable quotations used in the thesis unless with prior consent of the interviewee
  - Consent forms

Undertaking the interview

- Answers recorded in interview notes as a written record
- Questions to be asked exactly as written on the interview schedule
- Keep to time
  - No more than 1 hour for the whole interview
  - Allow interviewees to develop trails of thought but ensure all questions are asked
- Ask additional questions as required
- Final thank you statement to acknowledge the time the interviewee spent during the interview

Five expert interviews were undertaken. Interviewees had a range of expertise (see Table 2.8), gained from 15-25 years professional work, but were recruited from the author’s existing network. Given that all interviewees were known to the author there is a risk that such familiarity may lead to biased responses. This risk was mitigated by: 1) where possible, ensuring that interviewees were in senior positions within their respective organisations; and 2) ensuring that the interview protocol was followed closely (see Table 2.7). Interviews were carried out in accordance with the University of Strathclyde’s ethical code of practice (University of Strathclyde, 2013) including the specific measures outlined in the intervention protocol at Table 2.7. Detailed interviews were undertaken lasting approximately one hour and comprising 28 questions.

Table 2.8 Step 7 expert interviews – interviewee expertise

Interviewee reference	Interviewee expertise
I-1	Woodland ecology; land use of all kinds; practical conservation management (i.e. nature reserves); practical management of various ecosystems; access
I-2	Land use planning; ecology
I-3	Landscape architecture; urban design; working at a range of scales from detailed design and implementation up to masterplan and urban strategy
I-4	Management; flood risk management (FRM); contaminated land; environmental management
I-5	Landscape scale urban planning; strategic physical planning; making projects happen on the ground; people and place – improving peoples’ lives by addressing poor landscape quality

Question 2.2 in the interview schedule (see Appendix 2) asked interviewees to describe their expertise. The responses to this question provide a broad indication of the types of expert interviewed at Step 7. Responses to this question are indicated in Table 2.8 along with a reference for each interviewee that has been used throughout the thesis.

2.4 Data analysis methods

This section describes the two key data analysis methods adopted in this research including the rationale behind their use.

2.4.1 Analysis of qualitative data

As described at sections 2.1 and 2.2, this research has adopted a qualitative approach based loosely on grounded theory. As such, the data analysis methods have also been qualitative and based on grounded theory principles. A key principle in this regard is the identification of core concepts from the data and then the linking of these concepts to develop categories (Trochim, 2006; Cresswell, 2009; Bryman, 2012; Dick, 2012). These concepts and categories then form the basis for the development of hypotheses and then substantive and formal theories (ibid). Trochim (2006) defines three key analytical strategies for qualitative data, each of which have been adopted, to varying degrees, in the analysis of data in this research:

- **Coding** – a process for categorising qualitative data and for describing the implications and details of these categories
- **Memoing** – a process for recording the thoughts and ideas of the researcher as they evolve throughout the study
- **Integrative diagrams** – an analytical tool used to pull all of the detail together and to help make sense of the data, with respect to emerging hypotheses and theories

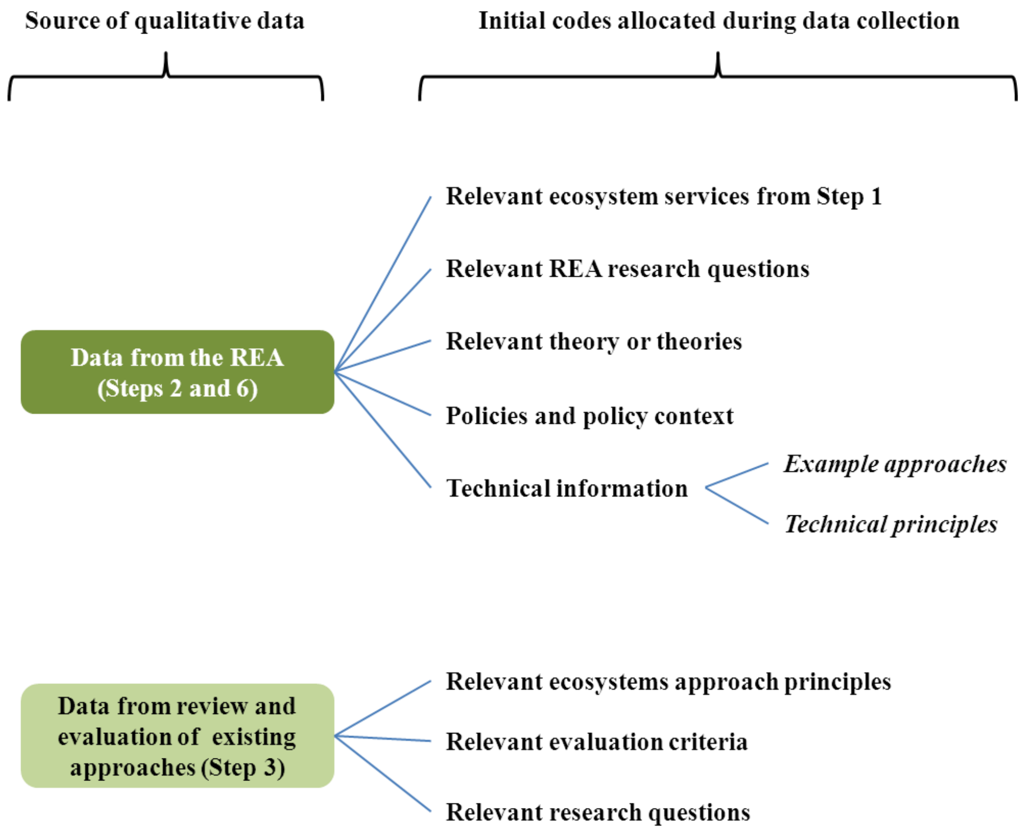


Figure 2.4 Initial codes allocated during data collection at Steps 2, 3 and 6

As intimated at sections 2.3.1 and 2.3.2, coding was, in part, undertaken simultaneously with data collection. In particular, the initial concepts identified through Step 1 – i.e. the ecosystem services considered in the research (see sections 2.2.2 and 3.2.5) – provided a framework for key data collection steps. In this regard, initial concepts and categories informed data collection protocols in Steps 2, 3 and 6 (see Tables 2.4 and 2.6), allowing data to be allocated to broad codes as it was collected (see Figure 2.4). The data was then subject to further analysis and coding, informing the synthesis of data as documented in the four evidence assessment Chapters in this thesis (see Chapters 3, 4, 5 and 6).

Memoing and integrative diagrams were used throughout the research. As indicated at sections 2.1 and 2.2, many factors influenced the research process including discussion and sharing of ideas with colleagues, associates, experts and of course the action research participants from Glasgow City Council (see section 2.3.3). As such, Memoing was a useful analytical device to keep track of emerging ideas, hypotheses and theories as the research developed. In practice, this equated to keeping notes within several notebooks during the lifetime of the project. Integrative diagrams were particularly helpful given the interdisciplinary nature of the research (see section 2.1.3 and Figure 2.1). The use of integrative diagrams in this regard helped to make sense of relationships between emerging hypotheses and theories, which often spanned multiple disciplines. Key examples of the use of integrative diagrams in this research can be found at Figures 3.10, 4.9 and 4.15 and Table 4.7.

2.4.2 Integrating qualitative data with existing spatial datasets in ArcGIS

The analysis of qualitative data from the REA (see sections 2.3.2 and 2.4.1) was used to identify key technical principles governing the impact of land use/management on the ecosystem services considered in this research e.g. the impact of slope on runoff generation (section 4.7.2), the impact of river morphology on flow velocity (section 4.5.3) and the impact of land use on landscape permeability for species (section 5.2.1). In effect, these are all factors that influence the value or importance of ecosystem services in a given context – e.g. runoff reduction services will be more valuable/important on steeply sloped ground located within catchments at risk of flooding. These factors are sometimes referred to as causal variables (CEP and Geodata Institute, 2008a; Eigenbrod et al, 2010; Sheate et al, 2012). Causal variables can help to illustrate the causal relationships between ecosystem services and the contextual factors that influence their value/importance. More often than not, causal variables are distinctly spatial in nature and can therefore be usefully considered within spatial analyses, facilitated through the use of Geographic Information Systems (GIS) technology.

A GIS combines hardware, software, data, people, procedures and institutional arrangements to collect, store, manipulate, analyse and display information about spatially distributed phenomena for the purpose of inventory, decision-making and/or problem solving (Jankowski, 2008; Ormsby et al, 2009; ESRI Overview webpage, undated). Crucially, the nature of GIS is such that it can work with a range of data, including qualitative and quantitative data, in a variety of ways. In particular, spatial features (polygons, lines, and points) stored in a GIS can be given attributes to link them to related datasets, recognising that there is more to a spatial feature than just its shape and location (Ormsby et al, 2009). Also, spatial features in a GIS can be analysed and integrated on the basis of their attributes e.g. through spatial models that solve problems analytically as part of a decision support system (ibid). In this regard, there are many examples of GIS applications that integrate qualitative data to add depth to spatial analyses or to further illustrate a spatial problem. For example, Jankowski (2008) discusses how the use of participatory GIS (P-GIS) tools can help the public to become more meaningfully involved in decision-making processes that affect communities and natural resources. Similarly, McCall (2003) outlines how P-GIS and the use of mobile GIS technology to capture qualitative data can be used as a means for greater participation in spatial planning. Ormsby et al (2009) explain how fields can be added to spatial datasets to capture any number of qualitative (or quantitative) attributes of spatial features.

Table 2.9 Causal variables and spatial datasets used in the new spatial models

Ecosystem service	Causal variable/contextual factor	Spatial datasets used in modelling
Flood storage See Chapters 4 and 7 for further information	**Fluvial flood risk:** flood extent and receptors affected under 1/200 year event, anticipated location of flooding within the catchment	• SEPA 1/200 year fluvial flood extent – *identifies the spatial extent of the flood hazard* • OS MasterMap – *identifies receptors affected by the flood hazard (e.g. homes, roads etc)*
	Morphology: presence and location of culvert and realignment pressures	• SEPA Water Framework Directive (WFD) pressures and measures dataset – *identifies the broad location of culvert and realignment pressures* • Historic map tiles – *identifies the historic, pre-modification route of the watercourse*
	Floodplain vegetation: type and location of existing vegetation cover, ecological potential to create new natural/semi-natural habitat – floodplain woodland and wetland	• PAN65 openspace – *identifies floodplain openspace that may be providing flood storage services already and/or that could be enhanced* • Glasgow and Clyde Valley (GCV) Integrated Habitat Network (IGN) Model data: ○ Habitat patches – *identifies existing floodplain habitat that could be providing flood storage service* ○ Low/high dispersal habitat network – *identifies potential area for habitat expansion within the floodplain* ○ Biodiversity opportunities – *identifies potential habitat expansion sites within the floodplain that are not within an existing functional habitat network*
	Floodplain topography: floodplain cross-section	• LiDAR topographical polylines – *used to evaluate*

Ecosystem service	**Causal variable/contextual factor**	**Spatial datasets used in modelling**
	gradient, presence and location of fine scale topographical features in the floodplain	*gradient of the floodplain cross-section*
Runoff reduction See Chapters 4 and 7 for further information	**Pluvial flood risk:** flood extent under 1/200 year event	• GCC 1/200 year pluvial flood extent – *identifies the spatial extent of the flood hazard and informs land use/management change for the enhancement of runoff reduction services*
	Topography: location of steeply sloped ground	• LiDAR topographical polylines – *used to construct a Digital Elevation Model (DEM) and identify areas of steeply sloped ground*
	Surface waterbodies: location, immediate catchment area	• GCC waterbodies dataset – *identifies the location of surface waterbodies and their immediate catchment (i.e. natural drainage features)*
	Impermeable ground: location, immediate catchment area	• OS MasterMap – *used to identify large areas of impermeable ground as a proxy for artificial drainage features*
Ecological networks See Chapters 5 and 7 for further information	**Habitat patches:** location, size **Functional habitat networks:** location, size **Ecological potential of land for habitat establishment:** location, value	• Glasgow and Clyde Valley (GCV) Integrated Habitat Network (IGN) Model data: ○ Habitat patches – *identifies existing habitat that could be protected and/or enhanced* ○ Low/high dispersal habitat network and biodiversity opportunities data – *integrated to identify management interventions to protect functional connectivity and prime sites for habitat creation that can contribute to enhanced functional connectivity*

This research has used GIS technology to integrate causal variables (as identified through the analysis of qualitative data – see Figure 2.2 and sections 2.3.2 and 2.4.1) with existing spatial datasets. Table 2.9 links the ecosystem services considered in this research to causal variables and spatial datasets. In essence, new spatial models have been developed that link existing spatial datasets with newly identified causal variables to identify where land use/management change may be required to protect or enhance the key ecosystem services considered in this research (see sections 2.2.2 and 3.2.5).

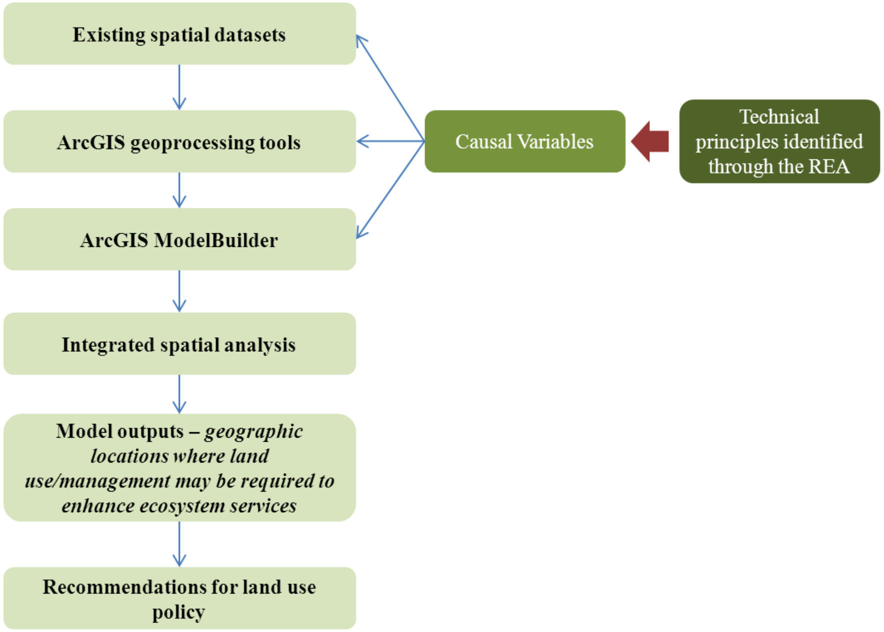


Figure 2.5 Analysis approach – integrating qualitative data with existing spatial datasets in ArcGIS

Note: Technical principles identified through the REA (see sections 2.3.2 and 2.4.1 and Figure 2.2) identified causal variables – the factors that influence the value/importance of ecosystem services in a given context. The causal variables data then informed the spatial analysis and the new spatial models thus: 1) identifying spatial datasets that could elucidate the causal variables in the spatial modelling (see Table 2.9); 2) helping to select geoprocessing tools and the setting of parameters therein (e.g. buffer distances, parameters for select operations); and 3) defining the integration sequence constructed in Arc ModelBuilder.

The overall approach to the GIS based analysis is shown at Figure 2.5 including examples of how qualitative causal variables data have informed the analysis. The research has used ESRI's ArcGIS software package including the full suite of geoprocessing tools (including spatial analyst[17] and 3D analyst[18]). The new spatial models have been constructed using ArcGIS ModelBuilder which is an application that allows users to create, edit and manage spatial models. Models in this regard are defined as "workflows that string together sequences of geoprocessing tools, feeding the output of one tool into another tool as input" (ESRI What is ModelBuilder webpage, 2012). Chapter 7 provides a detailed account of the structure, process and function of the three new spatial models.

---

[17] ESRI – What is the ArcGIS Spatial Analyst extension pages: http://resources.arcgis.com/en/help/main/10.1/index.html#/What_is_the_ArcGIS_Spatial_Analyst_extension/005900000001000000/ [accessed 22/04/14]
[18] ESRI – What is the ArcGIS 3D Analyst extension pages: http://resources.arcgis.com/en/help/main/10.1/index.html#/What_is_the_ArcGIS_3D_Analyst_extension/00q8000000wv000000/ [accessed 22/04/14]

The preceding Chapter describes the methodology adopted in this research. Chapter 3 overleaf is the first of the evidence assessment Chapters (see section 2.2) analysing the urban land use planning system in Scotland, the theory and science of ecosystem services and the interactions therein.

3. Urban land use planning and the ecosystems approach

As described at section 1.4, the overarching aim of this research is "to understand, develop, trial and evaluate new approaches to urban planning that can operationalise key aspects of the ecosystems approach". In order to meet this overarching aim, a substantive evidence assessment has been undertaken as documented in Chapters 3, 4, 5 and 6. The approach taken to the evidence assessment is described in the methodology Chapter at section 2.2. Section 2.4 describes how the data collated through the evidence assessment has been analysed to support other objectives of the research, especially the development of new approaches to urban planning that can operationalise aspects of the ecosystems approach (see Box 1.2).

The overall output of the evidence assessment is the development of a suite of new guiding principles for ecosystems approach based urban land use planning (see Appendix 3. The principles provide the overall framing for the new urban land use planning approaches developed through this research (see Chapters 7 and 8) and are intended to be of practical use in other urban planning contexts also. The evidence assessment has also informed the development of specific guidance to help practitioners interpret and act on outputs from the new models in the development of integrated urban land use/management strategies (see Chapters 7 and 8 and

Appendices 4, 5 and 6). This is the first of four chapters documenting the evidence assessment that has underpinned this research. The focus of this chapter is on urban land use planning in Scotland (section 3.1) and ecosystems approach concepts (section 3.2). In line with this focus, Chapter 3 has addressed five key research questions that informed the data collection activities undertaken (document review, REA and semi-structured interviews – see sections 2.3.1, 2.3.2 and 2.3.4) as well as providing a framing for the key findings of this part of the evidence assessment as discussed in the conclusions Chapter at section 9.2. The research questions considered within this part of the evidence assessment are as follows:

- What opportunities are there to integrate consideration of the natural environment and ecosystem services into urban land use planning in Scotland?
- How can the urban natural environment be characterised and defined for the purposes of ecosystems approach based urban land use planning?
- What is the relationship between ecosystem health/function and ecosystem services? How can ecosystems be managed for the provision of specific ecosystem services?
- Which ecosystem services can the urban natural environment provide? Which services are particularly important for northern European urban centres?
- What are the key principles of the ecosystems approach and how can they be operationalised in decision-making processes?

3.1 Urban land use planning – frameworks and opportunities in Scotland

Drawing on examples from the US, the UK and Scotland, section 1.3 provided an introduction to key urban land use planning concepts and objectives. Based on the examples considered, section 1.3 concluded that a key objective of urban land use planning is to help balance competing objectives/demands on land use. It also highlights how a plan document is frequently used to convey an agreed vision, objectives and strategy for future land use and development within the urban area. Chapter 6 looks specifically at existing examples of ecosystems approach based land use planning to identify elements of good-practice and gaps for consideration in this research, especially in relation to Research Objective No.4 (see Box 1.2).

The key purpose of this section therefore is to take a more detailed look at the existing system for urban land use planning in the pilot urban centre considered in this research – Glasgow (Scotland/UK)[19]. In doing so, the intention is to identify tangible opportunities within the existing plan-development process whereby the new urban planning approaches developed through this research (see Chapters 7 and 8), as well as ecosystems approach principles more generally, can be integrated. This has helped to ensure that recommendations developed through this research (see Chapter 9) are practical and grounded in reality[20] (i.e. linking specific outputs from the tools and models developed through this research to tangible decision-making windows within the plan-development process). The remainder of this section includes details of the land use planning system in Scotland (section 3.1.1), an analysis of the process for developing statutory urban land use plans in Scotland to identify opportunities for integrating ecosystems approach principles (section 3.1.2), a review of policy, practice and concepts used to define 'green' and 'natural environment' type urban land uses (section 3.1.3) and a review of Scotland's national level strategy for land use (section 3.1.4). As discussed at section 2.2.8, key findings from the expert interviews are included, where relevant, as a key component of the evidence assessment.

3.1.1 The land use planning system in Scotland

The Scottish Government (2013h) describe the purpose of the planning system in Scotland thus: "the planning system is used to make decisions about the future development and use of land in our towns, cities and countryside. It considers where development should happen, where it should not and how development affects its surroundings. The system balances different interests to make sure that land is used and developed in a way that creates high quality, sustainable places". In essence, the

---

[19] As discussed at sections 1.4 and 2.1.4, it has been necessary to use a pilot approach under Research Objective No.4 for pragmatic reasons, primarily concerning access to data and local stakeholders.

[20] Although key aspects of this research are specific to the pilot urban centre (e.g. the analysis of the Scottish land use planning system at section 3.1), Research Objectives Nos. 2, 3 and 4 are all of wider relevance (see Box 1.2). The strengths and weaknesses of the research in this regard (as well as recommendations for future research) are discussed at section 9.1.

planning system exists to regulate the use of land and buildings by granting or refusing planning permission (Scottish Government, 2009a). The planning system is split into three main components (Scottish Government, 2013h):

- **Development Plans:** the planning system in Scotland is plan led. The plans set out how places should change into the future
- **Development Management:** the process for making decisions on planning applications[21]. Legislation requires that decisions on planning applications be guided by policies in the development plan
- **Enforcement:** the process that makes sure development is carried out correctly and which can be used to take action when it has not

Table 3.1 Types of development plan in the Scottish planning system

(Source: Scottish Government, 2013i)

Type of development plan	Details
Strategic Development Plans (SDPs)	SDPs set out a vision for the long term development of the city regions and deal with region wide issues such as housing and transport
Local Development Plans (LDPs)	LDPs set out where most new developments will happen and policies that will guide decision making on planning applications

The Town and Country Planning (Scotland) Act 1997 as amended by the Planning etc (Scotland) Act 2006 together provide the legal framework for the Scottish planning system. As well as providing the legal basis for development management and enforcement (see above), planning legislation requires the production of Strategic and Local Development Plans (SDPs and LDPs) as detailed at Table 3.1 (Scottish Government, 2013i). SDPs are developed by strategic planning authorities[22] and LDPs by local planning authorities[23]. Development plans must be updated every five years (ibid). In addition to planning legislation, the Scottish

---

[21] Proponents require consent before they can legally progress a proposed development. The process of obtaining this consent is through planning applications.

[22] Such as the Glasgow and Clyde Valley Strategic Development Planning Authority (GCVSDPA): http://www.gcvsdpa.gov.uk/ [accessed 03/01/14]

[23] Such as Glasgow City Council: http://www.glasgow.gov.uk/index.aspx?articleid=2944 [accessed 03/01/14]

Government planning series (see Table 3.2) establishes national level policy, strategy and guidance supporting the work of strategic and local planning authorities.

Table 3.2 Details of the Scottish Government planning series

(Adapted from: Scottish Government 2009b; Scottish Government, 2013h)

Document	Details
Scottish Planning Policy (SPP)	SPP is the statement of Scottish Government policy on nationally important land use planning matters
National Planning Framework (NPF)	The NPF is the Scottish Government's strategy for Scotland's long term spatial development
Circulars	Circulars contain Scottish Government policy on the implementation of legislation or procedures
Planning Advice Notes (PANs)	PANs provide advice and information on technical planning matters

Note: Statements of Scottish Government policy in the SPP, NPF and Circulars may be material considerations to be taken into account in the development of SDPs and LDPs plans and in development management decisions.

This research focuses on the development plan component (LDPs in particular) of the Scottish planning system, as opposed to development management or enforcement. As part of the expert interview process (see sections 2.2.8 and 2.3.4 and Appendix 2), experts were asked – **to your mind, what are the three most important policies or regulatory frameworks that affect urban land use planning in Scotland?** All five interviewees highlighted development plans (including SDPs and LDPs – see Table 3.1) in this regard whilst one interviewee couched development plans in terms of the primary legislation that provides the legal basis for the statutory planning system in Scotland – i.e. the Planning etc (Scotland) Act 2006. This finding supports the thesis' focus on LDPs. Additional policies and regulatory frameworks highlighted were River Basin Management Plans (RBMPs) and the Water Framework Directive more generally (three interviewees), the Nature Conservation (Scotland) Act 2004 (one interviewee), the Scottish Land Use Strategy (one interviewee) and the Flood Risk Management (Scotland) Act 2009 (one interviewee).

Interviewees were also provided with a list of key Scottish 'land use delivery mechanisms' (Phillips et al, 2014) that included the various components of the statutory planning system (see Tables 3.1 and 3.2), key guidance notes from the Scottish Government planning series (see Table 3.2) and the statutory plans and guidance documents associated with the Flood Risk Management (Scotland) Act 2009 (see Chapter 4). Additional mechanisms that didn't fall into these categories were RBMPs, the Climate Change (Scotland) Act 2009 and the Scottish Land Use Strategy (see section 3.1.4). The full list of land use delivery mechanisms considered is provided at Appendix 2. Interviewees were first asked to identify which of the mechanisms they were familiar with (Question 4.3 – see Appendix 2) and then to prioritise, from this selection, what they felt were the five most important mechanisms for integrating the natural environment and ecosystem services into urban planning (Question 4.4 – see Appendix 2). Question 4.4 results are indicated on Figure 3.1. As is evident from Figure 3.1, LDPs were considered to be the most important land use delivery mechanism in this regard (four interviewees) with Scottish Planning Policy (SPP) and Development Management joint second (three interviewees). SDPs, RBMPs, Flood Risk Management Strategies and the Scottish Land Use Strategies were highlighted by two interviewees each. As such, this finding is also supportive of the thesis' focus on LDPs.

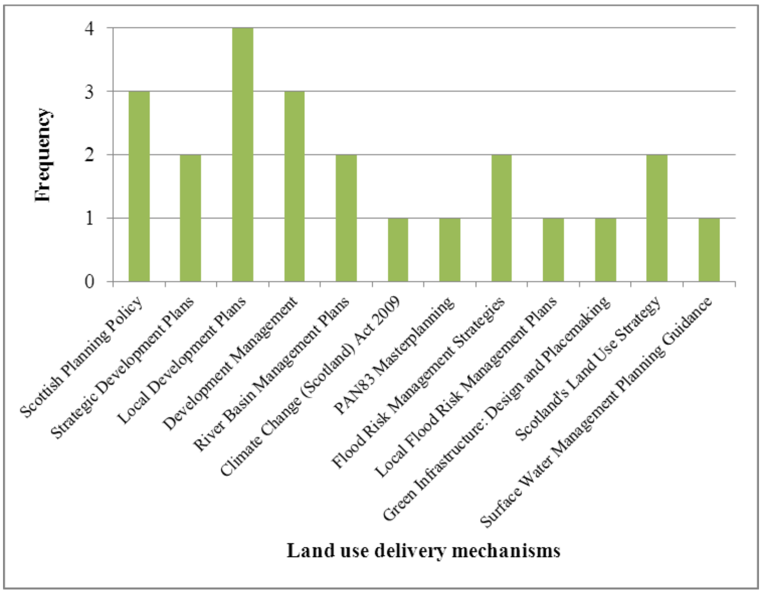


Figure 3.1 Expert interview Question 4.4 results – to your mind, what are the five most important land use delivery mechanisms for integrating the natural environment and ecosystem services into urban planning?

Note: Question 4.4 was based on a list of 16 potential land use delivery mechanisms provided by the researcher at Question 4.3. At Question 4.3 interviewees were asked to highlight which land use delivery mechanisms they were familiar with – the highlighted mechanisms then informed Question 4.4. Five experts were interviewed (see section 2.3.4).

In addition to key findings from the expert interviews described above, there are also a number of practical reasons as to why LDPs may provide a useful opportunity to integrate ecosystems approach principles with urban planning. In particular, LDPs for urban local authorities (e.g. Glasgow) establish the spatial framework and policy for land use and development in urban areas, they are strategic, spatially explicit and at a suitable spatial scale (i.e. they cover whole cities and are therefore likely to encompass key landscape features such as water catchments and contiguous areas of habitat network – see Chapters 4 and 5). Crucially, planning legislation in Scotland requires that decisions on planning applications (i.e. development management) are made in accordance with policies in the extant development plan (Scottish Government, 2009a). As discussed at section 1.3 it is this provision that gives development plans in Scotland (and elsewhere in the UK) their legal 'teeth' i.e. the statutory basis for driving forward a desired land use and development strategy (see section 1.3 for further information). The rationale for this research therefore is to develop new approaches to urban planning (including tools, models and guidance) that can inform the development of LDP strategy and policy from an ecosystems perspective. By improving policy and strategy, the intention is to contribute to better development management and enforcement (see section 8.3 for further information).

The Scottish Government (2009a) highlight how the purpose of the planning system is to balance competing demands to make sure that land is used and developed in the public's long term interest. In doing so, the planning system should support the Scottish Government's overarching objective of sustainable economic growth i.e. building a sustainable economy in conjunction with protection of the environment for future generations (ibid). This objective for the planning system chimes well with the ecosystem services concept and the principles of the ecosystems approach (see sections 1.2 and 3.2). As this thesis will go on to argue, there exists a key opportunity within urban land use planning practice to better consider the role played by 'green' and 'natural environment' type urban land uses providing key urban ecosystem services and supporting economic, social and environmental objectives (see section 3.1.3).

TYPICAL TIMINGS		LOCAL DEVELOPMENT PLAN	STRATEGIC ENVIRONMENTAL ASSESSMENT/ APPROPRIATE ASSESSMENT
weeks	cumulative		
	annual	Publish **Development Plan Scheme** (including **Participation Statement)**	Collate baseline environmental information
		Engage with key agencies etc. Prepare Monitoring Statement and Main Issues Report.	Prepare **Scoping Report**, submit to SEA Gateway, and await responses.
			Consider comments from Consultation Authorities and refine methodology.
			Environmentally appraise Main Issues Report. Screen to identify if Appropriate Assessment is required.
0	0	Publish **Main Issues Report** and **Monitoring Statement**	Publish **Environmental Report** and submit via SEA gateway. Publish **Appropriate Assessment** if necessary
6	6	Consult	Consult
26	32	Consider representations and prepare Proposed Plan and Action Programme	Consider responses. Environmentally appraise Proposed Plan, and amend Environmental Report (and Appropriate Assessment) if necessary (i.e. if significant changes between Main Issues Report and Proposed Plan).
10	42	Committee and printing	
0	42	Publish **Proposed Plan** and **Proposed Action Programme**	Publish **revised Environmental Report** if necessary and submit via SEA gateway. Publish revised **Appropriate Assessment**, if necessary.
12 (6 min*)	54	Period for representations. Notify neighbours	Consult if required
17	71	Consider representations. Prepare Summary of Unresolved Issues and Report of Conformity with Participation Statement.	Consider responses.
6	77	Committee and printing	
1	78	**Submit Proposed Plan, Action Programme** and **Report of Conformity** with Participation Statement to Ministers. Publicise submission of plan.	
35	113	**Examination** of Proposed Plan	Reporter refers to Environmental Report
0	113	**Report** published and submitted to planning authority	
3 months max*	126	Planning authority considers recommendations and prepares Modifications, Proposed Plan as modified and Statement of Explanation for not accepting any recommendations	Environmentally appraise modifications. Carry out appropriate assessment of modifications if required.
0	126	Publish **Modifications** and **Proposed Plan as modified**. Advertise intention to adopt Plan. Send Ministers the Proposed Plan as modified etc.	Publish and send to Ministers **revised Environmental Report** (and **Appropriate Assessment**) if required
4 min*	130	Planning Authority **adopts** plan	Publish **Post-Adoption SEA Statement** and submit to SEA Gateway
3 months max*	143	Publish **Action Programme**	

Figure 3.2 The statutory Local Development Plan (LDP) development process and integration with strategic environmental assessment (SEA)

(Source: Scottish Government, 2009b)

Note: starred timescales (*) in the typical timings column indicate statutory time periods.

3.1.2 *The LDP-development process*

The statutory basis for the LDP-development process is set out in the Planning etc (Scotland) Act 2006. The Scottish Government's practical guidance on developing LDPs is set out in Planning Circular 1/2009 on Development Planning (Scottish

Government, 2009b) and PAN 1/2010 on Strategic Environmental Assessment (SEA) of Development Plans (Scottish Government, 2010a). Within the statutory LDP-development process there are a number of key stages that could potentially provide tangible opportunities for the integration of ecosystems approach principles. Furthermore, the legislation describes a number of statutory provisions for LDPs, the development of which could potentially be informed and improved through consideration of ecosystems approach principles (see Table 3.3). The potential utility of these decision windows providing an opportunity for the integration of ecosystems approach inputs, as per this research, are discussed at section 8.3.

The statutory LDP-development process is shown on Figure 3.2 highlighting the nine key stages involved (shown in bold in the second column). Crucial to these is stage two – the development and publication of the Main Issues Report (MIR). The MIR is central to the Scottish Government's aspirations for a modern development planning regime – MIRs are intended to stimulate genuine debate on the proposed approach and alternatives to land use and development in the plan area as well as front-loading the LDP-development process to avoid delays later on (Scottish Government, 2010a). In this manner, MIRs are intended to encourage and facilitate debate on the content of the proposed LDP (Scottish Government, 2009b).

Scottish planning legislation requires that LDPs contain a spatial strategy, that they are concise map-based documents and that they focus on specific main proposals for land use and development within the plan area (Scottish Government, 2009a; Scottish Government, 2009b; Scottish Government, 2010a). The MIR contains a summary of these 'big ideas' and is the focus of stakeholder and public engagement on the LDP (Scottish Government, 2009b). As such, this thesis argues that the development of the MIR is the most useful opportunity whereby ecosystems approach principles and key outputs from the new approaches developed through this research could potentially be used to inform the *overall* LDP-development process (see section 8.3 for further information).

The MIR's focus on strategic proposals (for where development and land use change should and should not take place) and consideration of reasonable alternatives are particular strengths in this regard (e.g. the MIR-development stage could be a key opportunity to consider spatial priorities for important ecosystem services such as flood storage and habitat networks). Additionally, the Scottish Government (2009b) highlight how MIRs should be informed by a sound evidence base which could potentially include inputs such as ecosystem service maps (see section 8.2). Scottish planning legislation also sets out a number of key provisions that local planning authorities are legally required to include within MIRs. These statutory provisions are outlined at Table 3.3.

Although the MIR stage is a strong candidate there are other key decision-making windows within the LDP-development process that could also be utilised for the integration of ecosystems approach principles. In particular, the development and publication of the Proposed Plan (following consultation on the MIR) and post-modification Proposed Plan (following consultation on the Proposed Plan) could provide opportunities (see Figure 3.2). At both of these junctures, there is potential for new provisions to be included and/or for significant updates to MIR stage proposals to be made (Scottish Government, 2009b; Scottish Government, 2010a). Despite this, the MIR is the strategic focus of the LDP-development process (including the key issues outlined above and at Table 3.3) and is felt to offer the most useful opportunity for the integration of ecosystems approach principles. The important role of the MIR and early engagement in the LDP-development process more generally was highlighted in the expert interviews (see sections 2.2.8 and 2.3.4) in response to question 4.6 (see Appendix 2) – **from what you know about the Local Development Plan (LDP) process, what do you think is the most useful stage to integrate consideration of urban ecosystem services into plan-development?** Key responses include:

> *“Right at the start before the plan is even thought about – up front engagement. At the MIR or even before”* (I-1)
>
> *“Before – the whole process should be informed by these issues”* (I-3)
>
> *“Right at the beginning and through the MIR [formulating] what the vision is for land use in the area”* (I-5)

Scottish Ministers expect LDPs to be concise, map-based documents with a focus on the specific main proposals for the plan area. In meeting this requirement, local planning authorities have the option of presenting some of their plan material in supplementary guidance, especially minor proposals and detailed policies (Scottish Government, 2009b). Common types of supplementary guidance include development briefs and masterplans (i.e. plans that provide a detailed explanation of how the authority would like to see particular sites or small areas developed), strategies or frameworks on specific issues (e.g. guidance on the location of large windfarms, openspace strategies etc) and detailed policies (Scottish Government, 2009a). Given the nature of many supplementary guidance issues therefore, there is potentially an argument for considering ecosystems approach principles at this level of decision-making also. This issue is discussed further at section 9.3.

Table 3.3 Statutory provisions for inclusion in LDP Main Issues Reports (MIR)

(Adapted from: Scottish Government, 2009b; Scottish Government, 2010a)

Provision	**Details**
Spatial strategy	• Local planning authorities are required to set out **general policies** and **proposals** for **land use** and **development** in the plan area along with reasonable **alternatives** to these policies and proposals • For LDPs within the city regions[24] (e.g. Glasgow), the spatial strategy includes **site specific** proposals only • Proposals within the MIR will inform the **final** choice of spatial strategy at the **proposed plan** stage
Policies	MIRs are **not** expected to include the **detailed wording** of planning policies that will appear later in the proposed plan. Instead, the focus MIR on **strategic** policy issues only including: • Highlighting the **new** or **changed** issues that require a **policy response** (e.g. new flooding legislation, new regeneration priorities) • An **explanation** of the **broad changes** to policies or policy areas as opposed to setting out their detailed wording • An explanation and summary of the policy areas that are being **brought forward** from the extant development plan **unchanged** • A **discussion** of the policy **alternatives** considered to date • A **discussion** around **potential policy issues** that could be covered by **supplementary guidance** (e.g. the design and layout of housing allocations for a specific area, openspace strategy, renewable energy strategy etc)

---

[24] Scotland's main city regions (Aberdeen, Dundee, Edinburgh and Glasgow) are covered by Strategic Development Plans (SDPs) that set out a vision for long-term development including issues of regional importance such as transport and housing (see Table 3.1). SDPs establish a 'high level' spatial strategy including broad development areas but **not** site specific detail. As such, LDPs within the city regions are not required to develop a high level spatial strategy, rather they refer to the extant SDP to inform the development of their site specific spatial strategy.

Provision	**Details**
Proposals	• The MIR sets out **proposals** for where **land use change** and **development should** and **should not** occur within the plan area • Proposals must be **site specific** and set out clearly on a **map** showing the **location** and **intended use** of proposed sites • The MIR stage is **the key opportunity** for developers and others (e.g. community, conservation and other interest groups) to put forward **suggestions** for proposed sites • The MIR must consider individual sites as part of a **comprehensive spatial strategy** (i.e. what is the combined impact of all proposed sites in terms of strategic land use and development issues)

3.1.3 Urban land use, openspace and green infrastructure

Urban areas can contain many different types of land use. LDPs are required to set out proposals for how land use change and development should and should not occur. The agreed land use strategy in adopted LDPs then informs development management decisions (see section 3.1.1). In terms of Scottish planning legislation (see section 3.1.1), statutory land use classes are defined in the Town and Country Planning (Use Classes) (Scotland) Order 1997. In order to reflect specific local circumstances (e.g. the presence of a particular heritage asset, energy resource etc), local planning authorities can define a range of additional land uses in their LDPs with guidance from SPP, relevant PANs and Circulars (see Table 3.2). Figure 3.3 depicts an extract of the spatial strategy for Perth city centre taken from Perth and Kinross Council's LDP Proposed Plan. Crucially, the plan shows a range of different existing and proposed land uses in the urban area including:

- Residential
- Employment
- Mixed use
- Town and neighbourhood centres
- City centre secondary uses
- Commercial centres
- Openspace
- Green corridors

As discussed at sections 1.2 and 3.2, the primary focus of this thesis is on 'green' and 'natural environment' type urban land uses. It is these land uses that provide a backbone of greenspace and semi-natural habitats within a wider urban matrix, supporting urban ecosystem function and providing key land based urban ecosystem services (the landscape ecology principles that provide part of the rationale for this framing are outlined in Chapter 5). In terms of Scottish planning policy, these land uses are captured under the umbrella land use category of 'openspace' (Scottish Government, 2008; Scottish Government, 2010b). As part of the expert interview process (see sections 2.2.8 and 2.3.4 and Appendix 2), Question 3.2 asked – **to your mind, what are the key components of the urban natural environment?** The intention of this question was to explore how expert views of what constitutes the urban natural environment compares to policy (see below) and to tease out any additional subtlety that could be incorporated with the tools, models and guidance developed through this research (see Chapters 7 and 8). The views of the experts in this regard were broad though some common elements did emerge. Key responses are shown below with common themes highlighted in bold:

> *"Structural* ***habitat****. Also, access and functionality as human values are important"* (I-1)
>
> *"****River valleys****, fragmented* ***habitats*** *(primarily woodland), less intensively managed* ***openspaces*** *such as grassland meadows and some components of more* ***formal parks****. I wouldn't really consider parks and gardens and amenity greenspace [...] as their primary function does not mimic the natural environment"* (I-2)
>
> *"Could be a whole range of things though scale and significance is important –* ***parks*** *and* ***openspaces*** *are key in Glasgow due to the number of large Victorian parks. Infrastructure corridors – road, rail and* ***canals****. Water network and* ***river corridors****. Public useable space – allotments and school estates.* ***Vacant and derelict land****. Areas of semi-natural* ***habitat*** *will exist within all of the above"* (I-3)
>
> *"Green infrastructure –* ***blue/green corridors*** *that provide connectivity for surface water and biodiversity – this includes natural and engineered corridors and* ***canals*** *as a historic feature. Areas of limited human activity including* ***natural/semi-natural*** *greenspace and* ***vacant and derelict land****"* (I-4)

> *"What's outside peoples' doorstep/window – what people can interact with immediately e.g. private gardens. Urban landscapes are not very rich – some components are richer where development pressure is less e.g.* ***river valleys****"* (I-5)

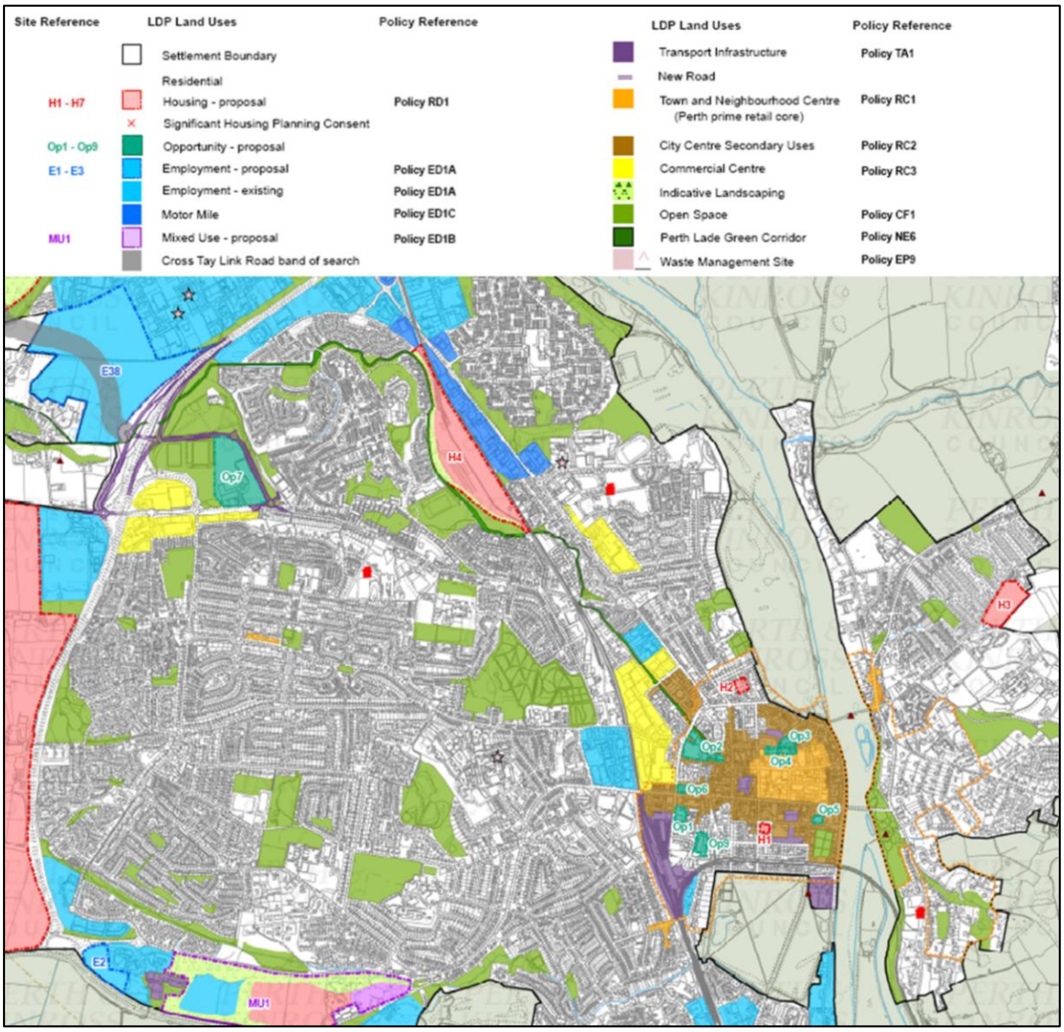


Figure 3.3 Example LDP spatial strategy – an extract from the Perth and Kinross LDP Proposed Plan showing land use in Perth

(Source: adapted from Perth and Kinross Council, 2012)

Note: The plan above has been adapted from the Perth and Kinross LDP Proposed Plan. It shows the proposed spatial strategy for central Perth which is the main urban centre in the plan area.

The Scottish Government (2008) recognise the importance of openspace land use within towns and cities, in particular its role supporting personal and community wellbeing, providing the setting for a wide range of social interactions, allowing individuals to interact with the natural environment, providing habitats for wildlife and helping to define the character and identity of settlements. Local planning authorities are required to undertake an audit of the openspace resource within their area (including an assessment of the degree to which the current resource meets the needs of the community) and to develop an openspace strategy to guide and improve the management and development of this resource (ibid).

Crucially, the purpose of the planning system is then to protect this resource where it is valuable and valued (ibid) by incorporating openspace land uses with the LDP spatial strategy and developing specific policy on the protection and enhancement of openspace. PAN65 on Planning and Openspace (ibid) defines the statutory typology for openspace shown at Table 3.4. The PAN65 typology has been adopted in this research to define and categorise the different green/natural environment type land uses that provide key land based urban ecosystem services.

Table 3.4 PAN65 openspace typology

(Source: Scottish Government, 2008)

Category	Description
1. Public parks and gardens	Areas of land normally enclosed, designed, constructed, managed and maintained as a public park or garden. These may be owned or managed by community groups
2. Private gardens or grounds	Areas of land normally enclosed and associated with a house or institution and reserved for private use
3. Amenity greenspace	Landscaped areas providing visual amenity or separating different buildings or land uses for environmental, visual or safety reasons and used for a variety of informal or social activities such as sunbathing, picnics or kickabouts
4. Playspace for children and teenagers	Areas providing safe and accessible opportunities for children's play, usually linked to housing areas
5. Sports areas	Large and generally flat areas of grassland or specially designed surfaces, used primarily for designated sports (including playing fields, golf courses, tennis courts and bowling greens) and which are generally bookable
6. Green corridors	Routes including canals, river corridors and old railway lines, linking different areas within a town or city as part of a designated and managed network and used for walking, cycling or horse riding, or linking towns and cities to their surrounding countryside or country parks. These may link green spaces together
7. Natural/semi-natural greenspace	Areas of undeveloped or previously developed land with residual natural habitats or which have been planted or colonised by vegetation and wildlife, including woodland and wetland areas
8. Allotments and community growing spaces	Areas of land for growing fruit, vegetables and other plants, either in individual allotments or as a community activity
9. Civic space	Squares, streets and waterfront promenades, predominantly of hard

Category	Description
	landscaping that provide a focus for pedestrian activity and can make connections for people and for wildlife
10. Burial grounds	Includes churchyards and cemeteries
11. Other functional greenspace	May be one or more types as required by local circumstances or priorities

Note: The PAN65 openspace typology has been adopted in this research as the definition for the 'green' and 'natural environment' type urban land uses that can be managed to provide key land based urban ecosystem services (see sections 1.2 and 3.2 for further information).

As described at section 1.2, this thesis has explored the degree to which an ecosystems approach to urban land use planning may be able to support the protection and enhancement of biodiversity whilst simultaneously delivering multiple benefits from urban land use. Current Scottish Government planning policy on openspace (Scottish Government, 2008; Scottish Government, 2010b) reflects this notion to a degree (e.g. PAN65 identifies a number of social, environmental and economic benefits of openspace land use at p.3) though the concept of multifunctional openspaces providing a broad range of multiple benefits is arguably not filtering through to LDP policy. For example openspace policy within the Perth and Kinross LDP Proposed Plan (Perth and Kinross Council, 2012) focuses on the more socio-economic functions of openspace/cultural ecosystem services (i.e. public access and community facilities) with little consideration of provisioning or regulating services.

Conversely, the concept outlined in this thesis and indeed elsewhere in the literature and policy on ecosystem services and sustainable urban land use (see sections 3.2 and Chapter 6) is one where urban openspace is truly multifunctional and fully integrated with the delivery of relevant urban services (e.g. flood risk management, access, biodiversity etc). In this manner, urban openspace moves from being a maintenance burden providing limited ecosystem services (Woodland Trust, 2011) to a valued resource providing diverse ecosystem services supporting a broad range of objectives in an integrated manner.

This concept is beginning to be recognised in Scottish Government planning policy – for example the proposed update to the SPP (Scottish Government, 2013j) focuses more on green infrastructure than openspace (as is the case in the extant SPP). In particular, the proposed SPP highlights how "green infrastructure is important to the health and wellbeing of our communities and the natural processes which provide a wide range of services on which our society and economy depends" (Scottish Government, 2013j p.38). Crucially, green infrastructure is referenced in the SPP in a variety of contexts and in relation to a broad range of benefits and land based ecosystem services including climate change mitigation and adaptation, water management, sustainable urban drainage, flood risk management, place-making, habitat networks/ecological connectivity, biodiversity, access, recreation and renewable energy (ibid). Green infrastructure is also central to the Scottish Government's planning guidance on *Green Infrastructure Design and Placemaking* (Scottish Government, 2011b) which includes a useful review of practice elsewhere, a comprehensive analysis of the ecosystem services that well designed green infrastructure can provide and guidance for its use and application at a variety of scales (see Figure 3.4). Further examples of green infrastructure interventions at different scales are provided at Figure 3.5.

The building – home, garden or workspace	Connections	The street	Connections	Neighbourhood	Connections	Strategic places
• Green roofs • Living walls • Gardens or grounds • Rainwater harvesting systems • Driveways (permeable)	• Pedestrian paths and rights of way • Cycling routes • Green Links and corridors	• Boundary features eg hedges • Street trees • Verges • Swales • Porous paving • Sustainable Urban Drainage Systems (SUDS)	• Pedestrian paths and rights of way • Cycling routes • Green Links and corridors	• Amenity greenspace • Informal recreation spaces • Playspaces • Allotments, community growing spaces • Playing fields • Sports areas • Urban parks • Burial grounds, cemeteries • Swales • Urban woodlands • Ponds • Water courses	• Pedestrian paths and rights of way • Cycling routes • Green Links and corridors • River and canal corridors including their banks	• Civic scale spaces • Public parks and gardens • Green Networks • Country & Regional Parks • Natural/semi-natural greenspaces • Forests and Woodlands • Grasslands • Designed landscapes • Formal gardens • City farms • Blue Networks • Rivers, lochs and Wetlands

Figure 3.4 The role green infrastructure at different scales

(Source: Scottish Government, 2011b)

Note: The Figure shows examples of green infrastructure at a range of scales for sites and places (e.g. buildings, streets, neighbourhoods) and for the connections between those places (e.g. cycle routes, green links and corridors, canals etc). At finer scales (e.g. buildings and gardens), green infrastructure is less about land use/defined land parcels and more about specific infrastructure intervention within defined areas of land – e.g. the green roofs, permeable paving and SuDS incorporated within a housing development to provide water management services. At broader scales (e.g. neighbourhoods and strategic places), the focus of green infrastructure is more concerned with different types of green/natural environment land uses such as those defined in PAN65 (see Table 3.4).

The green infrastructure concept is increasingly being recognised at the EU level also. In particular, the EC has recently published a communication on green infrastructure (EC, 2013a) outlining important links between green infrastructure and key EU policies in areas such as climate change and disaster risk management, regional policy and territorial cohesion and natural capital (especially in relation to land and soil, water and nature conservation). Crucially the communication includes a definition of green infrastructure (EC, 2013a p.3): "a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings". The EC definition arguably chimes well with the concept described at section 1.2 of urban ecosystems, comprised of greenspace and semi-natural habitats within a wider urban matrix, providing a range of urban land based ecosystem services.

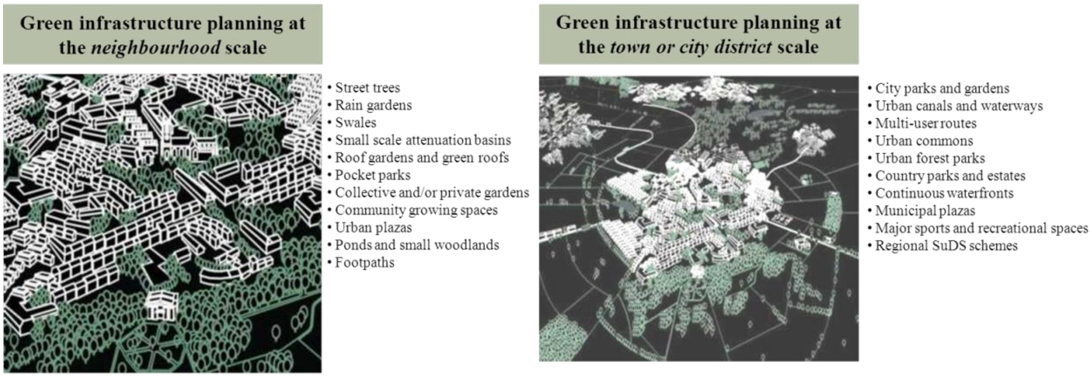


Figure 3.5 Green infrastructure planning/design at different scales

(Adapted from Landscape Institute, undated)

Note: The Figure highlights the role of different types of green infrastructure when planning and designing intervention at different scales. In particular, planning at the neighbourhood scale (left hand diagram) may incorporate consideration of specific infrastructure interventions e.g. water management features such as swales and rain gardens, green roofs through to individual street trees (see section 4.7.3). Planning at the town or city district scale (right hand diagram) is more likely to focus on land use/defined areas of land such as parks and gardens, estates, large scale civic spaces and sports grounds.

3.1.4 Getting the best from our land – Scotland's land use strategy

In addition to the statutory planning system and development plan process described at sections 3.1.1 and 3.1.2, Scotland also has a national level Land Use Strategy (LUS) entitled *Getting the best from our land* (Scottish Government, 2011d). The LUS is a statutory requirement of Scotland's climate change legislation – the Climate Change (Scotland) Act 2009 – recognising the key role of land use/management contributing to climate change mitigation and adaptation. Crucially, the LUS recognises that Scotland's land is not performing as best as it could, even though the demands placed on the land are ever increasing and often conflicting – from the production of energy, food, fibre and timber to flood risk management, maintenance of water resources, climate regulation and tourism (Scottish Government, 2011d; Scottish Government, 2013g; Phillips et al, 2014).

As opposed to the development of a new land use delivery mechanism, the Scottish Government's approach to the national level LUS is focussed on the use of strategic principles for sustainable land use (Scottish Government, 2011d; Phillips et al, 2014). Based on the premise that there are already a broad range of existing land use delivery mechanisms in Scotland (including the statutory planning system considered in this research and described at sections 3.1.1 and 3.1.2), the rationale behind this approach is that the LUS' strategic principles can be integrated with these existing mechanisms, without recourse to any additional processes or mechanisms for delivering land use. Key findings from the recently completed LUS Delivery Evaluation Project support this rationale (Phillips et al, 2014).

The Scottish Government have developed the LUS Principles to align with principles of sustainable development as well as key Government policy and priorities that inform land use decision-making across Scotland (Scottish Government, 2011d). Crucially, the LUS Principles have been designed to reflect the principles of the ecosystems approach and the Scottish Government have developed an information note on applying an ecosystems approach to land use to support implementation (Scottish Government, 2011c). As such, the LUS Principles are a key consideration in this research and in the development of new approaches to urban planning therein (see Chapter 8 and Appendices 4, 5 and 6). Although the principles are Scottish, they are arguably strategic and general enough to be of wider relevance and will certainly be relevant to land use/management planning elsewhere in northern Europe (see section 3.2.5).

Furthermore, Phillips et al (2014 p.121) highlight how "…there is no one perfect method or approach to support land use/management planning and delivery that can be used in all circumstances or for all ten LUS Principles" and how "…the methods and approaches identified through the [LUS Delivery Evaluation Project] can be used as an initial basis for the development of land use delivery methods though this should be supplemented by wider research etc". As such, the tools and methods developed through this research are, in part, intended to support the integration of the strategic LUS Principles within urban land use planning as per the statutory LDP process as a specific land use delivery mechanism (see Chapters 7 and 8 and Appendices 4, 5 and 6). The LUS' ten Principles for sustainable land use principles are shown at Table 3.5.

Table 3.5 Scotland's Land Use Strategy – principles for sustainable land use

(Adapted from Scottish Government, 2011d; Phillips et al, 2014)

Category	**Description**
Principle A	*Multiple benefits* Opportunities for land use to deliver **multiple benefits** should be encouraged
Principle B	*Regulation* **Regulation** should continue to protect essential public interests whilst placing as light a burden on businesses as is consistent with achieving its purpose. Incentives should be efficient and cost-effective
Principle C	*Primary use* Where land is highly suitable for a **primary use** (for example food production, flood management, water catchment management and carbon storage) this value should be recognised in decision-making
Principle D	*Ecosystem services* Land use decisions should be informed by an understanding of the **functioning of the ecosystems** which they affect in order to maintain the benefits of the **ecosystem services** which they provide
Principle E	*Landscape change* **Landscape change** should be managed positively and sympathetically, considering the implications of change at a scale appropriate to the landscape in question, given that all Scotland's landscapes are important to our sense of identity and to our individual and social wellbeing
Principle F	*Climate change* Land-use decisions should be informed by an understanding of the opportunities and threats brought about by the **changing climate**. Greenhouse gas emissions associated with land use should be reduced and land should continue to contribute to delivering climate change adaptation and mitigation objectives
Principle G	*Vacant and derelict land* Where land has ceased to fulfil a useful function because it is **derelict or vacant**, this represents a significant loss of economic potential and amenity for the community concerned. It should be a priority to examine options for restoring all such land to economic, social or environmentally productive uses
Principle H	*Outdoor recreation* **Outdoor recreation** opportunities and public access to land should be encouraged, along with the provision of accessible green space close to where people live, given their importance for health and well-being
Principle I	*People and decision-making* People should have opportunities to **contribute to debates and decisions** about land use and management decisions which affect their lives and their future

Category	**Description**
Principle J	*Land use and the link with daily lives* Opportunities to broaden our understanding of the **links between land use and daily living** should be encouraged

Note: Emphasis and principle titles in the above are taken from Phillips et al (2014) and are not directly referenced in the LUS.

3.2 Ecosystems, ecosystem services and the ecosystems approach

Urban land use and the ecosystems approach are central concepts of this research which aims to build on existing practice and ideas in the development, trialling and evaluation of new approaches to urban planning that can operationalise key aspects of the ecosystems approach (see Box 1.2). Section 3.1 looks in some detail at the Scottish planning system in order to identify potential opportunities whereby ecosystems approach principles can be integrated. Section 1.2 introduces the ecosystem services concept and outlines some of the main issues and problems that have led to the growing recognition of the natural environment’s role supporting wellbeing. It outlines the findings of ecosystem assessments undertaken at the global and UK levels and introduces the ecosystems approach as a strategy for integrating ecosystem services with decision-making.

Section 3.2 takes a more detailed look at the science of ecology and the ecosystem services concept (section 3.2.1), identifies a typology of ecosystem services and examines the relationship between urban land use/management and the provision of urban ecosystem services (section 3.2.2), explores the potential relevance and utility of ecosystem services in practical policy decision-making (section 3.2.3) and outlines the principles of the ecosystems approach (section 3.2.3). Finally, section 3.2.5 explains the rationale behind the consideration of certain urban ecosystem services in this thesis.

In doing so, the intention is to understand and characterise key aspects of the ecosystems approach that can be operationalised in urban land use planning systems (Research Objective No.4) as well as helping to identify key ecosystem services that can be provided by ‘green’ and ‘natural environment’ type urban land uses (Research Objective No.2). Furthermore, the material developed through this section has informed the new suite of principles for ecosystems approach based urban land use planning developed through this research (see Appendix 3). Chapters 4 and 5 look in more detail at the specific role of urban land use/management planning in the provision of flood storage, runoff reduction and ecological connectivity ecosystem services.

3.2.1 Ecosystems and environmental limits

The definition of an ecosystem that is used most widely is taken from the United Nations (UN) Convention on Biological Diversity – the CBD (MA, 2005; UKNEA, 2012; Mace et al, 2011). The CBD (UN, 1992 p.3) defines an ecosystem as "a dynamic complex of **plant, animal and micro-organism communities** and their non-living environment interacting as a functional unit". The first half of the definition (highlighted in bold) represents the biotic or living (biological) component of ecosystems and the latter half the abiotic or non-living (chemical and physical) component (Mace et al, 2011). It is the interactions between biotic and abiotic components of ecosystems that truly define them as systems (UKNEA, 2012) and these interactions "ultimately determine the quantity, quality and reliability of the ecosystem services" that flow from ecosystems (Mace et al, 2011 p.5).

As shown on Figure 3.6, the UKNEA (Mace et al, 2011) has developed this concept by framing land, air, water and all living things as the fundamental elements that underpin the biological, physical and chemical components of ecosystems. Crucially, the specific nature of these components then determines the functioning of ecosystem processes from which ecosystem services are derived (ibid). It follows therefore that changes in these interdependent components (e.g. species loss, land use change, waterbody modification etc) can bring about changes in the functioning of ecosystem processes and the supply of ecosystem services (ibid). This issue has been considered in the development of the new spatial models in this research (see Chapter 7)/

Building on the above, ecosystem function can be defined in terms of three key aspects: 1) ecosystem structure; 2) ecosystem composition; and 3) ecosystem processes (UKNEA, 2012; CBD Secretariat, 2013a). The effective functioning of ecosystems – via these three key aspects – is dependent on the biotic and abiotic components of ecosystems and the interactions therein. Healthy ecosystems are structurally and compositionally diverse (UKNEA, 2011). For example, a robust forest ecosystem would likely contain a number of different tree species (in addition to various species of bird, invertebrate, mammal etc) spanning a range of different age classes – from saplings and young trees at one end of the spectrum through to canopy trees and dead wood at the other. In contrast, a commercial conifer plantation under a clear fell silvicultural system may contain just one tree species (e.g. *Picea sitchensis*) and trees of one age class only (i.e. when maturity is reached the whole forest is clear felled ready for restocking). Healthy ecosystems are also dependent on the effective functioning of the three core ecosystem processes: 1) solar energy flow; 2) nutrient cycling; and 3) water cycling (UKNEA, 2012; CBD Secretariat, 2013a).

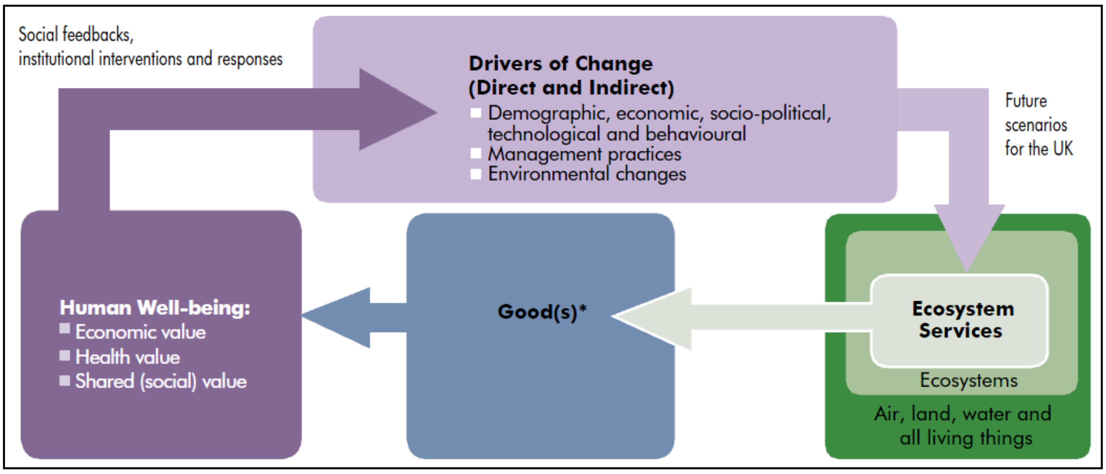


Figure 3.6 Overall conceptual framework adopted in the UKNEA

(Source: Mace et al, 2011)

Note: The figure above depicts the overall conceptual framework adopted in the UKNEA showing the links between ecosystems, ecosystem services, goods, human wellbeing and the drivers of change that can affect ecosystems and ecosystem services. Crucially, the UKNEA conceptual framework makes explicit the relationship between ecosystems/ecosystem function and the provision of ecosystem services (shown on the right-hand side of the diagram). Ecosystem function in this regard is expressed in terms of the fundamental elements of air, land, water and all living things underpinning the biological, physical and chemical components of ecosystems and the interactions therein.

Biodiversity is another crucial factor in ecosystem function and ecosystem services (Mace et al, 2011) though the importance of different aspects of biodiversity in this regard is not fully understood (UKNEA, 2012). As with ecosystems, the most widely used definition of biodiversity is taken from the CBD (UN, 1992 p.3): “biological diversity [biodiversity] means the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems". Although the relationship between biodiversity and ecosystem services is not fully understood, there are a number of useful conceptual framings for thinking about this relationship (Mace et al, 2011). In particular, the notion that biodiversity plays an important role in the fundamental ecosystem processes that underpin ecosystem services (ibid) is a crucial concept for this research (e.g. the role of soil biological communities supporting the effective functioning of nutrient cycles, the role of structurally[25] diverse forest ecosystems controlling runoff and supporting the effective functioning of the water cycle etc). In this manner, urban biodiversity, and its protection and enhancement through appropriate land use/management, is construed as a central premise of ecosystems approach based urban land use planning.

Recognising the important role played by biodiversity (including diversity within species, between species and of ecosystems) underpinning ecosystem function, the way in which species interact with their physical environment is also crucial for ecosystem services. In particular, the maintenance of biodiversity (and therefore key aspects of ecosystem function as described above) is dependent on the ability of species to migrate, disperse and interact, facilitating interbreeding, colonisation, natural regeneration etc (Watts et al, 2005; Smith et al, 2008; Corbett et al, 2009; Jones-Walters, 2009; Briers, 2011, SNH, 2011). These landscape scale[26] ecological processes are reliant on effective ecological networks to facilitate species movements beyond the bounds of individual habitat patches (IALE, undated; Watts et al, 2005; Gutzwiller and Forman, 2002; Smith et al, 2008; SNIFFER, 2008; SNH, 2011; James et al, 2013; Matthies et al, 2013; Phillips, 2013; Forest Research, 2014;

---

[25] Structurally diverse forest ecosystems in this regard could be managed under a continuous cover forestry (CCF) silvicultural regime i.e. management supports trees of a range of age classes meaning, therefore, that there is always a degree of mature forest cover (in contrast to a clear-fell regime for example. The potential role of CCF regimes in urban forestry has been considered in this research – see Chapters 7 and 8. See Forest Research's continuous cover silviculture pages for further information: http://www.forestry.gov.uk/fr/INFD-63CCQB [accessed 04/04/14]

[26] The notion of 'landscape scale' has been described variously though the definition used in this research has been adapted from SNH (2014a) and Forest Research (2014), namely that the particular definition of 'landscape scale' depends on the research question being addressed. In any event, both definitions recognise that landscape scale working is likely to examine issues at an extensive scale covering several square kilometres (e.g. water catchments) as opposed to the individual site scale. See section 5.1.1 for further information.

SNH, 2014a). As discussed at section 3.1.3 (see Figure 3.3 also), this issue can be particularly important in urban areas where the 'green' and 'natural environment' type land uses that provide the backbone of greenspace and semi-natural habitats are often located within a matrix of more hostile/less permeable urban land uses such as residential and commercial areas, paved surfaces and roads (James et al, 2013; Matthies et al, 2013; Phillips, 2013). As such, the maintenance and enhancement of urban landscape permeability is a vital component of urban ecosystem function, supporting the provision of key urban ecosystem services. Further information on the principles of landscape ecology is provided at Chapter 5. Ecological connectivity ecosystem services have been considered in the new spatial models developed in this research (see section 7.4).

The UKNEA (2012) recognises how the notion of an ecosystem as a spatially defined, functional unit is largely a human construct, designed with management in mind. In line with this approach, ecosystems can be defined (e.g. for management and planning purposes) as areas which share similar features across the following key characteristics (ibid):

- Climatic conditions
- Geophysical conditions
- Dominant use(s) by humans
- Surface cover (based on type of vegetative cover in terrestrial ecosystems)
- Species composition
- Resource management systems and institutions

In line with this characterisation approach, it is perfectly reasonable (as per UKNEA, 2011) to define and manage urban areas as ecosystems. In this manner, urban areas – as ecosystems – are comprised of biological, physical and chemical components interacting through urban ecosystem processes to produce urban ecosystem services. Importantly for this research and urban planning more generally, these components can be managed (within the constraints of environmental limits as discussed below) to manipulate ecosystem processes and urban ecosystem services.

The conceptual approach adopted in this research (in order to develop new approaches to urban planning that can operationalise key aspects of the ecosystems approach as per Research Objective No.4) is to frame the green/natural environment type urban land uses (see section 3.1.3) as the spatial 'building blocks' of urban ecosystems. In principle these 'building blocks' can then be managed, through urban land use planning, for the provision of key urban ecosystem services. This premise has been tested through this research as discussed further at Chapters 7 and 8.

The final crucial aspect of ecosystem function considered in this research is the concept of environmental limits "which can be seen as defining the boundaries of sustainability" (SNIFFER, 2010 p.5). The concept recognises that there are limits to the pressure that can be placed on ecosystems while maintaining their integrity and capacity to provide ecosystem services. Where such limits are exceeded, ecosystems can undergo substantial change, often with a loss of biodiversity, breakdown of ecosystem function and degradation of ecosystem services (Haines-Young et al, 2006; SNIFFER, 2010; CBD Secretariat, 2013a). This is indicated on Figure 3.7.

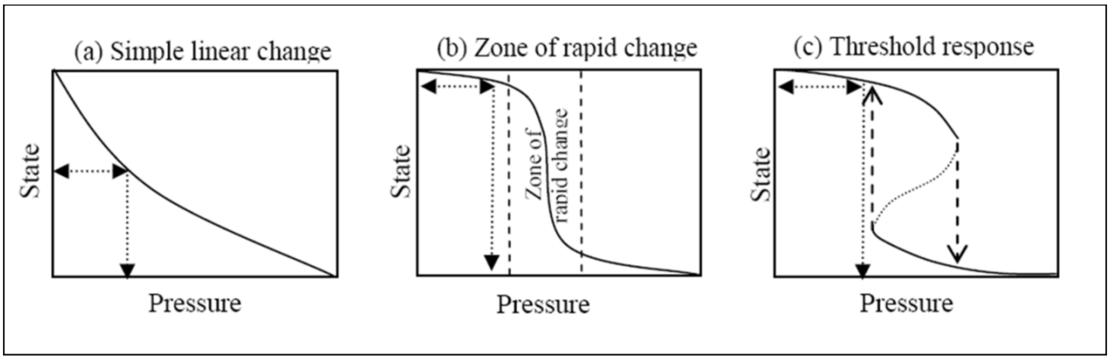


Figure 3.7 Identification of limits and thresholds in natural systems

(Source: Haines-Young et al, 2006)

Note: The figure above depicts three possible responses of a natural system to external pressure. In each case, the dotted line represents some kind of limit beyond which the system is judged to be damaged or at risk. In the context of the ecosystems approach, such limits are important as they can imply a breakdown of ecosystem function and loss or degradation of ecosystem services.

The literature recognises two key approaches for defining environmental limits: 1) *threshold limits* based on biophysical thresholds, established threshold relationships or breaking points – e.g. a known pollution concentration that is tolerable by an indicator species before it suffers drastic population decline; and 2) *non-threshold limits* based on societal preferences – e.g. the number of wind turbines tolerated in a given landscape (Haines-Young et al, 2006; SNIFFER, 2010). Regardless of the approach adopted, there will always be a degree of uncertainty involved and policy-makers and natural resource managers are encouraged to adopt a precautionary approach, through the use of policy options and management interventions e.g. application of a 'buffer zone' as systems begin to approach threshold or non-threshold environmental limits (ibid).

Given this, the environmental limits concept is potentially a useful tool for policy-makers and natural resource managers, helping to guide policy and management decisions towards the protection of ecosystem function and ecosystem services. For the purposes of this research, environmental limits are defined as "the level of some environmental pressure, indicator or environmental state or benefit derived from the natural resource system beyond which conditions are deemed to be unacceptable in some way" (Haines-Young et al, 2006 p.11). Furthermore, SNIFFER (2010) suggest that the following types of indicator can be used to define limits:

- An indicator reflecting a *pressure* on the ecosystem (e.g. discharge of a pollutant to water, development pressure resulting in the removal of vegetation and building over greenspace in urban catchments);
- An indicator reflecting the *state* of the ecosystem (e.g. presence/absence of a certain aquatic species); and
- An indicator reflecting the ecosystem *services* derived from the ecosystem (e.g. the availability of drinking water, natural flood storage etc).

This research argues that the environmental limits concept should be part of the framing for ecosystems approach based urban land use planning (indeed it is a principle of the ecosystems approach as outlined at section 3.2.4). In particular, the definition and indicators outlined above have been used to frame the tools, models and guidance developed in this research as part of the new approach to urban land use planning. In doing so, this thesis argues that environmental limits can help urban planners to think spatially about where land use/management change may be required to enhance ecosystem services, especially where this may be required to prevent an environmental limit being reached or to help restore ecosystems where that limit has already been exceeded (see Chapter 7 and section 8.2).

3.2.2 Ecosystem services – a generic typology

Section 1.2 introduces the concept of ecosystem services – for the purposes of this research, ecosystem services are framed in terms of healthy natural environments (comprised of landscapes, ecosystems and habitats) providing a range of *advantages* or *benefits* that are essential for societal wellbeing and prosperity (MA, 2005; Haines-Young and Potschin, 2008; Hughes and Brooks, 2009; Defra, 2011; Scottish Government, 2011c; UKNEA, 2011; Baker et al, 2013). Section 3.2.1 provides an outline of key established theoretical concepts, taken from the science of ecology, concerning the way in which ecosystems function and the relationship between healthy ecosystems and ecosystem service flows. The purpose of section 3.2.2 therefore is to further characterise the ecosystem services concept (including consideration of key conceptual and methodological developments made as a result of the UKNEA), to define a typology of ecosystem services. Section 3.2.3 then explores the potential relevance and utility of ecosystem services in practical policy decision-making[27].

The Millennium Ecosystem Assessment (MEA) was carried out between 2001 and 2005 with the aim of "assessing the consequences of ecosystem change for human wellbeing and establishing the scientific basis for actions needed to enhance the conservation and sustainable use of ecosystems and their contribution to human wellbeing" (MA, 2005 p.5). The MEA framed ecosystem services as "the benefits that people obtain from ecosystems" (ibid) and developed the categorisation for ecosystem services (see Figure 1.3) that has since been adopted in ecosystem assessments and policy elsewhere e.g. the UKNEA (Mace et al, 2011), the EU resource efficiency programme (EC, 2011b) and the UK Natural Environment White Paper (Defra, 2011). Crucially, the MEA's framing of ecosystem services drew attention to the integrated nature of the natural environment, especially the way in

---

[27] Chapters 4 and 5 look specifically at how urban land use/management can impact the key ecosystem services considered in this research as per Research Objective No.2 (see Box 1.2).

which multiple constituents of human wellbeing[28] are dependent on multiple ecosystem services which, in turn, are dependent on multiple interactions between the living and non-living components of ecosystems (see section 3.2.1). The integrating nature of the ecosystem services concept has since been described as one of its key strengths, especially as a means of encouraging policy-makers to think holistically about the natural environment as an interdependent system and not just as a series of discrete topics or issues that can be managed in isolation (Baker et al, 2013).

As described at section 1.2, the UKNEA was a direct response to the MEA. However, as the UKNEA commenced in 2009, the approach adopted benefitted from four years of conceptual and methodological developments (UKNEA, 2011). Similarly to the MEA, the UKNEA framed ecosystem services as "the outputs of ecosystems from which people derive benefits" as well as using the MEA's four broad headings for categorising ecosystem services – supporting, provisioning, regulating and cultural (Mace et al, 2011 p.6). Crucially however, the UKNEA introduced a further sub-categorisation under these broad headings that presents a particularly useful conceptual framing for this thesis and practical natural environment policy decision-making more generally.

In particular, the UKNEA (ibid) differentiates between three sub-sets of benefits that are derived from ecosystems: 1) ecosystem processes/intermediate services; 2) final ecosystem services; and 3) goods (see Figures 3.8 and 3.9). *Ecosystem processes/intermediate services* can be construed as the key aspects of ecosystem function described at section 3.2.1 (e.g. ecosystem structure, biodiversity, ecosystem processes etc). *Final ecosystem services* are, in effect, the 'raw materials' provided by ecosystems including trees, crops and the 'raw' hazard regulation benefits (e.g. flood storage) provided by ecosystems in the absence of any specific management/alteration of the natural environment (see Figures 3.8 and 3.9). Crucially, "people tend to intervene and/or manage ecosystems to influence the delivery of final ecosystem services" (ibid) as these, in effect, provide the ecosystem 'building blocks' that can be manipulated, managed, engineered, manufactured or

---

[28] Such as adequate livelihoods, sufficient nutritious food, shelter, security from disasters, social cohesion, access to clean air and water etc (see Figure 1.3).

otherwise altered to produce the *goods* that people value (see Figure 3.8 and 3.9). *Goods* are the ‘things’ that people value and that contribute directly to wellbeing (ibid). Importantly, the UKNEA conceptual framework recognises that “many goods can only be generated by applying manufactured capital (e.g. machinery) or human capital (e.g. ingenuity) to final ecosystem services” (Mace et al, 2011 p.9). This distinction has important consequences for this research as explained further below.

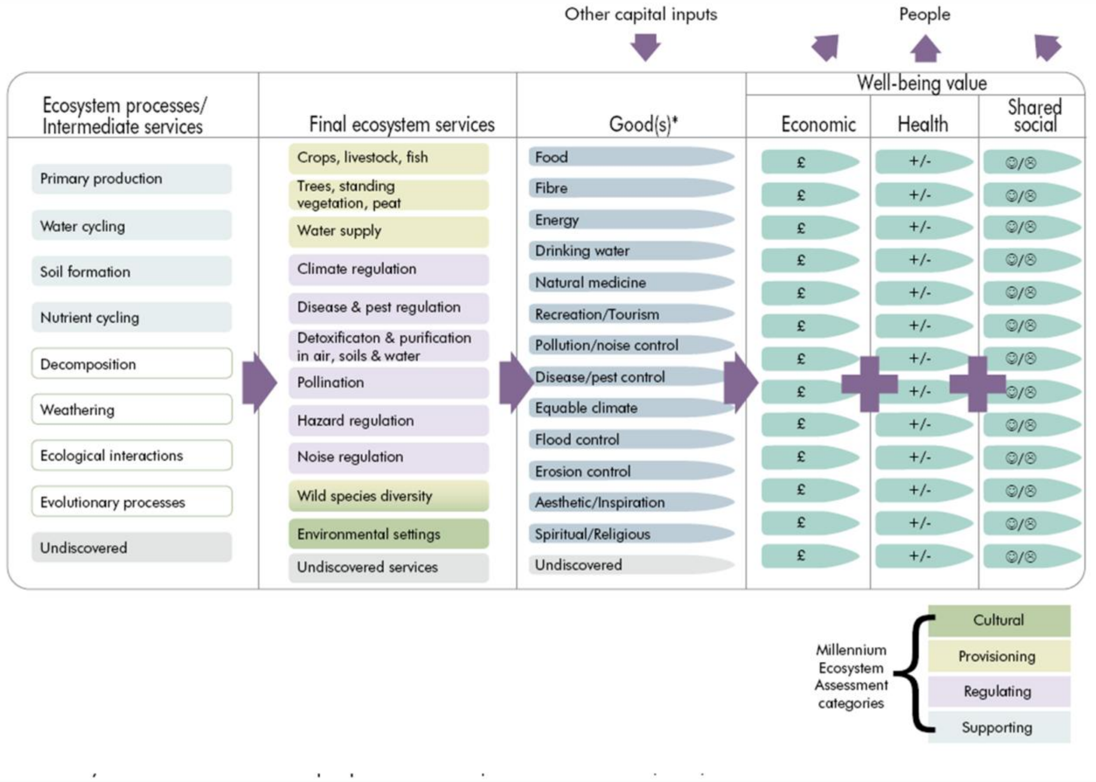


Figure 3.8 Ecosystem processes, services, goods and values used in the UK National Ecosystem Assessment (UKNEA)

(Source: Mace et al, 2011)

Note: Where relevant, the three sub-sets of benefits provided by ecosystems adopted in the UKNEA framework are also categorised in terms of the four broad headings for ecosystem services used in the MEA (key indicated at the right-hand corner of the figure above). As described at section 3.2.1, the *ecological interactions* ecosystem process/intermediate service shown on the figure above highlights the important role played by ecological networks supporting biodiversity and underpinning all other aspects of ecosystem process/function and ecosystem services. Ecological interaction is an additional ecosystem process/intermediate process that was not considered in the MEA but one that is of key relevance for this thesis and urban land use planning more generally, as described at sections 3.2.1 and 7.4 and Chapter 5.

	Final ecosystem services	Example ecosystem management for delivery of desired goods	Potential impacts of management on other final ecosystem services	Key goods available
Provisioning	*Trees, standing vegetation, [peat]*	Land drainage Periodic thinning Agro-chemical inputs (fertiliser, herbicide etc) Periodic clear-fell harvesting	Climate regulation +/-/? Water supply -/? Hazard regulation +/-/? Wild species diversity - Environmental settings -/?	Fibre (timber) Energy (biomass) Recreation/tourism? Flood control?
	[Trees, standing vegetation], peat	Re-wetting of peat forming soils (reversing land drainage)	Climate regulation + Peat + Hazard regulation + Trees/standing vegetation - Wild species diversity +/?	Equable climate (GHG mitigation) Flood control Aesthetic/inspiration +/-/?
	Water supply	Put forest into continuous cover silvicultural regime (reduce soil erosion risk and protect water resources)	Trees/standing vegetation -/? Hazard regulation +/-/? Wild species diversity +/? Environmental settings +/?	Fibre (timber) Energy (biomass) Recreation/tourism? Flood control?
Regulating	*Hazard regulation*	Reverse land drainage Put forest into continuous cover silvicultural regime (i.e. year round vegetation cover) Restore riparian cover and promote formation of LWD dams Promote wet areas within the forest	Climate regulation +/? Water supply + Wild species diversity + Trees/standing vegetation - Peat +/? Environmental settings +/?	Fibre (timber)? Energy (biomass)? Recreation/tourism Flood control Erosion control Equable climate (GHG mitigation)
Cultural	*Environmental settings*	Landscape sensitive forest design Creation and maintenance of foot/cycle paths Put forest into continuous cover silvicultural regime (i.e. promote consistency and longevity of landscape)	Trees/standing vegetation -/? Wild species diversity +/-/? Water supply +/-/? Hazard regulation +/-/?	Recreation/tourism Aesthetic/inspiration Spiritual/religious? Flood control Erosion control Equable climate (GHG mitigation)

Figure 3.9 Forest ecosystem services and management for specific goods

(Adapted from Hart, 1991; MA, 2005; Starr, 2005; Haines-Young and Potschin, 2008; EEA, 2010c; Mace et al, 2011; Quine et al, 2011 – images are the author's own)

Note: The figure above highlights key final ecosystem services provided by forest ecosystems, categorised as per the MEA framework (first column). As described in the text above, final ecosystem services can be regarded as ecosystem 'building blocks' that can be manipulated and managed to produce the goods that are valued by people and important for wellbeing (see Figure 3.8). In line with this distinction, the figure above highlights management examples (second column) that could be used to manipulate the key final ecosystem services provided by forests for the provision of desired goods (fourth column). In essence, this shows how different land management can affect ecosystem service provision – a key premise of this research (see section 8.2). For example, *hazard regulation* final ecosystem services can be managed to enhance *flood control* goods. Specific land management might include reversal of land drainage (i.e. blocking land drains), using CCF silvicultural systems (i.e. shifting to a system of permanent vegetation cover and therefore a greater degree of hydraulic roughness – see section 4.7) and the restoration of riparian woodland/promotion of large woody debris (LWD) dams to enhance the flood storage function of floodplain woodland. Crucially the third column shows the potential impacts of land management on other final ecosystem services, recognising that there can often be ecosystem services trade-offs and/or conflicts between management objectives. For example, reversing land drainage, whilst beneficial for hazard regulation (flood control), will likely be at the detriment of key provisioning services such as good quality timber (i.e. as soil moisture content increases and aerobic soil processes breakdown).

Although the purpose of these conceptual developments is to avoid double counting in economic analyses (ibid), the distinctions outlined above offer two useful concepts that have played an important role framing this research and the tools, models and guidance developed therein[29]. Firstly, the notion that final ecosystem services can be manipulated (i.e. to produce goods) to somehow alter their wellbeing value for people is crucial. In essence, this recognises that ecosystem services can be managed for specific ends, a central premise of this thesis which has developed new approaches to urban planning that can target urban land use/management (i.e. a type of human capital input as per Figure 3.8) for the provision of specific urban ecosystem services (see Chapter 7 and section 8.2). The concept of managing ecosystems and ecosystem services for specific ends/goods is illustrated on Figure 3.10 and variously in Chapters 4, 5, 7 and 8.

Secondly, the fact that ecosystem processes/intermediate services are excluded from economic analyses within the UKNEA framework highlights their irreplaceability and vital function within ecosystem services. In essence, this recognises that ecosystems can't just be managed for [final] ecosystem services; rather ecosystems must also be managed for the protection and enhancement of ecosystem health, as defined by the nine ecosystem processes/intermediate services shown on Figure 3.8. This management objective is crucial to ensure the ongoing supply of final ecosystem services from which valued goods can be obtained (see section 3.2.1 also). This principle has been reflected in the new tools, models and guidance developed in this research.

3.2.3 Ecosystem services and their potential role in decision-making

The rationale and utility of considering ecosystem services in decision-making is explained variously by MA (2003), Carpenter et al (2006), De Smedt (2010), Baker et al (2013), Geneletti (2013a), Helming et al (2013) and Partidario and Gomes (2013). In particular, an understanding of the link between ecosystem change (e.g. as a result of policy driving land use change) and change in ecosystem services (and

---

[29] Although fundamental to the UKNEA's overall approach, the language adopted in the tools, models and guidance developed in this research (see Chapters 7 and 8) does not differentiate between ecosystem processes, goods and services; rather it simply refers to ecosystem services

ultimately human wellbeing) is seen as a key input to policy-development and decision-making more generally (MA, 2003). A theoretical framing of this relationship, based on ecological principles, is described at section 3.2.1. Practical implications have been considered in the new tools, models and guidance developed through this research (see Chapters 7 and 8).

Additionally, ecosystem services are considered to be particularly relevant at the 'science-policy' interface by helping to translate the link between the natural environment/ecological processes and human wellbeing in a manner that is understandable and useful for policy-makers (Carpenter et al, 2006; Baker et al, 2013 Helming et al, 2013). In this manner, the use of ecosystem services can ensure that relevant scientific knowledge and evidence informs decision-making (ibid). The risk of *not* considering ecosystem services in decision-making is highlighted by Defra (2011) and EC (2011b). In particular, EC (2011b p.12) outline how "our economic prosperity and wellbeing depend on our natural capital, including ecosystems that provide us with a flow of essential goods and services" and how "many of these ecosystem services are used almost as if their supply is unlimited".

The issues discussed above help to explain why the ecosystem services concept is increasingly gaining prominence across many policy issues. Although the concept originates from the CBD and has a key focus on biodiversity protection (see section 1.2), it has a range of other practical applications in policy and ecosystem management decision-making that are now coming to light (e.g. Baker et al, 2013; Geneletti, 2013a; Helming et al, 2013; Partidario and Gomes, 2013). Table 3.6 outlines several practical benefits of ecosystem services for decision-making processes in general (noting that Chapter 6 considers benefits relating specifically to urban land use planning decision-making). Example policy areas and sectors where ecosystem services are currently being applied to practical policy decision-making are outlined below:

- Biodiversity protection and enhancement (e.g. EC, 2011a; Scottish Government, 2013l);

- European policy impact assessment including *ex ante* evaluation, a key example being the development of member state Rural Development Programmes (RDPs) under Pillar II of the EU Common Agricultural Policy – the CAP (e.g. Helming et al, 2013; Sheate and Phillips, 2014);
- Strategic/national level land use policy (e.g. Scottish Government, 2011d);
- Water management and river basin planning (e.g. EC, 2000);
- Urban land use/management planning (e.g. EERA, 2008; GCV Green Network Partnership, 2011; Sheate et al, 2012; Baker et al, 2013; Gaston et al, 2013; Geneletti, 2013b; Partidario and Gomes, 2013; James, 2013; Phillips, 2013); and
- As a framing for an overarching national approach to action and policy on the natural environment (e.g. Defra, 2011).

Table 3.6 General applications/benefits of ecosystem services for decision-making

(Adapted from Baker et al, 2013; Helming et al, 2013; Partidario and Gomes, 2013)

Application/benefit	**Details**
1. Supporting a holistic approach to the natural environment	• "Ecosystem services is an integrating concept which instead of dealing with discrete environmental 'topics' considers bundles of services that flow from the environment" (Baker et al, 2013 p.8) • In this manner, ecosystem services can help decision-makers to think about the environment more holistically, promoting consideration of ecosystem health and function (i.e. ecosystem processes/intermediate services – see Figure 3.8) which is essential for ecosystem services
2. Understanding how the natural environment can support policy objectives	• Many policies "do not explicitly address ecosystem services but are bound to cause impacts on ecosystem services as a side effect" (Helming et al, 2013 p.82) • For these policies, ecosystem services can be used as a framing to communicate opportunities whereby the natural environment may be able to support policy objectives (e.g. exploring the flood storage role of urban greenspace as part of a flood risk management strategy) • In this manner, ecosystem services can be used to help frame the natural environment as a benefit rather than a hindrance or constraint
3. Stakeholder and wider public engagement	• Ecosystem services can provide a useful means of engaging stakeholders and the wider public on decision-making that affects the natural environment • Framing the environment in terms of 'uses/benefits' as opposed to 'things' (e.g. habitats, species, water quality, landscape etc) can help non-technical stakeholders and the public to communicate perceptions and uses of the natural environment 'on their terms' (e.g. this is where I take my dog for a walk, this is where we go for a picnic on a nice day)
4. Casting a different light on conflict between	• Similarly to No.2 above, ecosystem services can demonstrate the value (monetary or non-monetary) of the natural environment • These values can be used to explore different angles to conflicts between

Application/benefit	Details
economic and environmental objectives	economic and environmental objectives e.g. the economic case for a transport infrastructure project may not be so compelling when compared to loss of ecosystem services as a result of land use change

Note: The general decision-making applications/benefits of ecosystem services outlined in the table above are all of relevance to urban land use planning. Chapter 6 also considers a range of specific applications/benefits of ecosystem services for urban decision-making contexts.

Although, as described above, there is arguably a strong case for using ecosystem services in practical policy decision-making, there are key problems and weaknesses that need to be balanced against the strengths. Example weaknesses include problems concerning the language of ecosystem services and communication with stakeholders, the complexity of the concept as a result of its inherently integrated nature, the contested nature of ecosystem service economic valuations[30] (e.g. for use as an input to cost benefit analyses alongside more conventional costs and benefits) and the additional resources required to consider ecosystem services, such as additional data needs and expertise requirements (Sheate et al, 2012; Baker et al, 2013; Phillips et al, 2014).

3.2.4 Key principles of the ecosystems approach

The purpose of this section is to outline the established principles for the ecosystems approach. In conjunction with material in sections 3.2.1, 3.2.2 and 3.2.3, this section provides the general science and policy framework for the ecosystems approach that this research is based on (noting that Chapters 4 and 5 provide more detailed, technical information on urban land use/management for the provision of the specific ecosystem services considered in this research – see section 3.2.5).

As described at section 1.2, the ecosystems approach was originally developed as a practical means of delivering the objectives of the CBD. At their fifth meeting in May 2000, the Conference of the Parties (COP) of the CBD endorsed the description, principles and operational guidance for the ecosystems approach[31] that has played a key role informing this research (CBD Secretariat, 2000). Despite the

---

[30] For example Phillips et al (2014 p.97) found that “land owners/managers would require a proven and consistent approach for ecosystem service assessment before data on ecosystem service values would be accepted as an input to decision-making processes”

[31] Following Recommendation V/10 of the CBD Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA): https://www.cbd.int/recommendation/sbstta/default.shtml?id=7027 [accessed 13/01/14]

availability of these principles and operational guidance (as well as other key resources such as the CBD Secretariat hosted ecosystems case studies[32] and sourcebook pages[33]), there is [at least] a perception that the ecosystems approach is not being effectively integrated into conservation strategies or indeed other policies affecting the natural environment and ecosystem services[34] (CBD Secretariat, 2006; Fee et al, 2009; Labiosa et al, 2013). The potential lack of methodologies and tools for adopting the ecosystems approach in urban land use planning, as with other decision-making contexts, is a key issue addressed in this research as discussed at Chapters 1 and 6.

The Parties to the CBD describe the ecosystems approach as 'a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way' (CBD Secretariat, 2000). This definition, in conjunction with the CBD's general approach (see section 1.2), is broadly reflected in policy and action on the ecosystems approach across the key contexts considered in this research – the EU (EC, 2011a; EC, 2011b; EC, 2013), the UK (Defra, 2007; Defra, 2011) and Scotland (Scottish Government, 2011c; Scottish Government, 2011d). This research has framed the ecosystems approach, in particular, in terms of maintaining healthy, functioning ecosystems to ensure consistent supplies of ecosystem services (e.g. in terms of the new spatial models' focus on ecosystem processes/intermediate services – see sections 7.3 and 7.4). In this manner, ecosystem health/function is considered on the one hand and ecosystem services and societal wellbeing and prosperity on the other. The intention here is not to pursue a less integrated approach, rather it aims to ensure that the natural environment is managed towards an overall objective of maintaining health and function *as well* as ecosystem service provision. This echoes the conceptual

---

[32] CBD Ecosystems Approach Case Studies pages: https://www.cbd.int/programmes/cross-cutting/ecosystem/cs.aspx [accessed 13/01/14]

[33] CBD Ecosystems Approach Sourcebook pages: https://www.cbd.int/ecosystem/sourcebook/default.shtml [accessed 13/01/14]

[34] Clearly the CBD resources on the ecosystems approach are intended to be globally relevant and therefore necessarily generic and potentially challenging to interpret elsewhere. In addition however, there are elements of research and good-practice development in ecosystems approach based decision-making elsewhere, including for key sectors such as urban land use planning as outlined further at Chapter 6. The intention of this thesis is to build on the strengths of existing research in the development of new practical approaches to urban planning that can operationalise key aspects of the ecosystems approach (see Chapters 7 and 8)

framework adopted by the UKNEA (Mace et al, 2011) as shown on Figures 3.6 and 3.8, especially the notion of ecosystem processes/intermediate services as separate to and underpinning the provision of final ecosystem services (see section 3.2.2). Key examples of how aspects of the ecosystems approach have been framed in EU, UK and Scottish policy are provided at Table 3.7.

Table 3.7 Ecosystems approach considerations in key EU, UK and Scottish policy

(Adapted from Defra, 2007; EC, 2011a; EC, 2011b; Defra, 2011; Scottish Government, 2011c; Scottish Government, 2011d; EC, 2013)

Policy reference	Ecosystems approach considerations
Defra (2007 p.10)	"The ecosystems approach has been defined in various ways, but the **core** of the approach lies in **integrating and managing** the range of demands placed on the natural environment in such a way that it can **indefinitely support essential services** and provide benefits for all"
EC (2011a p.5)	"In the EU, many **ecosystems** and their services have been **degraded**, largely as a result of land fragmentation. Nearly 30 % of the EU territory is moderately to very highly fragmented. Target 2 [of the EU Biodiversity Strategy to 2020] focuses on maintaining and enhancing ecosystem services and **restoring degraded ecosystems** by incorporating green infrastructure in spatial planning"
EC (2011b p.12)	"Biodiversity **underpins** many of our ecosystems and is vital to their resilience. Its loss can **weaken** an ecosystem, **compromising** the delivery of **ecosystem services** and making it more vulnerable to environmental shocks. Restoring degraded ecosystems is costly, and in some cases, change can become irreversible"
EC (2013 p.2)	"[Green infrastructure] is a successfully tested tool for providing **ecological**, economic and social benefits through natural solutions. Green infrastructure is based on the principle that **protecting and enhancing nature and natural processes**, and the many benefits human society gets from nature, are consciously integrated into spatial planning and territorial development"
Defra (2011 p.7)	"The benefits we get from nature are often described as 'ecosystem services'. Natural resources (such as food, timber and water) and **functioning natural systems** (such as healthy, fertile soils; clean water and air; and a regulated climate) are vital support services for our wellbeing and security, and are themselves **sustained by biodiversity**"
Scottish Government (2011c p.4)	"Land use decisions should be informed by an understanding of the **functioning of the ecosystems** which they affect in order to **maintain the benefits** of the ecosystem services which they provide"
Scottish Government (2011d p.1)	"We believe that there is potential for greater use of an ecosystems approach to improve decision making, increase the **quality of our natural environment**, and enhance the value which we obtain from it"
Scottish Government (2011d p.2)	"Consider **natural systems** – by using knowledge of **interactions** in nature and how **ecosystems function**"

Note: Emphasis in the table above has been added by the author. The example quotes are intended to highlight the crucial importance of considering ecosystem health and function (i.e. ecosystem processes/intermediate services as the UKNEA) in addition to final ecosystem services as part of an ecosystems approach. The policy examples in the table above exemplify this distinction.

As described at section 3.2.1, ecosystems are interdependent and complex and altering one aspect can have a significant impact on overall ecosystem function and ecosystem service flows (see Figure 3.6). This may be particularly significant where there is a risk of an environmental limit being reached (see Figure 3.7). Accordingly, when evaluating the impacts of policy decisions on the natural environment, the ecosystems approach shifts the emphasis from an assessment of impacts on discrete environmental media (e.g. air, water, biodiversity etc) to an assessment of impacts on whole ecosystems (Defra, 2007; Fee et al, 2009; SWT, 2009; Defra, 2011; CBD Secretariat, 2013a). The intention is to understand how the complex, interdependent aspects of ecosystem function may change, when impacted by a particular policy or policy option. Potential changes in ecosystem function can be further categorised on the basis of impacts on ecosystem structure, composition and process (ibid). As discussed at section 3.2.1, changes in ecosystem function can also bring about changes in the supply of ecosystem services meaning, therefore, that an understanding of potential changes in ecosystem function can support an understanding of potential changes in ecosystem service flows also (see Figure 3.8 for further information).

In relation to urban planning in particular, an identified key challenge/obstacle to the adoption of ecosystems approach based decision-making is a lack of practical tools, models and scenario evaluation frameworks that can allow urban planners to think strategically about their towns and cities from an ecosystems perspective (Chan et al, 2006; Gret-Regamey et al, 2013; Labiosa et al, 2013). This is reflected by Fee et al (2009) who identified key institutional, technical and capacity-related obstacles to adopting the ecosystems approach. Table 3.8 identifies general principles for the ecosystems approach from the CBD and relevant UK and Scottish policy (this builds on the key ecosystems approach considerations within sample EU, UK and Scottish policies identified in Table 3.7). These principles (along with all other analysis and synthesis in this Chapter) have underpinned the development of the new urban planning approaches that are a key output of this research under Research Objective 4 (see Chapters 7 and 8). They also provide part of the overall framing to the suite of guiding principles for ecosystems approach based urban planning developed through this research (see Appendix 3).

Table 3.8 International, UK and Scottish principles for the ecosystems approach

(Adapted from Defra, 2007; Scottish Government, 2011c; CBD Secretariat, 2013a)

Principles from Scottish Government (2011c)	Principles from Defra (2007)	Principles from CBD Secretariat (2013a)
Consider natural systems: by using knowledge of interactions in nature and how ecosystems function. This implies a need to consider the broad scale as well as the local; and the long term as well as the immediate. Ecosystem function often shows a capacity to accommodate some change, but a significant impact may result when a threshold is crossed and capacity exceeded	Taking a more holistic approach to policy-making and delivery, with the focus on maintaining healthy ecosystems and ecosystem services	**EsA_1:** Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems
	Ensuring environmental limits are respected in the context of sustainable development, taking into account ecosystem functioning	**EsA_2:** Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach
	Taking decisions at the appropriate spatial scale while recognising the cumulative impacts of decisions	**EsA_3:** Ecosystems must be managed within the limits of their functioning
	Promoting adaptive management of the natural environment to respond to changing pressures, including climate change	**EsA_4:** The ecosystem approach should be undertaken at the appropriate spatial and temporal scales
		EsA_5: Recognising the varying temporal scales and lag-effects that characterise ecosystem processes, objectives for ecosystem management should be set for the long term
		EsA_6: Management must recognise the change is inevitable
Take account of the services that ecosystems provide: including those that underpin social and economic wellbeing, such as flood and climate regulation, resources for food, fibre or fuel, or for recreation, culture and quality of life. All these services are supplied by our ecosystems. There are ways to account for some of these services using economic and other measures to inform policy and consider offsetting or mitigation	Ensuring that the value of ecosystem services is fully reflected in decision-making	**EsA_7:** Recognising potential gains from management, there is usually a need to understand and manage the ecosystem in an economic context. Any such ecosystem management programme should: a) reduce those market distortions that adversely affect biological diversity; b) align incentives to promote biodiversity conservation and sustainable use; and c) internalise costs and benefits in the given ecosystem to the extent feasible
		EsA_8: The ecosystem approach should seek the appropriate balance between, and integration of, conservation and use of biological diversity
Involve people: those	N/A	**EsA_9:** The objectives of management of land,

Principles from Scottish Government (2011c)	**Principles from Defra (2007)**	**Principles from CBD Secretariat (2013a)**
who benefit from the ecosystem services and those managing them need to be involved in decisions that affect them. Their knowledge will often be central to success. Public participation should go beyond consultation to become real involvement in decision making		water and living resources are a matter of societal choices
		EsA_10: Management should be decentralised to the lowest appropriate level
		EsA_11: The ecosystem approach should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations and practices
		EsA_12: The ecosystem approach should involve all relevant sectors of society and scientific disciplines

Note: The table above collates ecosystems approach principles from: 1) CBD Secretariat (2013a) – *Ecosystems approach principles*; 2) Defra (2007) – *Securing a healthy natural environment: an action plan for embedding an ecosystems approach*; and 3) Scottish Government (2011c) – *Applying an ecosystems approach to land use information note*. The table has been organised to show the links and cross-over between the principles in the three different policies. International and UK Government principles have been categorised under the Scottish Government principles reflecting the specific Scottish focus of this research (see sections 1.4 and 2.1.4). This analysis shows how the Scottish principles (left-hand column) are broad and aggregated when compared to the International principles in particular (right-hand column) which are numerous and specific. All these principles and the analysis of links and cross-overs therein have played a key role informing the development of the new approaches to urban planning in this research (see Chapters 7 and 8).

3.2.5 Prioritising ecosystem services for consideration in this thesis

The preceding sections introduce ecosystem services and the ecosystems approach which provide the overall theoretical framework for this research (see section 2.1.2). As per Box 1.2 however, Research Objective No.1 seeks "to identify urban ecosystem services that are particularly important in northern European urban centres". As described at section 1.4, this objective recognises the importance of defining a realistic scope for the thesis in terms of the key urban ecosystem services considered in subsequent objectives. The prioritisation of ecosystem services in this regard has been undertaken with reference to key EU and Scottish Government policies and reports to form a view on the challenges facing northern European urban centres (and Glasgow/Scottish urban centres) and therefore the urban ecosystem services that could potentially help to address these challenges (see sections 2.2.2 and 2.3.1). The ecosystem services considered in this thesis are: 1) flood storage; 2) runoff reduction; and 3) ecological connectivity.

The more general focus on northern Europe recognises, as per section 1.1, that many urbanisation problems can be influenced by key external factors, especially global climate change. As such, this thesis argues that ecosystems approach based solutions to climate change related urbanisation problems are likely to be applicable to urban centres with similar climates and facing similar climate change impacts. This is the main rationale for the thesis' focus on water management related ecosystem services. This rationale is supported by the review of key EU and Scottish Government policies and reports (see section 2.3.1) which frequently highlight the importance of urban land use/green infrastructure and ecosystem services contributing to urban climate change adaptation including flood risk management (FRM). Ecological connectivity has been included given the inherent importance of well-connected landscapes supporting biodiversity which, in turn, underpins all aspects of ecosystem function and ecosystem services (see sections 3.2.1 and 5.1).

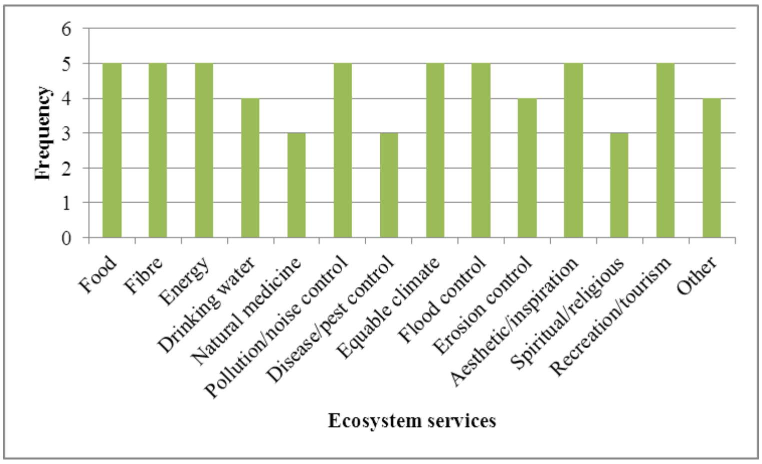


Figure 3.10 Expert interview Question 3.5 results – which services from the following list do you think the urban natural environment provides?

Note: In Question 3.5, interviewees were provided with a list of ecosystem goods from the UKNEA typology (see Figure 3.8). Five experts were interviewed (see section 2.3.4).

As described at sections 2.2.8 and 2.3.4, five land use/management planning experts were engaged through a semi-structured interview process in order to collect data that could validate (or otherwise) key findings that informed the evidence assessment. As part of this process, Question 3.5 (see Appendix 2) asked the experts which ecosystem services they thought the urban natural environment provides. Interviewees were asked to frame their response in the context of a northern European urban centre, such as Glasgow. Interviewees were provided with a list of the ecosystem goods[35] from the UKNEA typology (see Figure 3.8) and asked to tick all applicable goods. Responses to this question (see Figure 3.10) indicate that in the view of the experts interviewed, urban natural environments in northern Europe have the potential to provide all 13 ecosystem goods identified in the UKNEA typology. Goods/services identified under 'other' included *healthy lifestyles* (three interviewees) and *ecological networks* (one interviewee).

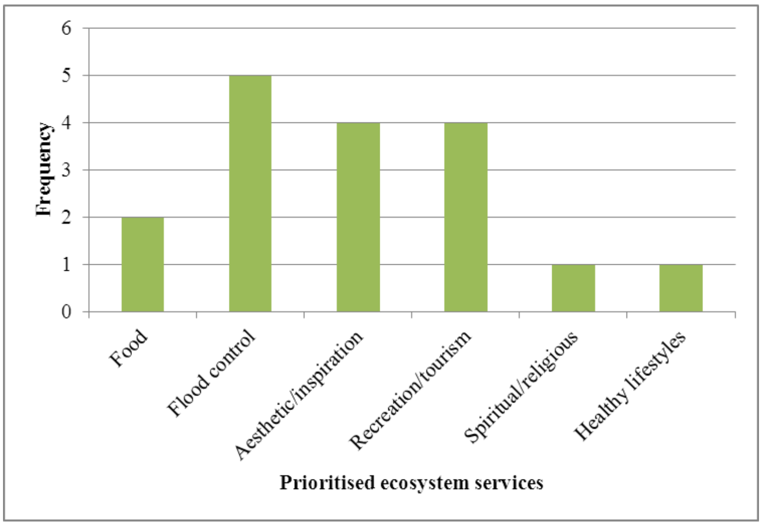


Figure 3.11 Expert interview Question 3.6 results – of the services you have identified, which three do you consider to be most important?

Note: Question 3.5, asked interviewees to identify ecosystem services that they felt the urban natural environment provides from a list of ecosystem goods taken from the UKNEA typology (see Figure 3.8). From the list of services at Question 3.5, Question 3.6 asked interviewees to prioritise the three services they considered to be most important. As with Question 3.5, interviewees were asked to frame their response in the context of a northern European urban centre, such as Glasgow. Five experts were interviewed (see section 2.3.4).

From the list of applicable services identified at Question 3.5, Question 3.6 (see Appendix 2) then asked interviewees to prioritise the three services they considered to be **most important** in the context of a northern European urban centre (such as Glasgow). Responses to this question (see Figure 3.11) indicate a distinct focus on key cultural ecosystem services – *aesthetic/inspiration*, *recreation/tourism* and *spiritual/religious*. Two of the interviewees highlighted the relationship between *food* and *healthy lifestyles*, noting that *healthy lifestyles* was one of the 'other'

---

[35] Ecosystem goods were felt to be more intuitive to urban land use stakeholders than final ecosystem services

services identified in Question 3.5 by three of the five interviewees (see Figure 3.10). The relationship between food (including community growing projects and allotments) and healthy lifestyles was felt to be highly important for Glasgow given particular aspects of the socio-economic context (e.g. high incidence of multiple deprivation, poor health record etc). Crucially however, *flood control* was identified by all five of the interviewees as a key ecosystem service for northern European urban centres. Importantly, this finding supports the rationale for the thesis' focus on water management related ecosystem services (see Chapter 4).

Chapter 4 now explores how urban land use/management can impact the functioning of the key water management related ecosystem services considered in this thesis – flood storage and runoff reduction.

4. Urban land use planning and water management

The overarching aim of this research is "to understand, develop, trial and evaluate new approaches to urban planning that can operationalise key aspects of the ecosystems approach" (see section 1.4). To meet this overarching aim, a substantive evidence assessment has been undertaken as documented in Chapters 3, 4, 5 and 6. The approach taken to the evidence assessment is described in the methodology Chapter at section 2.2. Section 2.4 describes how the data collated through the evidence assessment has been analysed to support other objectives of the research, especially the development of new approaches to urban planning that can operationalise aspects of the ecosystems approach (see Box 1.2).

The main output of the evidence assessment is the development of a suite of new guiding principles for ecosystems approach based urban land use planning (see Appendix 3). The principles provide the overall framing for the new urban land use planning approaches developed through this research (see Chapters 7 and 8) and are intended to be of practical use in other urban planning contexts also, as explained at section 8.1. The evidence assessment has also informed the development of specific guidance to help practitioners interpret and act on outputs from the new models in the development of integrated urban land use/management strategies (see Chapters 7 and 8 and Appendices 4, 5 and 6).

As outlined at sections 1.4 and 3.2.5, this thesis focuses on specific ecosystem services. This is the second of four chapters documenting the evidence assessment that has underpinned this research. This Chapter focuses on the specific role of urban land use/management contributing to key water management related ecosystem services – flood storage and runoff reduction. In particular, the evidence in this Chapter has underpinned the development of the flood control model (see section 7.2) and hydrological cycle model (see section 7.3). In line with this focus, Chapter 4 addresses three key research questions that have informed the research activities undertaken (REA and semi-structured interviews – see sections 2.3.2 and 2.3.4) as well as providing a framing for the key findings of this part of the evidence assessment, as discussed at section 9.2. The research questions considered within this part of the evidence assessment are as follows:

- What are the key natural processes that influence the hydrology of urban catchments?
- How can the management and use of urban land influence the provision of water management related ecosystem services in urban areas?
- What are the main techniques available for land use/management based urban water management?

This Chapter starts by explaining the interrelationships between urbanisation, drainage, climate change and flooding (section 4.1), it then goes on to discuss the key principles of sustainable, catchment-based approaches to flood risk management (FRM) with a focus on Scottish policy and guidance (section 4.2). The basics of Flood Risk Assessment (FRA) are then introduced at section 4.3 and section 4.4 outlines the key principles of hydraulics that are fundamental to FRM and several of the natural flood management (NFM) techniques considered in this research. The final sections (4.5 – 4.7) collate, analyse and synthesise information on three key land use/management based NFM measures that can be adopted in urban areas. The information here has played a crucial role informing the technical development of new spatial models for the consideration of water management related ecosystem services in urban planning (see sections 7.2 and 7.3). The three land use/management based NFM measures subject to particular consideration in this research are:

1. River restoration (section 4.5)
2. Floodplain/riparian zone woodland planting and restoration (section 4.6)
3. Land use/management and sustainable drainage system (SuDS) measures for reducing runoff at source and providing storm water storage (section 4.7)

Where relevant, additional land use/management based water management measures have also been considered, to a degree, in the tools, models and guidance developed in this research. These include the creation, restoration and enhancement of floodplain wetland features (e.g. RRC, 2002; Scottish Government, 2011a; Graham et al, 2012; Scottish Government, 2013a) and the construction of low level bunds to provide structures for the temporary inundation of openspace by flood waters (Nisbet et al, 2011a; Parliamentary Office of Science and Technology, 2011). In reality, both of these measures are considered within section 4.7.3 on sustainable drainage system (SuDS) measures for reducing runoff at source and providing storm water storage (i.e. the SuDS components considered include engineered storage such as detention basins and wetlands as an integral part of high quality retention ponds).

4.1 Urbanisation, drainage, climate change and flooding

In the parts of the world where climate change is contributing to wetter weather and increased incidences of precipitation related extreme weather events (including most parts of the UK), FRM is a crucial issue. Focussing in on Scotland, FRM is likely to continue climbing the public policy agenda as flooding continues to be exacerbated by climate change (Scottish Government, 2011a; Scottish Government, 2013a; SEPA, 2012). Projected changes in winter precipitation rates for Scotland in 2080 are shown on Figure 4.1, indicating the potential for significant increases (up to 70%) in some parts of Scotland (including Glasgow). Additionally, hazard regulation, flood control/storage etc are frequently discussed in the ecosystem services literature, particularly in an urban context (Baker et al, 2013; Defra, 2007; TEEB, 2011; Davies et al, 2011 Scottish Government, 2011c; UKNEA, 2011; Sheate et al, 2012).

For the most part, flooding is a natural process that only becomes a societal or public policy issue where flood hazards impact people and their livelihoods (Scottish Government, 2011a; Scottish Government, 2013a). This can include homes, businesses, schools, hospitals as well as the other infrastructure and assets that support our socio-economic systems such as road, rail and energy networks and agricultural land. This crucial socio-economic aspect of flooding is reflected in the Scottish Government's guidance on sustainable FRM where flood risk is defined as a measure of the **likelihood of an event occurring in conjunction with the potential consequences of the event** (Scottish Government, 2011a). In effect, the likelihood of a flood event occurring might be very high but if its consequences are minimal, the risk associated with the flood will also be minimal. This is depicted on Figure 4.2.

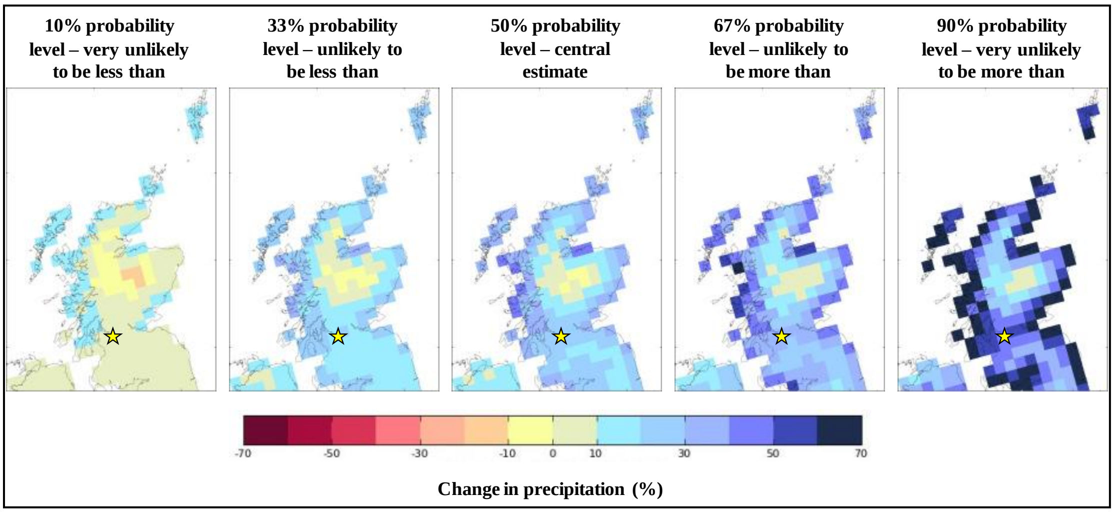
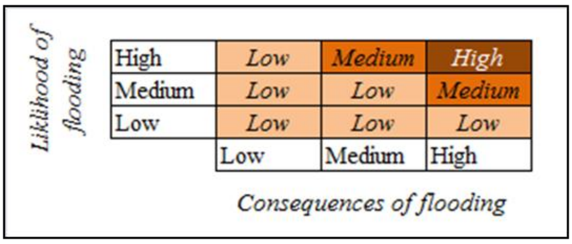


Figure 4.1 Predicted change in winter mean precipitation rate (%) in Scotland under high a emissions scenario by the 2080s

(Adapted from SCCIP, 2009)

Note: Approximate location of Glasgow depicted by yellow star.

As we have seen at section 1.1, urban areas are increasingly where most people choose to live and it is urban areas therefore where the greatest concentration of potentially vulnerable and/or valuable socio-economic receptors are located. In essence, urban areas are where the consequences of flooding are likely to be most pronounced. Additionally, the urban landscape is frequently heavily modified (Scottish Government, 2013a). This modification often extends to the loss of ‘green and’ ‘natural environment’ type urban land uses (i.e. removal of vegetation and building over greenspace – see section 3.1.3) which can contribute to the disruption and degradation of the natural drainage processes (see Tables 4.1 and 4.6) that they support (Susdrain, 2012; Scottish Government, 2011a; Scottish Government, 2013a; Swan, 2010). Crucially, these natural drainage processes combine to provide natural protection against floods and their absence can create significant problems.



Likelihood of flooding

High	*Low*	*Medium*	*High*
Medium	*Low*	*Low*	*Medium*
Low	*Low*	*Low*	*Low*
	Low	Medium	High

Consequences of flooding

Figure 4.2 Relationship between likelihood, consequences and risk of flooding

(Adapted from Scottish Government, 2011a)

Note: Potential flood risk is indicated by the coloured cells in the centre of the matrix.

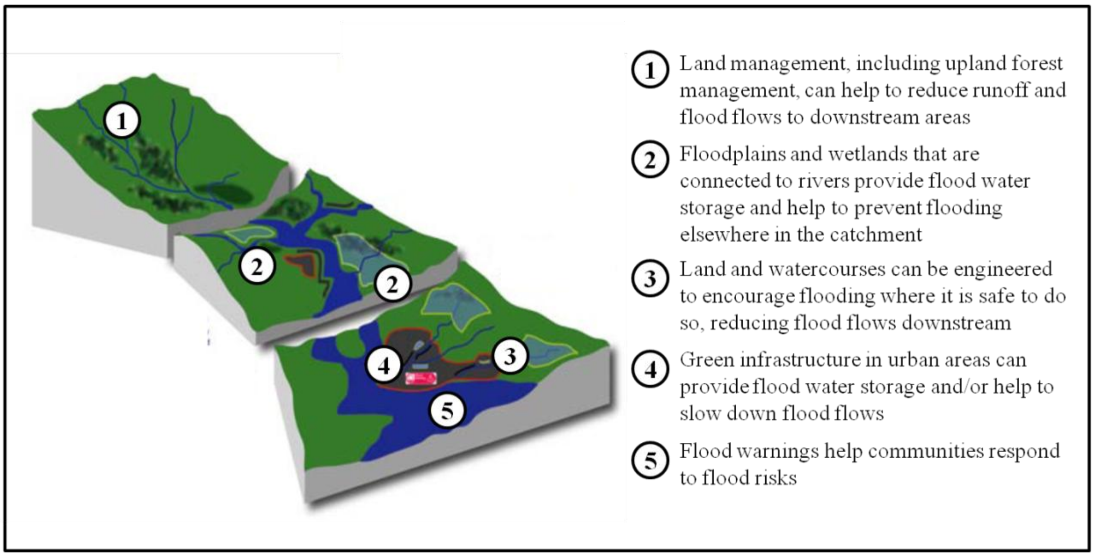
The frequent reference to urban flood risk management in the ecosystem services literature (see above) should come as no surprise. Although flooding is a component of the wider hydrological system with interdependencies operating at a range of spatial and temporal scales (see section 4.7.1), the impacts of flooding are felt locally and the demand for flood control goods and services will sometimes need to be met at or near the locus of that demand (i.e. where flooding is known or predicted to occur).

Table 4.1 Natural drainage processes

(Adapted from Susdrain, 2012; Scottish Government, 2011a; Scottish Government, 2013a)

Drainage process	**Details**
Interception and evapotranspiration	The processes by which vegetation cover helps to control water balance
Infiltration	The process by which surface water enters the soil
Attenuation	The storage and slow release of surface water runoff
Conveyance	The slow transportation of water on the surface

In any event, demand will have to be met within the same hydrological system – be that the catchment associated with a natural (e.g. a stream or burn[36]) or artificial (e.g. a waste water treatment works or individual surface water drain) drainage feature. In line with this, there are a range of practical land use/management strategies that can be used to increase flood storage away from the locus of the demand (i.e. the areas where the consequences of flooding will be severe such as urban areas) but within the geographical area defined by the catchment. These strategies aim to control the timing and magnitude of runoff in the catchment, thus helping to reduce the likelihood of flooding at more vulnerable locations or at least providing the relevant agencies with more time to issue flood warnings. This is exemplified by the recent shift towards catchment scale FRM as endorsed by the Floods Directive (Glasgow City Council, undated; EC, 2007; Scottish Government, 2011a; SEPA, 2012). Section 4.2 outlines the catchment based approach to sustainable FRM (see Figure 4.3) with particular reference to the requirements of the Flood Risk Management (Scotland) Act 2009.



① Land management, including upland forest management, can help to reduce runoff and flood flows to downstream areas

② Floodplains and wetlands that are connected to rivers provide flood water storage and help to prevent flooding elsewhere in the catchment

③ Land and watercourses can be engineered to encourage flooding where it is safe to do so, reducing flood flows downstream

④ Green infrastructure in urban areas can provide flood water storage and/or help to slow down flood flows

⑤ Flood warnings help communities respond to flood risks

Figure 4.3 A catchment based approach to sustainable flood risk management

(Adapted from Scottish Government, 2011a)

---

[36] The term *burn* is a Scots word meaning stream or small river. It’s use in this thesis has that meaning

4.2 A catchment based approach to sustainable flood risk management

Figure 4.3 depicts the catchment based approach to FRM. This type of approach offers a more sustainable, integrated means of delivering FRM actions that work with rather than against nature, by restoring and enhancing the natural landscape features that affect the timing, magnitude and duration of flood events (Scottish Government, 2011a; SEPA, 2012; Scottish Government, 2013a). In essence, catchment based FRM balances the use of more traditional flood defence orientated strategies (that mitigate the impacts of flooding in urban areas and other valuable/vulnerable locations) with more sustainable catchment focussed actions (that mitigate the sources of flooding). Wherever possible, this type of approach aims to reduce the likelihood of flooding in population centres and other valuable/vulnerable locations, thereby reducing overall flood risk and reducing the need for engineered flood defences (e.g. embankments) at these locations (see Figure 4.2). The three key land use/management based NFM approaches considered in this research (see sections 4.5 – 4.7) are all designed for use within a catchment based approach to sustainable FRM as per Figure 4.3.

The Scottish Government's statutory guidance on sustainable FRM (Scottish Government, 2011a) identifies five key outcomes for sustainable FRM in Scotland (see Table 4.2). There are clear areas of synergy between these outcomes and urban land use planning, as reflected in the Scottish Environment Protection Agency's (SEPA) technical guidance on Strategic Flood Risk Assessment (SFRA) and Development Planning (SEPA, 2012). In particular, the SEPA guidance suggests that linkages between the development planning and flood risk management planning processes should be exploited to ensure that overall increases in flood risk are avoided (SEPA, 2012). In essence, SEPA (ibid) encourage planning authorities to use SFRA in conjunction with the land use and development planning process (see section 3.1) to guide development away from areas where flooding is likely to occur (e.g. through constraints mapping) and to protect/enhance those existing land uses that control runoff at source (e.g. upper and mid catchment woodland) or provide flood storage (e.g. functional floodplains, wetlands, ponds etc).

Table 4.2 Scotland's guidance on sustainable Flood Risk Management (FRM) – key outcomes and links with urban land use/management planning

(Adapted from Scottish Government, 2011a; SEPA, 2012)

FRM outcome	Potential links with urban land use/management planning
1. A reduction in the number of people, homes and property at risk of flooding as a result of public funds being invested in actions that protect the most vulnerable and those areas at greatest risk of flooding	• Urban areas are where most people live and therefore where the consequences of flooding are likely to be most pronounced • Appropriate land use/management intervention can act to reduce runoff at source and/or provide increased flood storage in urban catchments • If designed and delivered effectively, these types of intervention can reduce the number of people, homes, properties and businesses at risk of urban flooding, supporting this FRM outcome
2. Rural and urban landscapes with space to store water and slow down the progress of floods	• Many NFM approaches (including the specific urban land use/management approaches considered in this research) work by restoring natural landscape features to increase flood water storage capacity and reduce runoff at source (i.e. providing flood storage and runoff reduction ecosystem services) • The land use planning system can introduce policies to protect areas of land that are already providing these services and/or require new development to enhance or provide these services (e.g. through planning conditions/planning gain – see sections 1.3 and 3.1.1) • Accordingly, well planned land use/management intervention can directly support this outcome
3. Integrated drainage that decreases burdens on our sewer systems while also delivering reduced flood risk and an improved water environment	• Land use/management intervention that provides flood storage and runoff reduction ecosystem services within urban catchments can increase the landscape's capacity to retain water (increase E_t) thereby reducing runoff • Recognising the high degree of interaction between different sources of flooding and natural and artificial drainage systems in modified urban catchments, this type of intervention has significant potential to reduce pressure on artificial drainage infrastructure (including sewer systems and waste water treatment plants), helping to reduce the incidence of untreated sewage effluent discharge and contributing to water environment outcomes • The land use planning system can introduce specific policies on integrated drainage and surface water management for urban catchments. It can also direct land management policy to enhance/restore the drainage processes provided by existing 'green' and 'natural environment' type urban land uses (see Tables 4.1 and 4.6)
4. A well informed public who understand flood risk and adopt actions to	• As FRM actions become more integrated with other policy agendas (e.g. land use and development planning) and exposure increases, the public may become more engaged with the

FRM outcome	**Potential links with urban land use/management planning**
protect themselves, their property or their businesses	process and begin to adopt their own FRM actions (e.g. Property Level Protection[37]) • The LDP process has statutory provisions around public consultation which may see integrated flooding and land use/management policies gaining increased public exposure. Involving people in land use decision-making is also a key principle of the Scottish Land Use Strategy (Scottish Government, 2011d) – see section 3.1.4
5. Flood management actions undertaken that will stand the test of time and be adaptable to future changes in the climate	• FRM that uses land use/management based structural measures is potentially more resilient than approaches based on ‘hard engineered’ structural measures such as embankments and culverts for a variety of reasons. For example, culverts have a defined capacity that may be difficult and/or expensive to increase and ongoing maintenance costs of underground infrastructure can be expensive (RRC, 2002) • Achieving a greater balance between NFM and hard engineered FRM measures arguably has the potential to increase urban resilience to climate change related flooding impacts

The Scottish Government’s guidance on sustainable FRM (Scottish Government, 2011a) covers six main sources of flooding: 1) river or fluvial flooding; 2) coastal flooding; 3) rainwater or pluvial flooding; 4) sewer flooding; 5) groundwater flooding; and 6) reservoir flooding and flooding from other infrastructure (see Table 4.3 also). Furthermore, the guidance recommends that SEPA and the other FRM stakeholders adopt the *source-pathway-receptor-impact* (SPRI) framework in the development of FRM actions (ibid). Specifically, the guidance describes sources of flooding as the weather events or conditions that result in flooding such as heavy rainfall, rising sea level, waves, dam break, river flows etc (ibid).

The SPRI approach provides a useful framework for planning sustainable FRM measures. Thinking in SPRI terms for example, there are arguably two key land use/management based strategies for mitigating flooding in urban areas: 1) reducing runoff at source, especially in the mid-upper reaches of urban catchments; and 2) increasing flood and storm water storage capacity at various locations throughout the catchment (Scottish Government, 2011a; SEPA, 2012). Both of these strategies provide increased flood storage and help to reduce runoff at source,

---

[37] See for example the Environment Agency’s advice on ‘preparing your property for flooding’: http://www.environment-agency.gov.uk/homeandleisure/floods/31644.aspx [accessed 04/04/14]

thereby helping to reduce and/or delay peak flows (see sections 4.6 and 4.7). All of the land use/management based NFM interventions considered in this research (see sections 4.5 – 4.7) fit into one or both of these categories.

Table 4.3 Definitions of pluvial and fluvial flooding

(Adapted from Scottish Government, 2011a)

Type of flooding	Definition	Source
Fluvial	Occurs when the water draining from the surrounding land exceeds the capacity of the watercourse	River flows
Pluvial	Caused when rainfall water ponds or flows over the ground before it enters a natural or artificial drainage system or watercourse, or when it cannot enter the drainage system because the system is already full to capacity	Heavy rainfall

4.3 Flood risk assessment (FRA) – the fundamentals

The initial stage of Flood Risk Management (FRM) planning is understanding the likelihood of flooding taking place at a given location – combined with an understanding of the consequences of flooding (i.e. an analysis of local receptors and their value and vulnerability), the technical stages of flood risk assessment (FRA) help to build up a picture of the contributory factors to flooding in a given catchment and an understanding of overall flood risk (i.e. the likelihood of flooding in combination with the consequences of flooding). Using this knowledge, FRM stakeholders can take steps to put in place suitable warning mechanisms, avoid the exacerbation of flood risk and reduce the likelihood and impacts of flooding e.g. though the use of structural FRM measures at the catchment scale that reduce runoff at source and/or provide sustainable flood storage interventions away from vulnerable receptors as well as traditionally engineered structural measures where required (Scottish Government, 2011a).

Understanding the likelihood of flooding taking place in a given location will involve hydrological and hydraulic modelling (SEPA, 2010; SEPA, 2012) to inform the development of maps and plans that show the spatial extent of flooding. Depending on the scale and complexity of the modelling undertaken, maps and plans may indicate other types of flood hazard[38] such as flood depth, flood flow pathways, flood flow velocity, inundation rates and the order in which various parts of the site/location are likely to flood, for a range of probabilistic return periods[39] (SEPA, 2010; Scottish Government, 2011a).

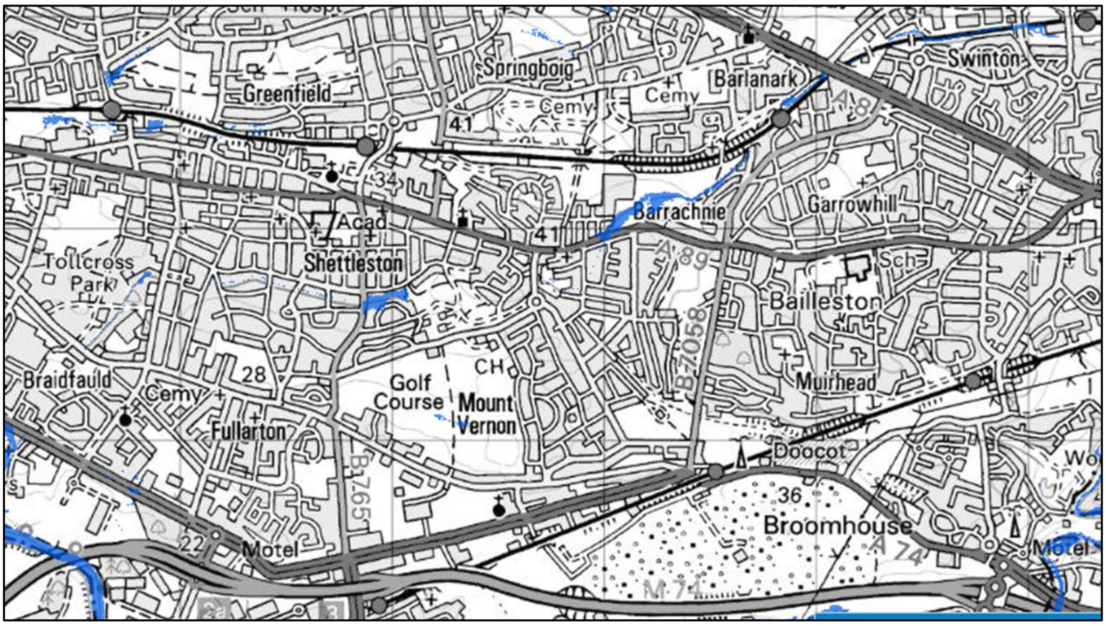


Figure 4.4 Flood extent for Tollcross Burn – short return period rainfall event

(Source: SEPA, 2014)

Note: The map above shows flood extent (dark blue areas) for the lower reaches of the Tollcross Burn (northeast Glasgow) under a short return period rainfall event i.e. where the likelihood of flooding happening in a given year is *high* (note how the flood extent shown on the map above is significantly less than that shown on Figure 4.5 for the long return period event). Where valuable and/or vulnerable receptors fall within the potential extent of flooding shown on the map above flood risk will be high as both the likelihood and the consequences of flooding are high (see Figure 4.2 and Table 4.4).

The greater the probability of flooding (i.e. flood events with a shorter return period) the lesser the extent of the flooded area as the associated rainfall event will be less severe (i.e. there will be less water in the drainage system and lower flows).

---

[38] Other key flood hazards include: 1) flood duration i.e. how long it takes for flood waters to dissipate; 2) water quality – heavy rainfall events can also result in sewer flooding/discharge of raw sewage effluent to water courses; and 3) sediment content – certain land uses within a catchment (e.g. agriculture, forestry) can be vulnerable to soil erosion during heavy rain (Scottish Government, 2011a)

[39] Return periods are statistical measurements that estimate the likelihood of an event occurring (e.g. a flood) based on historic data over an extended period of time

This concept is illustrated on Figures 4.4 and 4.5. The extant[40] Scottish Planning Policy (SPP) on flooding and drainage (Scottish Government, 2010; SEPA, 2012) defines flood risk by way of a three tiered risk framework as outlined in Table 4.4. The SPP risk framework (ibid) has informed the use of data in this research. In particular, the flood control model (see section 7.2) has used existing fluvial and pluvial flood maps showing flood extent for a 1 in 200 year rainfall event (i.e. 0.5% probability of occurring in any given year *or* medium – high risk as per the SPP risk framework shown at Table 4.4). Further information on the data is provided at section 2.4.2.

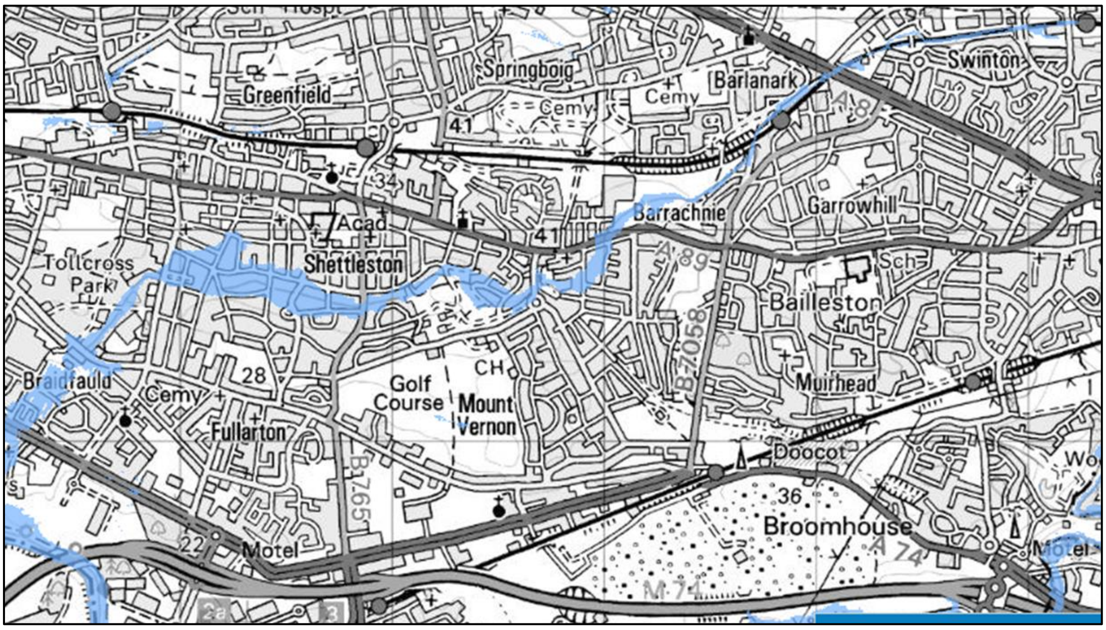


Figure 4.5 Flood extent for Tollcross Burn – long return period rainfall event

(Source: SEPA, 2014)

Note: The map above shows flood extent (light blue areas) for the lower reaches of the Tollcross Burn (northeast Glasgow) under a long return period rainfall event i.e. where the likelihood of flooding happening in a given year is *low* (note how the flood extent shown on the map above is significantly greater than that shown on Figure 4.4 for the short return period event) Where valuable and/or vulnerable receptors fall within the potential extent of flooding shown on the map above, flood risk will be low as although the consequences of flooding are high, the likelihood of a flood taking place in any given year is low (see Figure 4.2 and Table 4.4).

---

[40] Recognising that a review of SPP is currently underway with the finalised SPP due to be published in June 2014: http://www.scotland.gov.uk/Topics/Built-Environment/planning/NPF3-SPP-Review/SPP-Review [accessed 15/02/14]

Although this research has not involved the undertaking of any new FRA, a brief appraisal of commonly adopted FRA methods has been necessary to inform key aspects of the models, tools and guidance developed in this research (see Chapters 7 and 8) – for example, how do the characteristics of a catchment influence flood risk?

Table 4.4 Scottish Planning Policy (SPP) three tiered risk framework for flooding

(Adapted from Scottish Government, 2010 and SEPA, 2012)

Risk category	Probability of flooding	Qualitative description of flooding
Little or no risk	Annual probability of flooding is 0.1% i.e. a 1 in 1000 year return period	Under this flood risk category, the associated rainfall event is severe and the extent of the potential flooded area would be large. The probability of flooding however is low
Low to medium risk	Annual probability of flooding is between 0.1% and 0.5% or a 1 in 1000 – 1 in 200 year return period	Under this flood risk category the associated rainfall event is moderately severe and the extent of the potential flooded area would be large-medium. The probability of flooding however is low-medium
Medium to high risk	Annual probability of flooding is 0.5% or a 1 in 200 year return period	Under this flood risk category the associated rainfall event is more moderate and the extent of the potential flooded area would be smaller. The probability of flooding however is considered to be medium-high

FRA methods rely on data on historical flood events, gauge data (rainfall and river flow) and information on catchment characteristics to build up a picture of what contributes to flood events in a particular catchment (Scottish Government, 2011a). SEPA (2010) recommend the best-practice use of the Flood Estimation Handbook *or* FEH (CEH, 2009) to derive design river flood flows (or simply design flow[41]) and/or flow hydrographs for the catchment. In effect, the FEH approach is based on physiographic catchment and channel characteristics/descriptors (e.g. size, land use, topography, number of tributaries etc) and a database of model catchments and gauge data (the FEH/Hi-Flows UK database) to estimate how an actual catchment is likely to respond to rainfall events under different return periods. Other methods are

---

[41] SEPA (2010 p.10) highlight how design flow is often the most significant variable in determining the risk of flooding at a site. In fluvial flood modelling, design flow is an estimation of flow in the **river channel** for a given rainfall event (e.g. a 1 in 200 year/0.5% probability event etc). Flow is a measurement of volume per unit time and is usually measured in m^3/s. Once design flows have been established, engineers are then able to assess other parameters (e.g. the shape, area and roughness of the channel cross-section), using hydraulic modelling, to predict where flooding is likely to occur – i.e. flooding is likely to occur where the capacity of the channel is insufficient to hold the volume of water flowing through it.

available and SEPA (2010) suggest that the approach described above (known as the FEH statistical method) is not necessarily the best fit for all catchments[42].

In line with the above, a key parameter considered in FRA when determining design flows and modelling flood hazards (including flood extent) is catchment land use. In effect, different land uses have different properties in terms of their hydraulics (how rough or smooth they are), steepness and permeability. These properties affect the functioning of the natural drainage processes listed at Table 4.6 which in turn will affect the proportion of precipitation that drains to watercourses – i.e. runoff-precipitation ratios or runoff coefficients (Kuchment, 2014). The runoff coefficient of a catchment is an estimation of the integrated effect of catchment land use and other factors (e.g. geology, soils, land form etc) on these different drainage processes (ibid). In less modified catchments (i.e. where removal of vegetation and building over of greenspace has been kept to a minimum), the proportion of precipitation draining to watercourses will be lower as will runoff coefficients. In these cases, flooding is less likely to occur as a high proportion of precipitation is retained by the landscape. The opposite is true of more modified catchments. In modified urban catchments therefore, these key principles of hydrology and hydraulics can provide land use planners with the tools to consider how sustainable FRM objectives can be integrated with plans and programmes. These principles have been integrated with the new tools, models and guidance developed through this research (see Chapters 7 and 8).

4.4 Key principles of hydraulics for urban land use planning and water management

A key factor influencing the efficacy of NFM measures (including those considered in this research) is their impact on the hydraulic properties of the river/stream channel, the floodplain or areas of land in the wider catchment. In general terms, the greater the hydraulic ‘roughness’ of the land, river channel etc, the greater the flood storage/runoff reduction effect is likely to be. There are inevitably variations to this

---

[42] For example, the FEH statistical method is often not suited to small catchments as there is a paucity of small gauged catchments within the FEH Hi-Flows UK database (SEPA, 2010). Accordingly, there may be a lack of suitable comparisons to be drawn with model catchments.

rule[43] but for the purposes of informing strategic urban land use planning (i.e. as per the objectives of this research – see Box 1.2), this provides a useful general principle. The remainder of this section introduces the key principles of hydraulics that can have a bearing over how urban land is used and managed for water and flood risk management objectives. These principles have been integrated with the new tools, models and guidance developed through this research (see Chapters 7 and 8).

In simplistic terms, the hydraulic properties of an area of land (i.e. its degree of 'roughness') will influence the way in which water flows across it. In particular, a high degree of hydraulic roughness will provide flow resistance, dissipating the kinetic energy of flowing water and decreasing its velocity (Tabacchi et al, 2000; Nisbet et al, 2011c). In general terms, reducing the kinetic energy of flowing water/decreasing flow velocity (i.e. flow attenuation) can act to increase water depth/flood level and increase the area of land that is inundated during a flood event – i.e. the flood extent (Nisbet and Thomas, 2006; Nisbet and Thomas, 2008; Nisbet et al, 2011a; Nisbet et al, 2011c). There are clear FRM benefits that can be obtained by exploiting these properties e.g. changing land management at appropriate locations to increase flood storage/reduce runoff thereby helping to reduce or delay flood peaks (see Figures 4.9 – 4.12). This principle has been considered in the new flood control model in particular (see section 7.2).

A roughness coefficient is used as a proxy for kinetic energy losses from flowing water. One of the most commonly used is Manning's[44] **n** (Mansell, 2003; Ernst et al, 2010; SEPA, 2010). In hydraulic modelling, the channel and the floodplain are treated separately as the degree of roughness often varies significantly between the two, influenced by a number of factors. There can also be significant variation in roughness within specific stretches of the channel and floodplain (i.e. roughness is unlikely to be uniform) influenced by spatial variability in vegetation, soil type, land form, land management etc (see Figure 4.6 scenario C). This variation

---

[43] Equally, land use/management change to alter the hydraulic properties of land must be undertaken in a careful, planned manner to ensure that change doesn't actually increase runoff or act to synchronise peak flow discharge from tributaries to the main channel, thereby increasing and/or advancing downstream flood peaks (Nisbet and Thomas, 2008; Nisbet et al, 2011c; Parliamentary Office of Science and Technology, 2011).

[44] The Manning's formula is one of the most commonly applied uniform-flow formulae for open-channel computations (Mansell, 2003; Nisbet et al 2008; Nisbet et al, 2011a).

can be accounted for in hydraulic models though it is dependent on more granular input data e.g. topographic data, land cover data and soils data (ibid).

Factors affecting channel **n** (and therefore the nature of the flow therein) include: a) channel irregularities; b) channel alignment; c) scour and deposition within the channel; d) size and shape of the channel; e) water temperature; f) suspended material; and g) bedload (Nisbet et al, 2008; Nisbet et al, 2011a). Nisbet and Thomas (2008) and Nisbet et al (2011a) highlight how the most significant factors affecting channel **n** are the type of material forming the riverbed and banks and the cross-sectional shape of the channel. As described in further detail at sections 4.5 and 7.2.4, this is a key issue for river restoration based NFM measures which are designed to restore a more natural morphology in watercourses e.g. reversing river realignment/channelisation by reintroducing meanders (RRC, 2002; Parliamentary Office of Science and Technology, 2011). Floodplain **n** (and therefore the nature of flows across the floodplain) is also subject to variability and is influenced, in combination, by the following factors: 1) the nature of the bare sediment and soils; 2) surface irregularities; 3) the presence of obstructions; and 4) the nature of floodplain vegetation (Nisbet and Thomas, 2008). Similar factors will affect the hydraulic properties of land in the wider catchment, influencing overland flow based runoff generation mechanisms (Nisbet et al, 2011c; Parliamentary Office of Science and Technology, 2011; Kuchment, 2014) – see section 4.7. This variation in the hydraulic properties of land is, in part, what creates the opportunities for water management based on changes to land use/management.

Floodplain based NFM measures have the potential to provide a particularly significant FRM benefit (Nisbet and Thomas, 2006; Nisbet et al, 2011c). Accordingly, the hydraulics of riparian and floodplain land management are explored further in order to identify the key principles that urban land use/management should account for in relation to floodplain based NFM measures. As indicated on Figure 4.6, living and dead plant structures in the riparian zone and floodplain can influence hydraulic processes, namely flow routing and turbulence (Tabacchi et al, 2000). The hydraulic properties of floodplain/riparian vegetation is dependent on height and stiffness (Fathi-Maghadam and Kouwen, 1997), both of which affect the flow velocities that vegetation can withstand before it is flattened (resulting in reduced turbulence and less dissipation of kinetic energy). Seasonal factors in living plant structures (e.g. presence of foliage etc) and the presence/location of dead plant structures (which are mobile) will also influence the hydraulic properties of floodplain/riparian zone vegetation (Tabacchi et al, 2000).

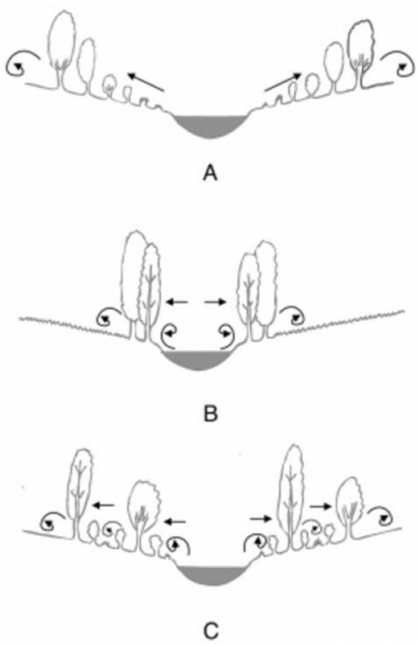


Figure 4.6 Potential hydraulic influences of riparian vegetation during overbank flows

(Source: Tabacchi et al, 2000)

Note: Land management can influence the hydraulics of the floodplain and riparian zone, increasing or decreasing flow resistance and the kinetic energy of flowing water. The figure above shows three types of riparian vegetation patterns and the hypothetical influences on flow resistance during overbank flows. Horizontal arrows indicate lateral resistance to flow, spiralling arrows indicate turbulence. (A) Regular transverse profile simulates progressive succession of riparian vegetation – this is considered to cause minimal lateral resistance and turbulence. (B) Sharp, dense and narrow corridor comprised of trees only – high lateral resistance and turbulence at internal and external edges. (C) Wide, heterogeneous corridor (i.e. a common profile found in more natural watercourses) inducing a better dissipation of kinetic energy but favouring numerous small-scale turbulences.

As such, management of the floodplain and riparian zone can have a significant influence on its hydraulic properties by obstructing, diverting or facilitating flows (ibid). For example, dead wood may be cleared, natural succession in the floodplain may be prevented as part of land management in the wider river corridor (e.g. to maintain other adjacent land uses such as housing, sports pitches etc) and the maintenance of path networks in the floodplain/riparian zone may provide flow routes for flood waters.

In line with the hydraulic principles introduced above, land management in the floodplain/riparian zone must be designed carefully to ensure that management supports desired water/flood risk management objectives. In particular, the nature of vegetation and its management can have beneficial or adverse effects (see Figure 4.6) depending on the specific water/flood risk management objectives for the catchment or a given stretch of the watercourse and its floodplain. For example, very high riparian zone vegetation densities can be virtually impenetrable to overbank flows (Naot et al, 1996), essentially acting as embankments and reducing connectivity between watercourse and floodplain. Conversely, where natural flooding is desirable (e.g. where the absence of vulnerable/valuable receptors is such that an area of land can provide useful flood storage), riparian/floodplain land management can be designed, in accordance with the principles of hydraulics, to promote out of bank flows and dissipate kinetic energy, thus increasing flood height and temporary flood storage (Tabacchi et al, 2000). As indicated on Figure 4.6, land management will require careful consideration to ensure that the hydraulic properties of the floodplain/riparian zone are such that they do not completely impede lateral flow whilst causing sufficient turbulence such that kinetic energy is dissipated and flood height increases. This is best indicated by riparian vegetation pattern C on Figure 4.6. The land management principles inherent to this pattern of riparian vegetation have been considered in the new flood control model (see section 7.2 and Appendix 4).

4.5 River restoration

River watercourse morphology (i.e. the physical characteristics of rivers) has been modified by humankind for centuries for a variety of reasons. Key reasons for historic and present day modification include flood defence, facilitating infrastructure construction (e.g. roads, railways etc), facilitating land gain for urban development and as a result of historic industrial activity such as the construction of mill lades[45] (UKTAG, 2003). This section considers the potential role of river restoration providing key water management ecosystem services within urban land

---

[45] A mill lade is an artificial watercourse that conveys water/flow to a mill

use/management planning and delivery. This includes an outline of the main problems caused by river modification (section 4.5.1), an introduction to some of the common morphology pressures affecting small urban watercourses (section 4.5.2) and an explanation of the relationship between river modification and ecosystem services and key restoration strategies (section 4.5.3).

4.5.1 Problems caused by river modification

The replacement of small urban watercourses with culverts and other drains is recognised as a key cause of surface water flooding in urban areas (EA, 1999; SEPA, 2006; Scottish Government, 2011a; Scottish Government, 2013a). Additionally, development and urbanisation pressures (e.g. removing vegetation and building over greenspace) can fundamentally alter natural drainage processes in urban catchments by reducing infiltration and evapotranspiration rates, thereby increasing the volume and rate of runoff (i.e. increasing runoff coefficients – see section 4.7.1). Combined with reduced capacity of the natural drainage network (i.e. as a result of culverting and other modifications) and the finite capacity of the artificial drainage network (i.e. surface water drains, foul water drains and combined drains), increased runoff in urban catchments can result in flooding when surface water can't reach the drainage network or when the capacity of the drainage network is exceeded (Scottish Government, 2013a).

Table 4.5 Key pressures on the morphology of river watercourses

(Adapted from UKTAG, 2003)

Pressure	**Description**
Bed and bank reinforcement	Strengthening of river beds for various purposes (e.g. ford construction, erosion control); flood protection using flood walls, embankments; bank protection using gabion baskets, boulders, sheet piling, wood, willow spiling, geotextiles, etc
River realignment	Removal of meanders: increase in channel gradient, flow velocity, flood capacity
Culverting	Complete enclosure of river channel, often impassable to fish

As such, well designed projects that restore urban watercourses can create a significant opportunity to help address surface water flooding by creating additional capacity within the natural (modified) drainage network. Furthermore, where a modified stretch of a watercourse flows through an area of openspace, there may be further potential for sustainable FRM by reconnecting the watercourse with its floodplain (i.e. the surrounding area of openspace) and restoring a more natural flooding regime. Indicated on Figures 4.7 and 4.8, these principles have played a key role informing the development of the new flood control model in this research (see section 7.2 and Appendix 4).

4.5.2 Key morphology pressures affecting small urban watercourses

This research has approached river restoration as a key land use/management based strategy for sustainable FRM in the sense that project interventions will require close integration between land and water management, as outlined further below. In doing so, there has been a focus on two key morphological pressures: 1) river realignment/bed and bank reinforcements; and 2) culverting (see Table 4.5), the rationale being that these pressures are often common to small urban watercourses and the costs and benefits of restoration are often agreeable (Wild et al, 2010).

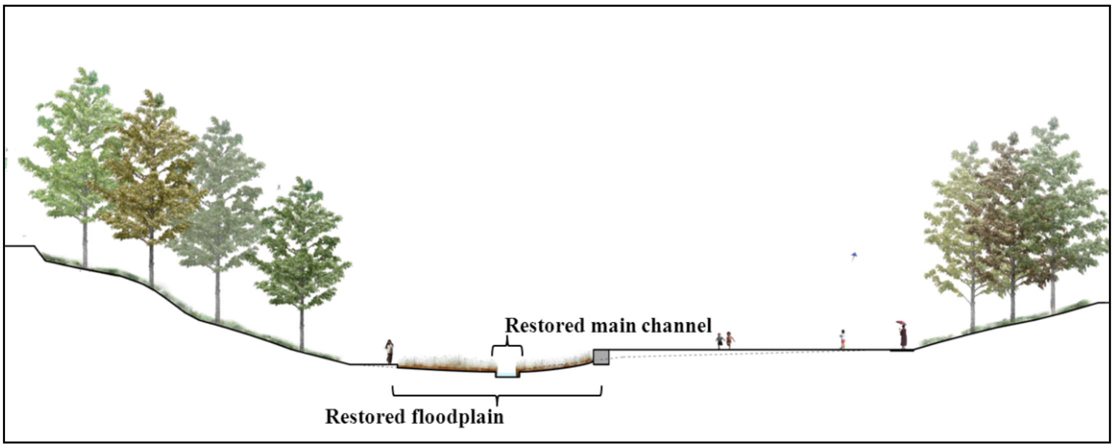


Figure 4.7 Section through a formerly culverted stretch of watercourse showing restored channel and floodplain – low flows

(Source: Glasgow City Council, 2013)

Note: The cross-section above shows a restored watercourse under low flow conditions (flow accommodated within the main channel). As a result of the deculverting and channel/floodplain restoration however, the barrier between channel and floodplain has been removed and a natural flooding regime restored. Under high flow conditions, the main channel will reach bank full and overspill to the newly created wetland area within the floodplain, thus providing flood storage and potentially helping to delay and reduce peak flows downstream (see Figure 4.8).

Although the EU Water Framework Directive (WFD) will often be the primary driver for projects and investment addressing morphology pressures (see below for further information), the restoration of urban waterbodies in the manner considered in this research can present a real opportunity for the delivery of FRM as well as wider multiple benefits. In effect, well designed river restoration projects have the potential to deliver true 'win-win' outcomes in terms of the number of benefits and functions that they can provide (RRC, 2002; Wild et al, 2010). This is exemplified by the many existing examples of river restoration delivering multiple benefits in the UK and elsewhere (ibid).

The primary drivers for culverting a watercourse are land gain for development (i.e. culverting removes the need to design the development around the watercourse) and the need to provide bridging structures for transport routes (SEPA, 2006; CIWEM, 2007). River realignments can meet similar objectives by removing meanders, thus reducing the area encompassed by the river corridor. The construction of bed and bank reinforcements as part of realignments can help to control erosion and provide *local* protection against floods (ibid).

Both river realignments and culverts provide local flood protection by creating a barrier between the river and its floodplain, thereby disconnecting the two features and preventing flooding within the locale (though this will be limited by the infrastructure's design capacity). As discussed in more detail below however, this disconnection of river and floodplain and consequent removal of flood storage has the effect of shortening peak flow response times and potentially increasing the magnitude of the flood peak (due to the loss of functional floodplain/reduced flood storage). The net effect of this is that downstream receptors (e.g. homeowners, businesses etc) have less time to respond to flood warnings and the extent, depth, velocity and other downstream flood hazards may be more severe. Additionally, the finite capacity of culverts and realigned/reinforced channels does not offer a resilient and flexible approach in the face of climate change and the likely increases in extreme rainfall events (CIWEM, 2007; Wild et al, 2010; Parliamentary Office of Science and Technology, 2011).

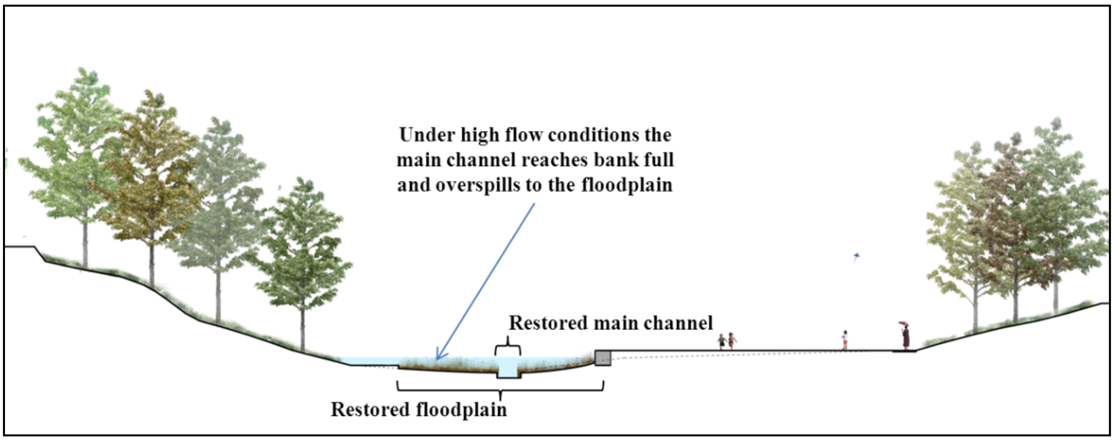


Figure 4.8 Section through a formerly culverted stretch of watercourse showing restored channel and floodplain – high flows

(Source: Glasgow City Council, 2013)

Note: The cross-section above shows a restored watercourse under high flow conditions (flow accommodated within the main channel and floodplain). As a result of the deculverting and channel/floodplain restoration, the barrier between channel and floodplain has been removed and a natural flooding regime restored. Under high flow conditions as indicated on the section above, the main channel has reached bank full and overspilled to the newly created wetland area within the floodplain, thus providing flood storage and potentially helping to delay and reduce peak flows downstream.

Generally speaking, morphology pressures such as culverts and river realignments adversely affect the landscape and ecological value of a watercourse by physically disrupting the continuity of the river corridor (Environment Agency, 1999; CIWEM, 2007). In particular, culverting results in loss of daylight which in combination with the culvert's concrete channels will result in loss of natural in-stream and bank-side habitats (SEPA, 2006; CIWEM, 2007).

4.5.3 River modification and ecosystem services

As discussed at section 3.2, the key rationale for the ecosystems approach is the inherent link between ecosystem health/function and the supply of ecosystem services. This link is particularly evident in the natural processes underpinning river function. In particular, the roughness provided by channel, bank and floodplain vegetation has a fundamental role to play in maintaining the river's flow regime (Environment Agency, 1999; UKTAG, 2003; SEPA, 2006). In effect, the hydraulic roughness of vegetation (in combination with the roughness afforded by the river's natural morphology e.g. meanders, variation in channel geometry etc) creates longitudinal and lateral variations in flow velocity and water depth, increased turbulence and slower flows (Emery et al, 2003; Bockelmann et al, 2004; Parliamentary Office of Science and Technology, 2011). This in turn promotes out of bank flows during high flow conditions, helping to connect the river with its floodplain (Nisbet and Thomas, 2006; Nisbet et al, 2008). Where rivers are straightened, channelised and engineered with concrete, the roughness of the channel and banks is largely lost, channel gradients are steepened, flows are smoothed out and flow velocities increase (Parliamentary Office of Science and Technology, 2011). This has the effect of reducing peak flow response times/increasing peak flows downstream as the natural flood storage function of a connected floodplain is lost. These types of effect are cumulative so the greater the length of watercourse subject to morphology pressures, the greater the likelihood and extent of flooding problems further down the catchment as under high flows, large volumes of water will be rushed downstream (ibid).

Furthermore, culverts and reinforced river realignments etc are more prone to blockage by natural debris and litter. Where these blockages occur in culverts their removal can prove very difficult due to access problems. Screens are often installed at the upstream end of culverts to trap debris though these too can cause problems by disrupting the flow and/or trapping debris (Environment Agency, 1999; SEPA; 2006; CIWEM, 2007; Wild et al, 2010). All of these blockages can act to restrict high flows, causing water to back-up and potentially contributing to upstream flooding as well[46]. These issues are also exacerbated by climate change in many circumstances (i.e. where anticipated impacts of climate change include increased extreme rainfall events). Furthermore, many urban culverts, reinforced river realignments etc have been designed to accommodate flows that, with climate change, are now being met or exceeded on an alarmingly regular basis (SEPA, 2006). Due to the engineering associated with culverts in particular (i.e. they are buried structures), it is very difficult to change the amount of water a culvert can carry to avoid flooding (ibid).

In light of the above, river restoration projects that address culvert and realignment pressures can raise significant opportunities for FRM by reconnecting

---

[46] As discussed in relation to floodplain woodland planting at sections 4.6, 7.2.5 and 7.2.8 it can sometimes be a desirable FRM strategy to promote the backing up of flood waters and associated out of bank flows though this needs to be delivered in a planned manner and in the absence of vulnerable receptors upstream of the intervention.

the watercourse with its floodplain, either as a standalone measure or in conjunction with other sustainable FRM measures such as those outlined at sections 4.6 and 4.7. Clearly this approach relies on the presence of a floodplain, therefore culverted and realigned watercourses flowing under or through developed areas are likely to be unsuitable for this sort of intervention (unless major land use change is proposed). That said, urban watercourses have frequently been culverted and realigned through areas of openspace[47], often to address perceived safety issues (Nolan and Guthrie, 1998; RRC, 2002; Wild et al, 2010). Where this is the case, openspaces such as parks, areas of natural/semi-natural habitat, sports areas etc can provide the physical space for temporary inundation by flood waters under high flows (i.e. they are restored as functioning floodplains). Some of the key practicalities of this approach are indicated on Figures 4.7 and 4.8.

There are many good-practice examples of river restoration from the UK and elsewhere, including urban projects that address culvert and realignment pressures. In particular, the River Restoration Centre[48] (RRC) is a UK based national information and advisory centre on all aspects of river restoration and enhancement and sustainable river management. The RRC's Manual of River Restoration Techniques (RRC, 2002) has been a useful resource informing the key aspects of the tools, models and guidance that have been developed in this research, especially Step 4 of the flood control model (see section 7.2.4).

4.6 Floodplain/riparian zone woodland planting and restoration

There has been a variety of research into the role of woodland in flood risk management (Robinson et al, 1998; Calder and Alyward, 2006; Nisbet and Thomas, 2006; Beedell et al, 2012). Furthermore, much of the UK research has been commissioned by key national agencies, especially Defra[49] and the Forestry

---

[47] These types of river restoration project can also be integrated with development and regeneration strategies e.g. where a modified watercourse runs through a regeneration area, there may be opportunities to fully integrate the restoration of that watercourse with the proposed development. The restored watercourse could provide a range of functions within the development e.g. as a focal point within new openspaces as well as supporting and being fully integrated with the development's drainage system (Susdrain, 2012).

[48] River Restoration Centre homepage: http://www.therrc.co.uk/index.php [accessed 22/02/14]

[49] Department for Environment, Food and Rural Affairs (Defra): http://www.defra.gov.uk/ [accessed 12/10/13]

Commission[50] (Nisbet and Thomas, 2008; Odoni and Lane, 2010; Broadmeadow and Nisbet, 2010; Nisbet et al, 2011a; Nisbet et al, 2011b). In line with section 4.2, the role of woodland in catchment based approaches to sustainable FRM can be differentiated in terms of whether it contributes to runoff reduction or flood storage based FRM strategies. The hydrological and hydraulic properties of woodlands and their soils are fundamental to the manner in which woodlands are able to provide flood control goods (Nisbet and Thomas, 2006; Nisbet et al, 2011b). In addition, the relative importance of these properties varies between the flood storage and runoff reduction functions of woodland. The remainder of this section provides further information on the hydrological and hydraulic properties of woodland in relation to flood storage (section 4.6.1), an analysis of the main constraints and opportunities for floodplain woodland in urban areas (section 4.6.2) and an analysis of the main strengths and weaknesses of floodplain woodland as a structural FRM measure (section 4.6.3).

4.6.1 The hydrological and hydraulic properties of trees and woodland

Woodlands have three key hydrological/hydraulic properties that can be manipulated in urban land use/management planning to provide water management related ecosystem services. These are: 1) the greater use of water by trees; 2) the so called ‘sponge effect’ exerted by forest soils; and 3) the greater hydraulic roughness associated with riparian and floodplain woodland (Nisbet and Thomas, 2006; Nisbet and Thomas, 2008; Nisbet et al, 2011a; Nisbet et al, 2011b). The first two properties are of greater relevance to runoff reduction and are dealt with in relation to land use/management intervention aimed at enhancing runoff reduction ecosystem services (see section 4.7). The third property however creates an opportunity for increasing flood storage and reducing/delaying peak flows in urban and rural catchments and is discussed in more detail below.

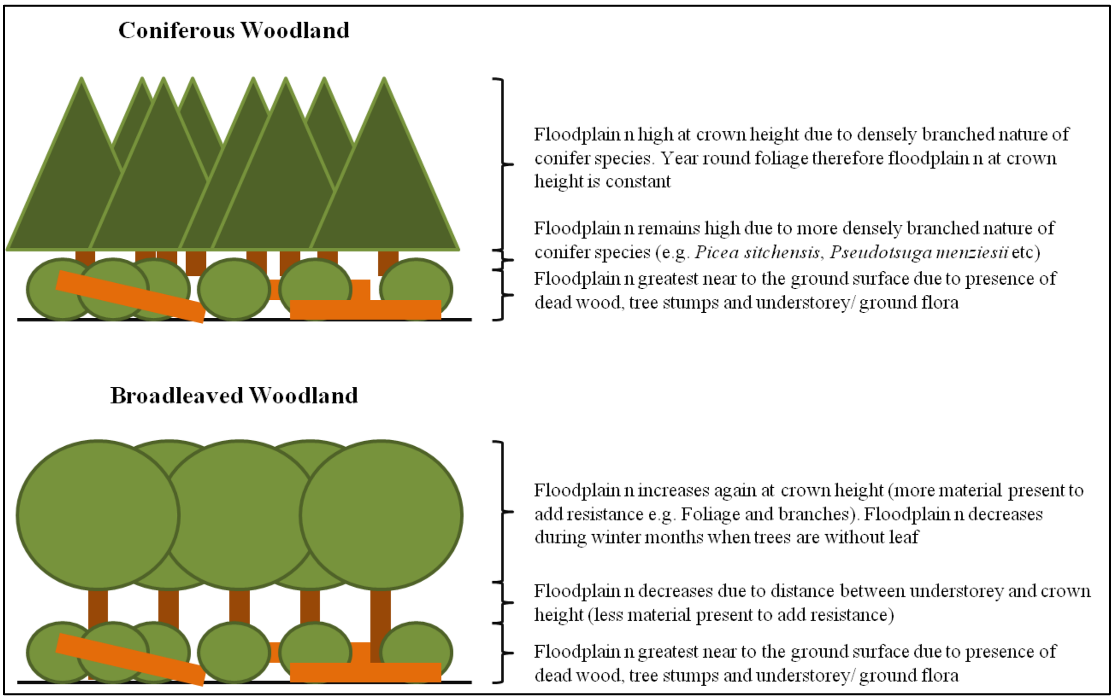
Nisbet and Thomas (2006) argue that the appropriate use of riparian and floodplain woodland to delay the progression of flood flows offers the greatest potential to assist sustainable FRM. As described in more detail at section 4.4, the premise of such an approach is that riparian and floodplain vegetation, especially

---

[50] Forestry Commission: http://www.forestry.gov.uk/ [accessed 12/10/13]

woodland, acts to increase the roughness of the floodplain (i.e. altering the value of Manning's **n** for the floodplain) which in turn, helps to reduce the energy of flowing water in river channels and on the floodplain. Riparian and floodplain vegetation's contribution to roughness is in addition to that made by vegetation in the open channel and along riverbanks and the roughness of the channel itself and other hydraulic features such as bridges, embankments and culverts (see section 4.4).

The presence of floodplain woodland can affect all of the factors listed at section 4.4 that may influence Manning's **n** value for the floodplain. For example, mounding (a silvicultural technique involving the planting of tree saplings in raised mounds of earth) is often undertaken at wet sites to provide increased space for root growth above the water table (Hart, 1991; Nisbet and Thomas, 2006). By definition, this approach would introduce obstructions on the floodplain and, combined with deadwood and the large woody stems of the trees themselves, could be used to manipulate floodplain **n** (see Figure 4.9).



Coniferous Woodland

Floodplain n high at crown height due to densely branched nature of conifer species. Year round foliage therefore floodplain n at crown height is constant

Floodplain n remains high due to more densely branched nature of conifer species (e.g. *Picea sitchensis*, *Pseudotsuga menziesii* etc)

Floodplain n greatest near to the ground surface due to presence of dead wood, tree stumps and understorey/ ground flora

Broadleaved Woodland

Floodplain n increases again at crown height (more material present to add resistance e.g. Foliage and branches). Floodplain n decreases during winter months when trees are without leaf

Floodplain n decreases due to distance between understorey and crown height (less material present to add resistance)

Floodplain n greatest near to the ground surface due to presence of dead wood, tree stumps and understorey/ ground flora

Figure 4.9 Impact of tree species choice and management on floodplain hydraulics

(Adapted from Nisbet and Thomas, 2008; Nisbet et al, 2011)

Furthermore, the presence of large woody debris (LWD) dams in the channel can have a dramatic influence on channel **n**. Frequently located in the mid to upper reaches of river catchments, LWD dams are a natural feature of native riparian and floodplain woodland (Nisbet and Thomas, 2008; Odoni and Lane, 2010; Nisbet et al, 2011a). LWD dams have the effect of raising water levels in the channel and promoting out of bank flows, thus connecting streams and rivers with the floodplain and providing increased flood storage (ibid). When combined with the introduction and/or restoration of riparian and floodplain woodland, the associated increases in both channel **n** and floodplain **n** have the potential to create a significant flood storage effect.

4.6.2 Constraints and opportunities for floodplain woodland planting in urban areas

The sensitive introduction and/or restoration of riparian and floodplain woodland can contribute positively to flood storage (sees section 4.6.1). Where appropriate, this may be complemented with the sensitive construction/facilitation and management of LWD dams. Dependant on the specific constraints and opportunities of the site, this type of measure could be designed to reduce the velocity of flood flows, promote out of bank flows and increase the depth and extent of flooding in and around the newly wooded area of the floodplain (see section 4.4). In effect, this approach aims to manipulate flooding in locations where it is safe to do so, thus helping to increase flood storage and reduce the likelihood of flooding at more vulnerable locations further downstream – i.e. helping to reduce overall flood risk (see section 4.2 and Figure 4.2).

Clearly, the availability of suitable urban sites where this type of land use/management based NFM intervention can be utilised safely will be constrained by the prevalence of vulnerable land uses such as residential and business areas. Furthermore, using floodplain and riparian woodland to increase floodplain **n** and promote out of bank flows can lead to the ‘backing-up’ of floodwaters (Nisbet and Thomas, 2008; Nisbet et al, 2011a). In these circumstances, valuable and/or vulnerable receptors upstream of the woodland may end up being subjected to higher levels of flood risk as a result of the woodland planting, thus negating the downstream benefits. Accordingly, situations where urban floodplain woodland can be utilised safely as a NFM measure are likely to be focussed where burns flow through substantial areas of openspace. In these situations, the openspace can provide the physical space for increased flood storage (see Figures 4.7 and 4.8), assuming that additional receptors are not placed in flood risk due to any backing-up of flood waters. The principle has been considered within the new flood control model (see section 7.2.3). Additional FRM and other water environment and biodiversity benefits may be realised if a scheme incorporates measures to address morphology pressures (see sections 4.5 and 7.2.4) and/or incorporates a diverse mosaic of different habitats within the floodplain such as wetland and wet woodland (see sections 4.7.3 and 7.2.5).

4.6.3 Strengths and weaknesses of floodplain woodland for FRM

Defra have recently commissioned a number of studies to look at the potential role of floodplain woodland as part of a wider catchment based approach to sustainable FRM (Nisbet and Thomas, 2008; Odoni and Lane, 2010; Nisbet et al, 2011a; Nisbet et al, 2011b). One such project in North Yorkshire (United Kingdom) looked at the role of floodplain woodland in the River Laver/Skell catchment helping to reduce flood risk in the City of Ripon (Nisbet and Thomas, 2008). The project used hydraulic modelling to understand the likely impact of restoring floodplain woodland on peak flows in Ripon. Four sites were considered for woodland restoration ranging from 4.3ha – 19.3ha. The impact on peak flows in Ripon was modelled for individual sites and for all four sites in combination.

In summary, Nisbet and Thomas (2008) found that the restoration of floodplain woodland and the associated changes in floodplain **n** would contribute to increased flood depth, increased flood extent and a reduction in flood velocity in and around the area of restored floodplain woodland. In addition, the modelling suggested that planting 8.1ha of woodland across three sites would have a combined impact of delaying peak flows at Ripon by 22 minutes (ibid). Although this impact is relatively insignificant by itself, the work suggests that strategically planned, larger scale planting could have a more significant impact in terms of delaying and reducing peak flows (ibid). Nisbet et al (2011a) noted analogous findings in a similar study undertaken for the River Severn catchment. Examples of these impacts from the River Laver study (Nisbet and Thomas, 2008) are indicated on Figures 4.10 – 4.13. The magnitude of the impacts varied across each site, influenced by a range of factors including the area of the flood envelope, the area of woodland planted, the topography of the floodplain and the presence of relic side channels, backwaters and ponds. These and other technical issues have been captured in Appendix 4 as part of the suite of technical guidance for interpreting and acting on flood control model outputs.

Despite the positive impacts on flood flows identified in Nisbet and Thomas (2008) and Nisbet et al (2011a), other similar studies have noted less positive results. For example, work by Price (2005) in Glen Urqhart, Northern Scotland (UK), modelled the flooding impacts of large scale woodland planting across the entire floodplain. Model predictions suggested that although the flood peak would be delayed by an hour, the magnitude of the peak flow would only be reduced by 0.8%. Given the scale of the planting involved (i.e. across the whole floodplain), the benefits were considered to not stand up against the costs involved (e.g. land use change, loss of other revenues, materials, maintenance etc). On the other hand, Price (ibid) suggest that a more targeted and potentially smaller scale approach to planting along tributary catchments could have a greater impact by desynchronising flood flows to the main channel. This desychronisation effect is a key area where smaller scale, targeted floodplain woodland planting can be used to deliver a significant overall impact on flood flows with relatively low levels of intervention. Similarly, work by Park and Cluckie (2006) in the River Parrett catchment in Dorset/Somerset (UK) predicted that planting a 200m wide riparian/floodplain woodland strip along the main river channel (equivalent to 3% of the catchment area) would have a negligible effect on flooding.

In spite of this, Nisbet et al (2011b) suggest that some of the variation in hydraulic model outputs are due to the parameter values adopted in the calculations, especially that of Manning’s **n** (see sections 4.4 and 4.6.1). For example, Nisbet and Thomas (2008) and Nisbet et al (2011a) used quite different values for channel and floodplain n in their work on the River Laver and River Severn catchments respectively. In the former, converting grassland to a cover of native floodplain woodland was represented by increasing floodplain **n** from 0.05 to 0.3 (an increase of

83%) and in the latter from 0.05 to 0.12 (an increase of 58%)[51]. Clearly this is a significant difference and could feasibly have a dramatic impact on outputs were the models for each catchment to be re-run with the different values for floodplain **n**.

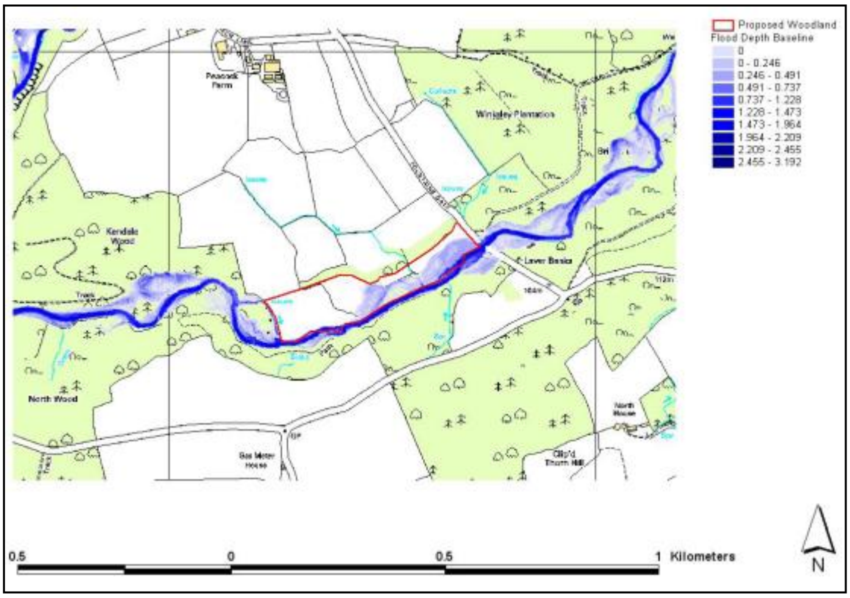


Figure 4.10 Literature examples of floodplain woodland impact on flood storage – flood extent and depth at Ings Bridge (base case)

(Source: Nisbet and Thomas, 2008)

Note: This map shows the modelled flood extent and depth for the base case i.e. without proposed woodland planting (shown in red). The darker blue indicates greater flood depths.

That said, the impact of floodplain woodland planting on downstream peak flows is influenced by a whole range of factors other than woodland related surface roughness – i.e. the influence of woodland design and management. It is these factors that should be considered in the development of planting scenarios and tested in hydraulic models to identify an overall and preferential planting strategy (e.g. in terms of size, dimensions, location, species and silvicultural choices etc) for floodplain woodland based NFM. In particular, it is noted that smaller scale planting targeted to specific sites can yield similar (or indeed better) results to blanket planting of the whole floodplain (Price, 2005; Nisbet and Thomas, 2006; Nisbet and Thomas, 2008; Nisbet et al, 2011a; Nisbet et al 2011b).

---

[51] Both studies explain the rationale for increased floodplain n on the basis of specific woodland design and management measures.

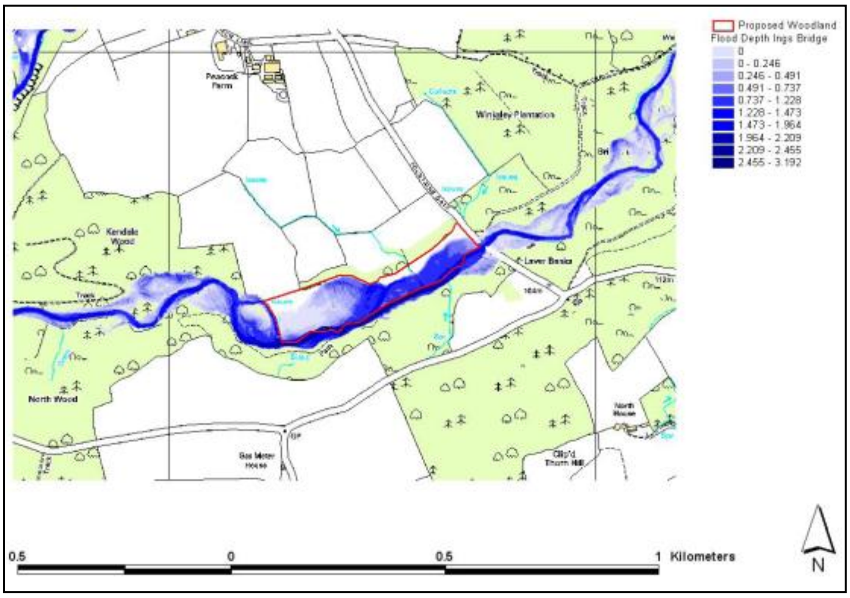


Figure 4.11 Literature examples of floodplain woodland impact on flood storage – flood extent and depth at Ings Bridge (with woodland planting)

(Source: Nisbet and Thomas, 2008)

Note: This map shows the modelled flood extent and depth for a scenario with the proposed woodland planting (shown in red). The darker blue indicates greater flood depths. The map clearly shows how the model predicts a greater flood extent and depth under the scenario with woodland planting, particularly around the area of planting itself (shown in red).

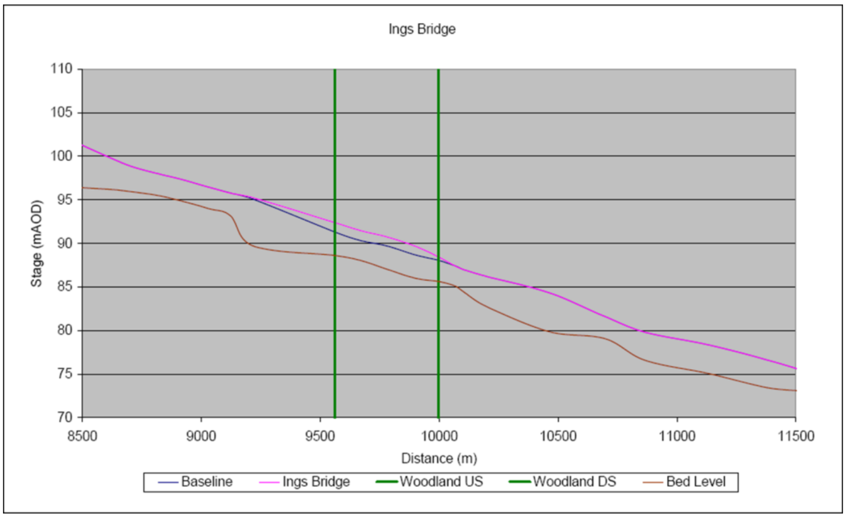


Figure 4.12 Literature examples of floodplain woodland impact on flood storage – impact of woodland planting on flood depth at Ings Bridge

(Source: Nisbet and Thomas, 2008)

Note: ‘Distance’ on the above figure relates to the river channel. The two vertical green lines represent the distance of the channel encompassed by the proposed woodland planting at Ings Bridge. The pink line represents the impact of the woodland planting on flood depth. Note how the modelled impact of the planting at Ings Bridge results in the slight backing up of flood waters upstream of the planted stretch.

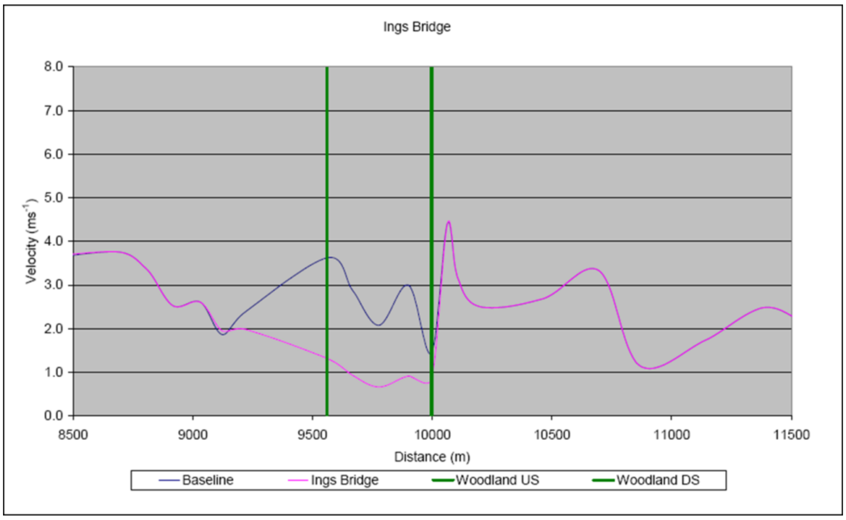


Figure 4.13 Literature examples of floodplain woodland impact on flood storage – impact of woodland planting on flood flow velocity at Ings Bridge

(Source: Nisbet and Thomas, 2008)

Note: 'Distance' on the above figure relates to the river channel. The two vertical green lines represent the distance of the channel encompassed by the woodland planting at Ings Bridge. The pink line represents the impact of the woodland planting on flood flow velocity. Note how the modelled impact of the planting at Ings Bridge causes a decrease in flood flow velocity at the planted stretch.

Nisbet and Thomas (2006) and Nisbet et al (2011a; 2011b) discuss how the scale of woodland planting can impact downstream peak flows. They note that the scale (in terms of spatial extent) of planting appears to have a lesser impact on the flood storage function of floodplain woodland intervention (i.e. increased flood storage) whereas wider catchment woodland intervention (i.e. reducing runoff at source) is impacted more strongly. The River Severn case study for example considered floodplain woodland planting equivalent to 0.07% of the 90km^2 catchment (Nisbet et al, 2011a) and a case study from the River Cary considered planting equivalent to 2% of the 82km^2 catchment (Nisbet and Thomas, 2006). Both interventions were predicted to have a significant impact on the timing and/or magnitude of downstream peak flows. Although these smaller scale planting strategies should be considered, Nisbet and Thomas (2008) and Nisbet et al (2011a) highlight the potential for larger floodplain woodlands or networks of smaller woodland patches to exert a much greater effect on the timing and magnitude of downstream peak flows and these larger scale strategies should not be discounted from options appraisal within land use planning processes. The full range of design and management principles for floodplain and riparian woodland planting identified through this evidence assessment are documented in Appendix 4 and have been considered in the new flood control model as explained at section 7.2.

4.7 Land use/management measures for reducing runoff at source

As discussed at section 4.2, a catchment based approach to FRM can offer a more sustainable, integrated means of delivering FRM actions that work with rather than against nature. This is achieved by restoring and enhancing the variety of natural landscape features that affect the timing, magnitude and duration of flood events. These wider catchment land use/management based NFM measures that address sources of flooding (runoff reduction measures) should be designed to work in tandem with more traditional structural flood defence measures (e.g. floodwalls, embankments, below ground drainage/storage etc) as well as NFM measures in the floodplain (flood storage measures) such as those described at sections 4.5 and 4.6. For example, NFM measures in the wider catchment/floodplain may reduce peak flows to an extent (i.e. helping to reduce the *likelihood* of flooding). Although these measures may *partially* reduce the requirement for traditional structural flood defences (e.g. the height of a floodwall), a degree of structural flood defence in urban areas (i.e. where the *consequences* of flooding are high) is likely to still be required[52], especially as opportunities to change land use/management in the wider catchment/floodplain are likely to be constrained by other management objectives.

In terms of the source-pathway-receptor-impact (SPRI) framework for FRM actions described at section 4.2, land use/management measures in the wider catchment are source control measures – i.e. they are intended to reduce runoff at source. These types of measure can play a key role in modified urban catchments by helping to restore the more natural functioning of the hydrological cycle, by addressing the historic removal of vegetation and building over of greenspace (see Figure 4.14). This section of the thesis provides an overview of the hydrological

---

[52] A case in point is the White Cart Water Flood Prevention Scheme in metropolitan Glasgow. The scheme uses upper catchment flood storage areas in rural East Renfrewshire combined with floodwalls in the urban lower catchment in south Glasgow. The upper catchment storage areas reduce river flows by 45% meaning that although still required, the design capacity/height of the floodwalls can be reduced also (by 15% or up to 1m in places): http://www.educationscotland.gov.uk/Images/WhiteCartWaterFloodPreventionScheme2_tcm4-716465.pdf [accessed 23/02/14]

cycle and its constituent natural drainage processes from an urban land use/management perspective (section 4.7.1). In particular, opportunities are highlighted whereby sustainable urban land use/management can be utilised to manipulate these processes in order to restore the more natural functioning of the hydrological cycle and reduce runoff. Several practical measures are then introduced that have informed the tools, models and guidance that have been developed in this research (sections 4.7.2 and 4.7.3).

4.7.1 The hydrological cycle and its relationship with land use/management

As described at section 3.2.1 and 3.2.2, the hydrological cycle is one of three core ecosystem processes that influence the health and functioning of ecosystems and the supply of ecosystem services (see Figure 3.8). In urban catchments in particular, the removal of vegetation and building over of greenspace has the effect of modifying hydrological cycle function (see Figure 4.14). In wet climates such as the west coast of Scotland/Glasgow (see section 4.1) and northern Europe more generally (see sections 1.4, 2.1.4 and 3.2.5), this modification can contribute to significant flooding problems as the natural drainage processes supporting hydrological cycle function are absent or greatly diminished, resulting in more limited retention of water by the landscape and high runoff coefficients. This section provides an overview of the hydrological cycle and its key constituent processes that can be manipulated by land use/management to help restore hydrological cycle function in modified urban catchments, reducing runoff at source and contributing to sustainable FRM.

As shown on Figure 4.14, a key component of the terrestrial hydrological cycle is the generation of river runoff and the movement of water in river networks (Kuchment, 2014). The timing and magnitude of river runoff is dictated by natural drainage processes – interception/depression storage, evapotranspiration, infiltration and attenuation (ibid). In natural/undeveloped catchments (the top diagram on Figure 4.14), a portion of the precipitation falling onto a surface will be intercepted by vegetation and evaporate back into the atmosphere. A further portion will infiltrate into the ground (groundwater recharge) where some of this will be taken back up by vegetation and evaporated back into the atmosphere (transpiration). The combined term for these two processes is evapotranspiration.

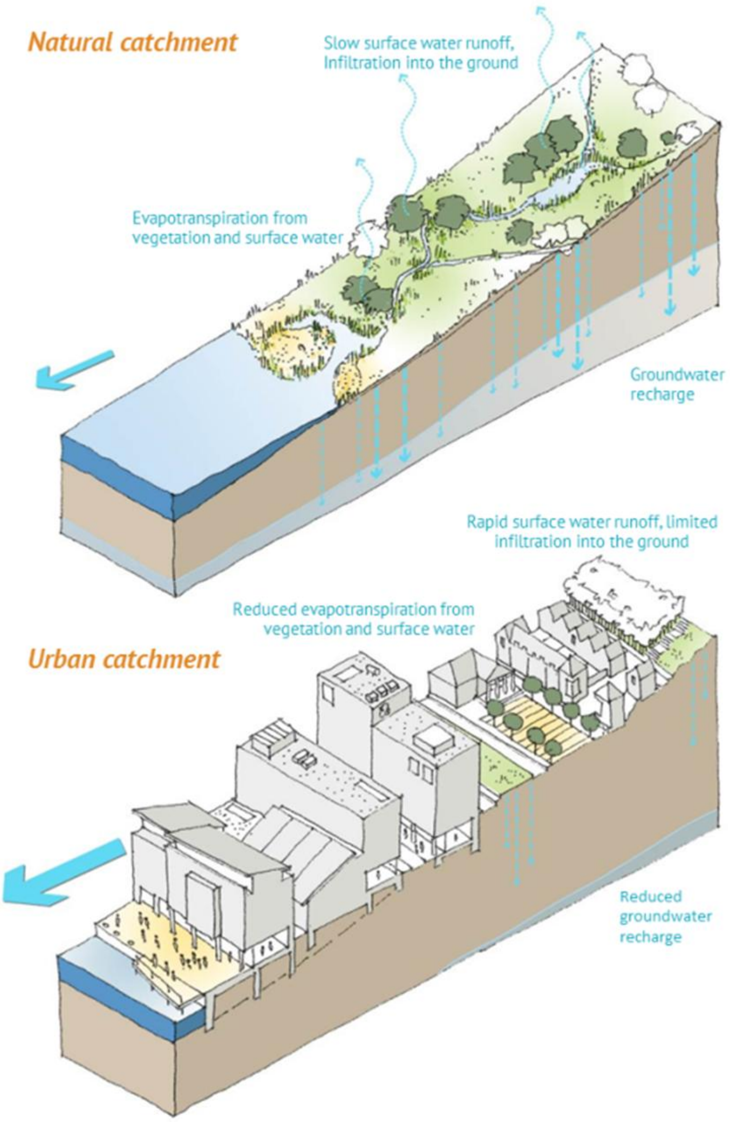


Figure 4.14 Drainage processes in natural catchments and urban catchments

(Source: Susdrain, 2012)

Note: The figure above shows the functioning of natural drainage processes in natural (undeveloped) and urban (developed) catchments. Surface runoff (indicated by the larger blue horizontal arrows) is much greater in urban catchments as other natural drainage processes (i.e. interception, evapotranspiration, infiltration and attenuation) are constrained by the prevalence of impermeable surfaces and the absence of vegetation and greenspace.

After losses from each of these processes, any excess will drain as surface water runoff via a network of small and large watercourses and lakes to the sea (Scottish Government, 2013a; Kuchment, 2014). The hydraulic roughness (see section 4.4) of vegetation in natural catchments can also act to disrupt and slow surface water runoff, helping to attenuate flows and delay the passage of water. Attenuation is a key drainage process that can be exploited in urban land use/management planning to support FRM objectives. Further details of these natural drainage processes and their relationship with urban land use/management are provided at Table 4.6.

In urban/modified catchments (the bottom diagram on Figure 4.14), the natural drainage processes found in unmodified catchments can be absent or greatly diminished (Scottish Government, 2013a; Kuchment, 2014). In particular, the removal of vegetation and building over of greenspace reduces evapotranspiration and infiltration losses due to the absence of plants and the impermeable nature of the landcover, meaning therefore that the surface water runoff component is larger (ibid). In urban areas, as discussed at section 4.5, this issue can be compounded where natural drainage features are replaced with drains and culverts that have a finite capacity (Wheater and Evans, 2009; Wild et al, 2010; Scottish Government, 2013a). In these situations, complex flooding problems can arise due to the interaction of different sources of flooding e.g. where high river levels prevent surface water drains from discharging freely or where the capacity of the artificial drainage network is exceeded contributing to pluvial flooding/ponding of water on the surface (ibid). The interrelated nature of natural and artificial drainage systems in urban areas highlights the need for restorative land use/management action that can enhance natural drainage processes and reduce runoff at source. This is addressed in the new hydrological cycle model described at section 7.3.

4.7.2 Land use/management based measures for reducing runoff at source

Scottish Government (2011a) and Scottish Government (2013a) highlight the role of land management in catchment based approaches to sustainable FRM (see section 4.2). In particular, the restoration of natural landscape features within catchments, including forests and floodplains, is highlighted as a key structural action for the management of flood risk (ibid). Furthermore, Scottish Government (2011a) suggest that natural landscape features can be altered or manipulated in order to enhance their FRM benefit (i.e. increasing flood storage or runoff reduction capacity).

This principle of land use/management change for the enhancement of water management related ecosystem services is a key premise of this research and something that has been factored into the tools, models and guidance developed therein (see Chapters 7 and 8). Within urban catchments, this principle can be applied to the existing network of greenspace and semi-natural habitats that support urban ecosystem function and supply key land based urban ecosystem services (see section 3.1.3). In essence, this thesis argues that for any given urban area, there may be potential to change land management[53] across the network of green and natural environment type urban land uses (i.e. PAN65 openspace as detailed at Table 3.4) in order to restore and/or enhance the natural drainage processes detailed at Table 4.6. In doing so, the intention is to positively alter physiographic conditions (i.e. land use) within the catchment, fundamentally altering catchment hydrology, reducing runoff and runoff coefficients and contributing to sustainable FRM (see sections 4.2 – 4.4). Accordingly, the key purpose of the hydrological cycle model developed through this research (see section 7.3) is to identify and prioritise locations where this sort of management intervention may be delivered, in conjunction with the enhancement of biodiversity and ecological networks (see Chapter 5 and section 7.4).

As intimated at Table 4.6, land management for the restoration of natural drainage processes will generally be premised on changing vegetation cover to increase hydraulic roughness. This has the effect of increasing losses from interception, transpiration and infiltration and the rougher landcover can help to attenuate surface water runoff and delay peak flows (see Table 4.6 and section 4.4). Trees and woodlands (i.e. a type of natural/semi-natural greenspace or a component of other types of PAN65 openspace as per Table 3.4) have particular utility in this regard due to the roughness of their foliage (contributing to higher rates of interception and transpiration) and the nature of woodland soils which are more open in structure, contributing to the so called ‘sponge effect’ and higher rates of infiltration (Nisbet and Thomas, 2006; Nisbet et al, 2011c).

---

[53] This could include, for example, land management recommendations/policy for the existing ‘green’ and ‘natural environment’ land resource or any new resource being delivered as a result of development and associated legal agreements as part of planning consent (see sections 1.5 and 3.1.1).

Table 4.6 Potential relationships between natural drainage processes and land use/management

(Adapted from: Nisbet and Thomas, 2006; Nisbet et al, 2011c; Susdrain, 2012; Scottish Government, 2013a; Kuchment, 2014)

Drainage process	**Details**	**Implications for land use/management**
Interception and depression storage	• Vegetation and other types of surface cover will intercept a certain portion of precipitation before it reaches the land surface • Some of this precipitation will evaporate back to the atmosphere and some will flow down on vegetation stems to the land surface • Interception losses are influenced by the storage capacity of vegetation • Depression storage occurs when precipitation reaching the land surface fills up depressions • Depression storage capacity is influenced by physiographic conditions and land use within the catchment	• Interception losses from vegetation vary between species, age class and density of vegetation cover • In general terms, trees and woodlands intercept more precipitation than shorter types of vegetation (e.g. shrubs and grasses) due to their greater degree of roughness • Conifers have a greater interception capacity than broadleaves as their foliage is rougher – a dense conifer stand can intercept 25-30% of rainfall whereas broadleaves only intercept 15% with leaf and 7% without (Kuchment, 2014) • Interception losses from *dense* grasses and herbs can be as much as for broadleaved tree species • Interception losses from trees and woodland decreases as the size and intensity of a rainstorm increases. In major storm events, interception losses from dense conifer stands are likely to be <10% (Nisbet and Thomas, 2006) • Land can be manipulated to increase depression storage e.g. through the construction of detention and retention basins (see section 4.7.3)
Evapo-transpiration	• The evaporation of water from the land surface or from vegetation is dependent on energy from solar radiation • Evaporation of water by plants is called transpiration. The sum total of evaporation from land and transpiration from plants is called evapotranspiration • Transpiration is influenced by environmental and biological factors. Key biological factors include the type, stage and growth of plants, leaf and root structure and the density and behaviour of stomata • Stomatal characteristics/leaf area are incorporated within the formula for	• Transpiration losses can be particularly high where vegetation cover is dense • Experimental data from central Russia indicates that transpiration contributes to 45% of evapotranspiration losses in conifer forests and 50% in broadleaved forests (Kuchment, 2014)

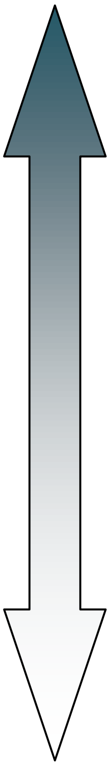
Drainage process	**Details**	**Implications for land use/management**
	calculating transpiration losses	
Infiltration	• Infiltration is the flow of water through the soil surface – the rate and volume of infiltration is influenced by conditions on the soil surface, soil properties and soil moisture content • *Conditions on the soil surface* – the presence (or not) of vegetation influences infiltration. The impact of raindrops on bare soils can produce silt/clay particles that clog soil macropores and reduce infiltration • *Soil properties* – soil structure is characterised by bulk density, pore-size distribution and vertical profile. The presence of soil organic matter influences pore size and the action of soil fauna (e.g. worms) can create macropores in the soil, increasing porosity and infiltration capacity	• The presence of vegetation can act to protect the soil surface from raindrop impacts, reducing erosion and the production of silt and clay particles that can clog soil macropores. In principle, the greater the hydraulic roughness of the vegetation (i.e. the greater the interception/transpiration losses – see above), the more pronounced this effect will be • Different types of vegetation will have different effects on soil structure. In particular, woodland soils tend to have a more open (and therefore more porous) structure due to greater amounts of organic matter, the action of tree roots and soil fauna and fewer disturbances by human activities • This characteristic of woodland soils in known as the ‘sponge effect’. Land use change to woodland is potentially a useful management strategy for vulnerable soils to preserve and/or enhance their infiltration capacity and reduce erosion risk
Attenuation	• Catchment runoff coefficients are influenced by physiographic factors relating to catchment characteristics (e.g. size, shape, topography, soils, land use etc) and channel characteristics (e.g. slope, hydraulic properties, shape etc) • Catchment characteristics influence runoff rates. Of particular relevance to this research, the roughness of the land in terms of land use and vegetation cover influences overland flow based runoff generation mechanisms • In this manner, the roughness of the land can act to slow down or attenuate flood flows, delaying their passage downstream	• Similar principles apply as per interception described above – i.e. the rougher the land/vegetation, the greater the attenuation effect • Attenuation has no impact in terms of reduction in runoff volume i.e. peak flows will still have the same magnitude. Rather, flows are attenuated/slowed down meaning, therefore, that peak flows arrive later • Despite this, land use/management intervention that enhances attenuation capacity may also enhance other drainage processes (see above) that act to reduce **as well** as delay peak flows • As such, land use/management measures that provide an attenuation benefit can give relevant agencies more time to issue flood warnings, put in place emergency preparedness measures etc

As a general principle (see Table 4.6), green and natural environment type urban land uses with denser, taller and more structurally diverse vegetation will be hydraulically rougher and have more porous, open structured soils. These sites therefore will have a greater capacity to reduce runoff at source via the four key mechanisms outlined at Table 4.6. At the other end of the spectrum, areas of amenity greenspace, such as the highly managed areas of amenity grassland found in many urban settings (e.g. housing estates, parks and recreation grounds), will have a much less significant runoff reduction function where vegetation is generally characterised by short mown grass (Woodland Trust, 2011). This is supported by empirical data – for example infiltration rates of soils under young native woodland was found to be 60 times that of soils under grazed pasture land (Nisbet and Thomas, 2006; Nisbet et al, 2011c) which itself will be hydraulically rougher than the amenity grassland found in many urban areas. Table 4.7 explores some of the key issues influencing the hydraulic properties of different types of green and natural environment type urban land use and ranks the PAN65 openspace typology by hydraulic roughness.

Table 4.7 PAN65 openspace typology ordered by potential hydraulic roughness

(Adapted from: Scottish Government, 2008; Greenspace Scotland, 2010; AECOM, 2011; Google Maps, 2014)

Roughness	Category	Example site	Rationale – hydraulic properties
Most rough ↕	Natural/ semi-natural greenspace	 Open semi-natural greenspace	Includes woodland which, for the purposes of this research, is considered to be the roughest land use type. Also includes open-semi natural habitats such as rough grassland, meadow and naturally colonised brownfield land (see aerial photo opposite) – vegetation on these types of site will generally be relatively dense/structurally diverse and is considered to provide a significant degree of roughness in this regard
	Green corridors	 Green corridors – riparian routes	Green corridors are either green access routes (e.g. accessible disused railways) or riparian routes (e.g. canal towpaths, accessible river corridors etc). Green access corridors can be managed extensively and may contain diverse vegetation including trees and shrubs. Riparian routes are frequently wooded (see photo), especially when located in steep sided glens where more intensive

Roughness	Category	Example site	Rationale – hydraulic properties
			management can be problematic
	Public parks and gardens	 Public park and garden with areas of woodland	Public park and garden sites are often multifunctional by design and will contain a mixture of intensively managed land (e.g. flower beds, amenity grassland) and less intensively managed land (e.g. woodland, rough grassland, meadow etc). The diversity of vegetation and land management in park and garden sites is such that they may exhibit a high degree of roughness
	Allotments and community growing spaces	 Allotments	Allotments contain a variety of vegetation though cover will vary throughout the growing season and dependent on specific management objectives, including at plot level. Cultivated soils may have a more open structure supporting infiltration. Sites may also contain small scale water storage (e.g. water butts) which can provide source control management
	Private gardens or grounds	 Private gardens	The hydraulic properties of private gardens and grounds are likely to vary significantly depending on the spatial extent of the land and specific (private) management objectives – e.g. some gardens may contain structurally diverse vegetation including trees, shrubs and grasses whereas others may only comprise lawns or hard-standing
	Burial grounds	 Burial grounds	Similarly to private gardens and grounds, the hydraulic properties of burial grounds may be dependent on the spatial extent of the site and the specific management objectives (which may be private). Burial grounds frequently contain trees (including conifers such as *Taxus baccata*) though open areas may be heavily managed
	Playspace for children and teenagers	 Playspace	Playspace is frequently linked to housing areas or located within public parks and gardens. Sites are often heavily managed for safety and are less likely to contain significant vegetation. Sites often contain areas of hard-standing (e.g. skateparks, seating areas) and therefore hydraulic properties for runoff reduction may be poor

Roughness	Category	Example site	Rationale – hydraulic properties
	Sports areas	 Sports areas	Greenspace Scotland (2010) define five sub-classes for sports areas including sites that may have some degree of hydraulic roughness (e.g. playing fields with associated woodland – see aerial photo opposite) and those likely to be les rough (e.g. bowling greens). Heavily managed components of sports areas (e.g. grass playing surfaces) are likely to have poor hydraulic properties for runoff reduction
Least rough	Amenity greenspace	 Housing amenity greenspace	Greenspace Scotland (2010) define three sub-classes of amenity greenspace – housing, business and transport. As with sports areas, sites may contain areas of rougher land use (including areas of natural/semi-natural greenspace) although the heavily managed areas (i.e. areas used for informal social and recreational activities) often comprise short mown grass which will have more limited hydraulic properties in terms of runoff reduction

In line with the discussion above and Tables 4.6 and 4.7 therefore, this thesis argues that prioritised management intervention can be undertaken to improve the hydraulic properties of existing ‘green’ and ‘natural environment’ type land uses in urban areas[54] (i.e. the range of PAN65 openspace detailed at Table 3.4). Equally, where new openspace is being developed (e.g. as part of new development or through a section 106 agreement – see section 1.3), the design and management of new sites should be informed by simple hydraulic criteria (such as those outlined at Table 4.6) to ensure that they contribute to catchment scale hydrological improvements. The hydrological cycle model developed through this research (see section 7.3) has been designed to support both of these processes.

In terms of practical land management intervention, this thesis argues that at prioritised sites/locations (i.e. those identified through the hydrological cycle model developed in this research – see section 7.3), the management of existing

---

[54] A similar premise is adopted by the GCV Green Network Partnership in their green network opportunities mapping technique (see section 6.3) which incorporates data on openspace typology and condition within the GIS modelling approach. Lower value sites (e.g. amenity greenspace) and sites that are in poor condition are then weighted more heavily in the analysis and highlighted as opportunities for enhancement

green/natural environment type land uses (PAN65 openspace) can be altered to change the hydraulic properties of the site. As discussed further at Chapter 8, this must be undertaken sensitively and with respect to existing constraints (e.g. landscape and natural heritage designations, other primary land uses such as peat/carbon rich soils). For example, the management of a public park and garden site could be altered to include a greater density of tree planting and some areas of amenity grassland within the park could be converted to rough grassland or meadow. The overall effect would be to improve the hydraulic properties of the site whilst maintaining its primary use as a public park and garden. This is illustrated on Figure 4.15 though the same principles apply to all types of green and natural environment type urban land uses. The economic benefits of this sort of approach, in terms of reduced annual maintenance costs, have been demonstrated by Woodland Trust (2011) though the economic implications of land management have not been considered in this research.

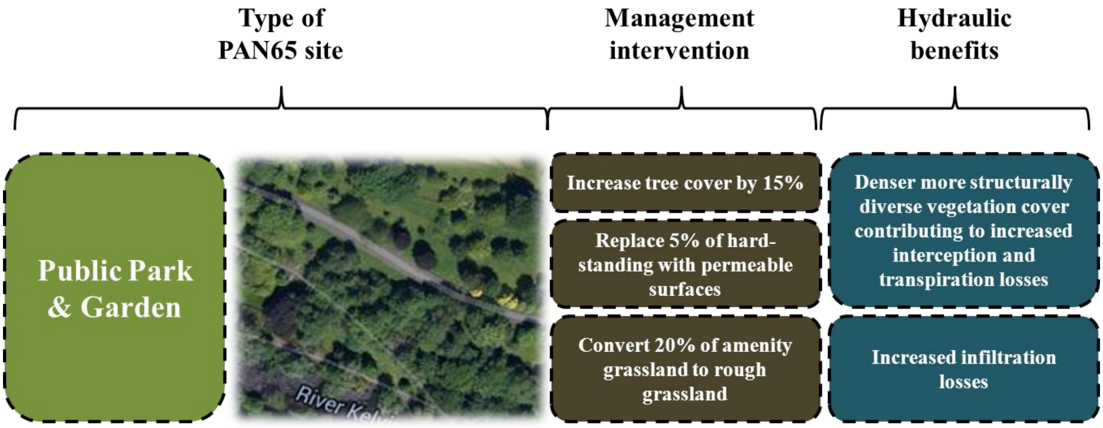


Figure 4.15 Managing PAN65 sites for hydraulic benefits

4.7.3 SuDS measures for reducing runoff at source and providing storm water storage

Section 4.7.2 describes how land use/management measures can be used to reduce runoff at source by helping to restore the function of the natural drainage processes detailed at Table 4.6. In effect, these are land parcel scale measures and realising a water management benefit (i.e. reducing or delaying runoff to the extent that peak flows are reduced or delayed also) using land use/management based measures is likely to require targeted action across multiple land parcels (e.g. changing the management regime across all amenity greenspace sites located within a given catchment). In addition to these broader, land use/management based measures however, there may also be scope to deliver water management benefits in urban areas through the use of targeted green infrastructure measures (see section 3.1.3), namely sustainable drainage system (SuDS).

In technical terms, SuDS are defined as "a sequence of management practices, control structures and strategies designed to efficiently and sustainably drain surface water, while minimising pollution and managing the impact on water quality of local waterbodies" (Susdrain, 2012 sustainable drainage background section). Similarly to the land use/management based measures described at section 4.7.2 therefore, SuDS techniques are designed to mimic and/or restore natural drainage processes in urban catchments (Susdrain, 2012).

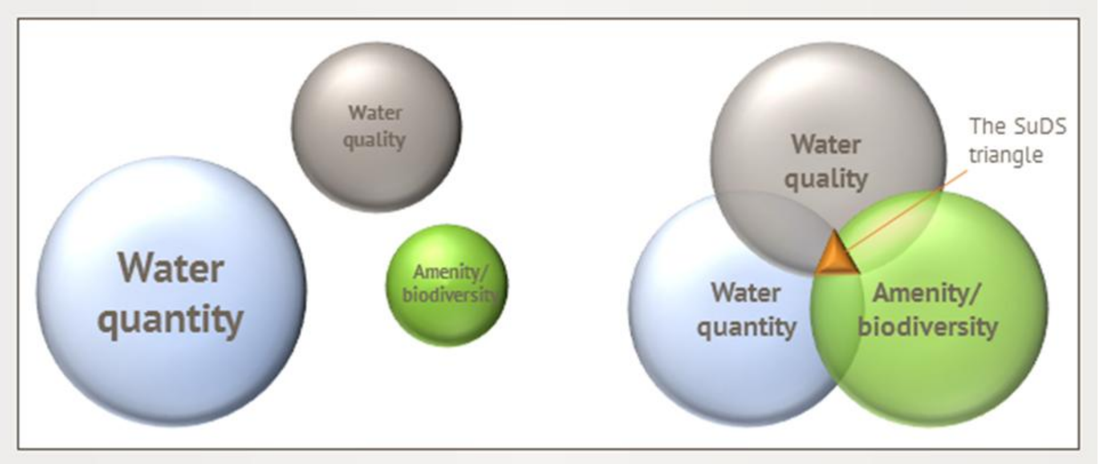


Figure 4.16 The SuDS triangle

(Source: Susdrain, 2012)

Note: The sustainable drainage system (SuDS) triangle recognises that effective SuDS intervention should deliver multiple benefits, especially water quality improvements, water quantity management/flood risk reduction and amenity/biodiversity enhancements. The consideration of SuDS in this research (i.e. as a measure for reducing runoff at source and providing storm water storage – see Chapters 7 and 8) focusses on the water quantity/flood risk reduction function. There is some consideration of biodiversity benefits in relation to integration of SuDS with habitat networks.

The rationale, concept and design/engineering practice of SuDS stems from the historic modification of urban catchments described elsewhere in this Chapter (see Figure 4.14 for example). Particular objectives of SuDS however include pollution reduction and water quality improvement, through the treatment of runoff before it is discharged to watercourses and/or by reducing surface water inputs to the sewerage system (ibid). This issue is outlined by Graham et al (2012 p.1) "for too long we have treated rainwater as waste, paved over our urban areas and simply flushed surface water down pipes into an overloaded sewerage system". Whilst this is a key benefit of SuDS and part of the 'SuDS triangle' (see Figure 4.16), it is not a particular consideration for this research[55] which is focussing more on the water quantity (i.e. flood risk management) benefits of SuDS. The amenity/biodiversity benefits of SuDS (see Figure 4.16) are considered to a degree, particularly in relation to opportunities for integration of SuDS siting and design with existing and potential habitat networks (see Chapter 5 and sections 7.4 and 8.2).

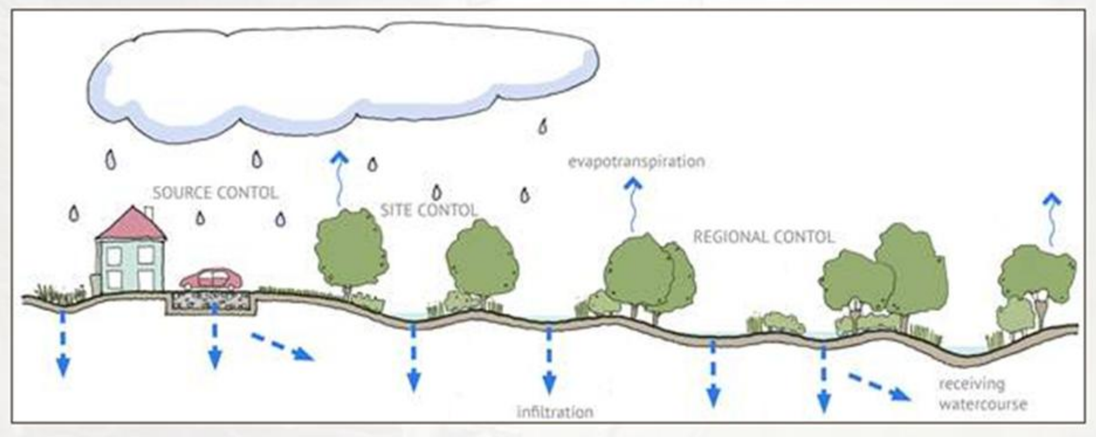


Figure 4.17 The SuDS management train

(Source: Susdrain, 2012)

Note: The SuDS management train is a series of nested control measures designed to manage water quantity and quality. As illustrated on the Figure above, intervention at source, site and regional level are designed to enhance all the natural drainage processes described at Table 4.6.

The design and engineering of SuDS intervention is based around the concept of the SuDS management train (Graham et al, 2012; Susdrain, 2012). This is

---

[55] That said, any SuDS intervention delivered as a result of strategic land use/management planning direction from the tools and models developed in this research (see Chapters 7 and 8) would deliver water quality benefits by either: 1) providing some degree of treatment for runoff before it enters natural watercourses; or 2) reducing the volume of surface water entering the sewerage systems and therefore helping to reduce pressure on waste water treatment infrastructure. In contrast, the water quantity and flood risk management benefits of SuDS are considered in this research through the use of spatial datasets and spatial modelling to target where land use/management and green infrastructure intervention (i.e. SuDS) may be required for the delivery of flood storage and runoff reduction ecosystem services

illustrated on Figure 4.17. In line with the definition of SuDS provided at the start of this sub-section, the SuDS management train is a sequential process involving a hierarchy of treatment, management practices, control structures and strategies for the management of water quality and quantity and the delivery of wider multiple benefits, especially amenity and biodiversity enhancement (ibid). As illustrated on Figure 4.17, the SuDS management train is, in effect, a series of nested control measures: 1) source control; 2) site control; and 3) regional control. Source, site and regional control measures are designed such that they each provide a degree of water quantity and quality control, reducing and/or delaying peak flows and improving the quality of runoff that is eventually discharged to the receiving waterbody (i.e. a surface or groundwater body) or waste water treatment works as the case may be[56]. Much like the land use/management measures described at section 4.7.2, SuDS techniques are designed to mimic and/or restore the natural drainage processes that combine to support hydrological cycle function (see Table 4.6). In principle, different stages of the SuDS management train should work to restore all of the natural drainage processes outlined at Table 4.6 (see Figure 4.17). This critical aspect of SuDS design has been considered in the new tools, models and guidance developed through this research (see sections 7.4 and 8.2 and Appendix 5).

An additional key drainage process provided by SuDS is conveyance. Certain SuDS components (e.g. swales[57] and channels/rills[58]) are designed to provide surface water conveyance which is defined as the movement of surface water across a site between different SuDS components/treatment stages (ibid). The need for conveyance recognises that individual stages of the SuDS management train and the components therein may not provide adequate water quality treatment and/or the necessary capacity to provide storm water storage under a range of different rainfall

---

[56] In some circumstances it may not be possible for surface water to be discharged to a waterbody e.g. the soil type is such that infiltration to groundwater is not possible or it may not be physically possible (e.g. in terms of topography) to convey treated surface water to a waterbody. In these situations, SuDS techniques can still be used to help attenuate/slow down storm water flows thereby reducing pressure on combined sewers and helping to prevent pluvial and sewer flooding. Also, the use of SuDS in this regard can still provide wider benefits in terms of amenity value and biodiversity enhancement

[57] Susdrain pages on swales: http://www.susdrain.org/delivering-suds/using-suds/suds-components/swales-and-conveyance-channels/swales.html [accessed 29/03/14]

[58] Susdrain pages on channels/rills: http://www.susdrain.org/delivering-suds/using-suds/suds-components/swales-and-conveyance-channels/channels-and-rills.html [accessed 29/03/14]

conditions (ibid). In this regard, it may be necessary to convey surface water to another part of the site where additional treatment and/or storage capacity can be provided. This particular facet of SuDS design and engineering has, however, not been considered in this research (i.e. in the development of the spatial models for prioritising locations where runoff reduction and flood storage ecosystem services may be required – see Chapters 7 and 8).

Whilst the above outlines the general concepts behind SuDS design and engineering, it also necessary to understand the utility and function of key SuDS components. This information forms the basis for SuDS related recommendations in the spatial models developed through this research that target locations where flood storage and runoff reduction ecosystem services may be required (see Chapters 7 and 8 and Appendix 5). Once target locations have been identified through the models described at Chapter 7, the understanding of SuDS component utility and function provides the necessary input to inform the development of relevant aspects of integrated land use/management proposals for the delivery of multiple benefits (see sectionr 8.2). In this regard, Table 4.8 outlines a range of key SuDS components of relevance to this research including summary information on their advantages, disadvantages and potential water quantity/flood risk management performance.

Table 4.8 Key SuDS components – advantages/disadvantages and FRM performance

(Adapted from: Graham et al, 2012; Susdrain, 2012)

SuDS component	Advantages/disadvantages	Likely FRM performance
Source control measures – *“managing rainfall at source is the fundamental SuDS concept in providing the first treatment stage. It ensures silt and pollution does not enter the management train and controls the flow and quality of water for use further downstream”* (Graham et al, 2012 p.15)		
Green roofs: multi-layered system covering the roof of a building with vegetation cover/ landscaping – can be particularly important for high density urban areas with limited space. Green roofs are designed to **intercept** and retain precipitation i.e. helping to **reduce** runoff volume and therefore the magnitude of peak flows	**Key advantages:** mimics pre-development (i.e. greenfield) hydraulic and hydrological conditions, can be retrofitted, no additional land take, ecological/aesthetic benefits, helps manage urban heat island effect **Key disadvantages:** cost compared to conventional roofs, N/A for steep roofs, maintenance, retrofit options may be limited by roof structure (e.g.	• Peak flow delay: **medium** • Runoff volume reduction: **medium**

SuDS component	Advantages/disadvantages	Likely FRM performance
	strength)	
Permeable surfaces (e.g. grass, reinforced grass, gravelled areas)**:** rainwater passes through the surface allowing for the storage, treatment, transportation and, where appropriate, infiltration of water. Depending on the specific intervention used, permeable surfaces provide **infiltration** and/or **attenuation** (e.g. if infiltration to groundwater is constrained permeable surfaces can provide temporary storage to attenuate storm water flows) benefits i.e. helping to **reduce** runoff volume and the therefore the magnitude of peak flows	**Key advantages:** reduces runoff from hard surfaces thereby helping to reduce peak flows and downstream flood risks, allows dual use of space/no additional land take **Key disadvantages:** cannot be used where large sediment loads may be washed/carried into the surface (risk of clogging), limited amenity or biodiversity benefit	• Peak flow delay: **good** • Runoff volume reduction: **good**
Rain gardens: used in sites with freely draining soils, rain gardens are small depressions in the ground that act as **infiltration** points for roof water and other 'clean' sources of surface water. Rain gardens can be used in a variety of scales from domestic (i.e. private gardens) to public realm. They receive runoff from buildings (via downpipes) or paved areas (e.g. in a public realm context) and are planted with species able to tolerate short periods of inundation. Depending on the circumstances, rain gardens provide **infiltration** and/or **attenuation** benefits i.e. helping to **reduce** runoff volume and the therefore the magnitude of peak flows	**Key advantages:** easy to retrofit, can be small (e.g. when used in private gardens) so limited land take, can be planned as landscaping features (e.g. in public realm projects), can reduce rate of runoff and some reduction of volume, can act as a 'stepping stone' as part of urban habitat networks **Key disadvantages:** due to their often small size, runoff **volume** reduction impact can be small unless they are delivered at scale (e.g. all private gardens within a given catchment), rain gardens and surrounding landscape need management to maintain function, not suitable for areas with steep slopes	• Peak flow delay: **good** • Runoff volume reduction: **medium**
Site control measures – *"this describes those SuDS features within or at the edge of developments that provide a second or third treatment stage including storage for runoff that has been conveyed from source control structures. The most common features are retention and detention basins, swales and small urban ponds"* (Graham et al, 2012 p.22)		
Detention basins: vegetated depressions/surface storage basins which temporarily hold water – i.e. they provide flow control through attenuation of storm water runoff. Detention basis are normally dry and therefore provide an additional land use. Detention basins can provide some minimal reductions in runoff volume through **infiltration** though this will depend on soil conditions etc. In this regard, their primary function water quantity/flood	**Key advantages:** can cater for a wide range of rainfall events, simple to design and construct, allows dual use of land, easy maintenance **Key disadvantages:** little or no reduction in runoff volume (via infiltration only), detention depths (and therefore volume) may be constrained by system inlet and outlet levels	• Peak flow delay: **good** • Runoff volume reduction: **poor**

SuDS component	Advantages/disadvantages	Likely FRM performance
risk reduction function is to **attenuate** flood flows thereby delaying the arrival of peak flows downstream		
Regional control measures – *"this provides the last water quality 'polishing' before discharge into the wider catchment. When storage of runoff cannot be easily accommodated within the development it may be possible to convey these excess volumes out of the development itself into public openspace"* (Graham et al, 2012 p.24)		
Retention basins and associated wetlands: can provide both storm water attenuation and treatment containing permanent water and other wetland habitats e.g. temporary pools, wet grassland, wet woodland and reed beds. Retention basins are designed to store additional storm water runoff, releasing it at a controlled rate during and after the peak flow has passed. In this regard, their primary function water quantity/flood risk reduction function is to **attenuate** flood flows thereby delaying the arrival of peak flows downstream	**Key advantages:** can cater for a wide range of rainfall events, delays peak flows, high potential ecological/aesthetic benefits, may add value to local properties, links urban and suburban wetland habitats with the wider landscape **Key disadvantages:** no reduction in runoff volume, land take may limit use in high density sites, may not be suitable for steep sites, colonisation by invasive species may increase maintenance	• Peak flow delay: **good** • Runoff volume reduction: **poor**

Note: Likely FRM performance data is taken from Susdrain (2012).

Graham et al (2012) provides extensive guidance on how SuDS components (including those outlined at Table 4.8) can be improved from a biodiversity and amenity perspective. Most of the issues in Graham et al (ibid) are of greater relevance at the micro-siting/design level and, as such, have been disregarded from the Table 4.8 summary. The rationale for this is explained further below.

SuDS components have been selected for inclusion in Table 4.8 where they are suitable for consideration in strategic (e.g. whole city/catchment) land use/management planning as per the objectives of this research (see Box 1.2). For example, SuDS components have been disregarded where effective design and siting is reliant on the consideration of key micro-siting issues such as detailed topographical analysis (e.g. filter strips[59]). On the other hand, SuDS components have been included where they have the potential to be covered by a generic land use/management policy e.g. *"where possible, the use of green roofs and permeable*

---

[59] Susdrain pages on filter strips: http://www.susdrain.org/delivering-suds/using-suds/suds-components/filtration/filter-strips.html [accessed 29/03/14]

*surfaces should be promoted within neighbourhood **x**”*. As discussed above, conveyance measures have not been considered in this research.

Chapter 5 now explains how urban land use/management can impact the provision of ecological connectivity services in urban areas, by either facilitating or disrupting urban habitat networks.

5. Urban land use planning, landscape ecology and habitat networks

The key aim of this research is “to understand, develop, trial and evaluate new approaches to urban planning that can operationalise key aspects of the ecosystems approach”. An evidence assessment has been undertaken to meet this overarching aim as documented in Chapters 3, 4, 5 and 6. The evidence assessment approach is described at section 2.2. Section 2.4 describes how the data collected through the evidence assessment has then been analysed to support other objectives of the research, especially the development of the new approaches to urban planning that can operationalise aspects of the ecosystems approach (see Box 1.2).

The overall output of the evidence assessment is the development of a suite of guiding principles for ecosystems approach based urban land use planning (see Appendix 3). The principles provide the overall framing for the new urban land use planning approaches developed through this research (see Chapters 7 and 8) and are intended to be of practical use in other urban planning contexts also. The evidence assessment has also informed the development of specific guidance to help practitioners interpret and act on outputs from the new models in the development of integrated urban land use/management strategies (see Chapters 7 and 8 and Appendices 4, 5 and 6).

As outlined at sections 1.4 and 3.2.5, this thesis focuses on specific urban ecosystem services. This is the third of four chapters documenting the evidence assessment that has underpinned this research. The Chapter focuses on the role of urban land use/management in the provision and function of urban habitat networks. In particular, the evidence in this Chapter has underpinned the development of the habitat network model (see section 7.4). Section 5.1 introduces the core concepts of landscape ecology which define the current thinking and practice in relation to urban habitat networks. Section 5.2 provides a more detailed outline of the key ecological principles that underpin habitat network planning, design and delivery as well as introducing the models and data that are used to define habitat networks in a modelled environment. Section 5.2 also introduces the data produced by habitat network modelling and its application in urban land use/management planning as per this thesis (section 7.4). Finally, section 5.3 explores some of the wider multiple benefits that urban habitat networks can provide. In line with this focus, Chapter 5 addresses three key research questions that have informed the research activities undertaken (REA and semi-structured interviews – see sections 2.3.2 and 2.3.4) as well as providing a framing for the key findings of this part of the evidence assessment in the conclusions Chapter at section 9.2. The research questions considered within this part of the evidence assessment are:

- What factors influence species movements in urban areas?
- How can the management and use of urban land influence the provision of ecological connectivity related ecosystem services in urban areas?
- What are the potential multiple benefits of natural/semi-natural habitats and habitat networks in urban areas?

5.1 The key principles of landscape ecology

Landscape ecology has been defined variously as “the study of spatial variation in landscapes at a variety of scales” (IALE, undated, what is landscape ecology) and “the study of the interactions between the temporal and spatial aspects of a landscape and the organisms within it" (Forest Research, 2014a the 'basics' of landscape ecology). The principles of landscape ecology are fundamental for the development of ecosystems approach based urban land use/management systems, as per the objectives of this research (see Box 1.2). In particular, landscape ecology provides the theoretical framing for assessing and predicting the impacts of land use/management change on the ability of species to migrate, disperse and interact, through tools such as integrated habitat network (IHN) modelling (SNIFFER, 2008). As discussed at section 3.2.1, it is these landscape scale ecological processes (where species move beyond the bounds of individual habitat patches) that help to maintain biodiversity by supporting and facilitating interbreeding, colonisation, natural regeneration etc (Gutzwiller and Forman, 2002; Watts et al, 2005; Smith et al, 2008; SNIFFER, 2008; SNH, 2011; James et al, 2013; Matthies et al, 2013; Phillips, 2013; Briers, 2011).

Furthermore, biodiversity itself is a fundamental component of ecosystem function and therefore the supply of ecosystem services (see section 3.2.1 and Figures 3.6 and 3.7). In this regard, maintaining the connectivity of the landscape (thereby facilitating the migration, dispersal and interaction of species and populations) is essential for maintaining biodiversity, ecosystem function and ecosystem services. The importance of this issue is highlighted by Jones-Walters (2009 p.vi): "changes in the patterns of land use have impacted more than any other factor on Europe's biodiversity […] all over Europe habitats and ecosystems are becoming smaller, more fragmented and their isolation from other areas is increasing […] this prevents species from reaching migration and dispersal destinations and forces them to live in habitats that may not be large enough to maintain viable populations". Crucially, Jones-Walters goes on to discuss the potential implications of this degradation for the provision of ecosystem services and climate change adaptation as well as highlighting the need for further research into practical mechanisms for delivering ecological networks on the ground (ibid). In an urban context, this is a key gap that this thesis seeks to address (see sections 7.4 and 8.2 and Appendix 6).

There are two key principles of landscape ecology that are of direct relevance to this research: 1) how we define landscapes in terms of their structure and function;

and 2) the notion that landscape structure and function can somehow be measured and evaluated to inform land use/management planning. These are described briefly in sections 5.1.1 and 5.1.2 and in more detail in section 5.2 in the specific context of planning and managing urban habitat networks.

5.1.1 Landscape and landscape scale

The word 'landscape' is often used as a descriptor for spatial scale (extent) whereby the notion of 'landscape scale' is used to define an area of land covering several square kilometres (Forman, 1995; Forest Research, 2014a). This broad definition of landscape scale has been adopted in this research. In particular, undertaking urban land use/management planning at broader scales (spatial extents) is necessary to ensure that opportunities are adequately considered – e.g. identifying spatial priorities for joining up gaps in strategic habitat networks and improving overall connectivity (see section 5.2 also). In this regard, land use/management planning at broader spatial scales could include whole city or whole catchment planning. This issue was also highlighted through the expert interviews (see section 2.3.4 and Appendix 2). For example:

> *"[Land use/management planning] at the local authority scale is important for understanding the resource, the pinch points and the opportunities"* (I-1)
>
> *"[Choice of scale] depends on what aspects of ecosystem services you are looking at – ecological connectivity will be influenced by patch size. Small patches will make a negligible contribution to ecological networks at the landscape scale but may be important locally"* (I-2)

In terms of a landscape ecology focussed definition of landscape (i.e. a definition that is reflective of how a landscape 'works' in terms of its structural and functional connectivity for species – see section 5.2.1), landscapes can be defined as entities with structural elements of patch, matrix and corridor reflecting a mix of ecosystems and habitats that combine to create heterogeneity within an area (Gutzwiller and Forman, 2002; Forest Research, 2014a). In line with this, Forest

Research (ibid) highlight how much of the landscape ecology field has developed around the paradigm of a landscape mosaic comprising structural elements of patch (e.g. discrete habitats) arranged in a matrix (i.e. the predominant habitat or land use) with additional structural elements that can pose barriers to movement (e.g. linear infrastructure) or provide corridors that facilitate movement (e.g. river corridors and their associated riparian habitat). This is illustrated on Figure 5.1 using an urban landscape from Glasgow as an example.

Figure 5.1 Defining an urban landscape in terms of its structural elements

(Adapted from: Forest Research, 2014a; Google Maps, 2014)

Note: The Figure depicts a heterogeneous urban landscape (the Kelvinbridge area of Glasgow's west end) comprising elements of matrix, patch, barrier and corridor. The predominant land use is urban comprising roads, yards, driveways and housing – this constitutes the matrix within this landscape. There are also numerous patches, primarily private gardens (an example of which is shown at Patch 2) but also other types of habitat such as the brownfield site at Patch 1. The river and its riparian habitat provide a corridor whereas main roads are likely to pose a barrier to species movements.

Furthermore, species interact with these landscape elements in a variety of different ways. In terms of patches for example, species may prefer a certain type of habitat (e.g. wetlands/ponds) and may not be able to breed or feed away from that habitat type. In terms of matrix, where one land use dominates the landscape, this can have a dramatic impact on species interactions with the wider landscape – e.g. if the matrix is uniformly inhospitable such as arable land or high density urban land this can have an isolating effect on species (ibid). Given this, the structure and spatial configuration of patches, corridors and matrices within the landscape mosaic can have a profound impact on landscape connectivity, species movements and other landscape scale ecosystem processes (Jones-Walters, 2009; Scott and James, undated).

5.1.2 Measurement and evaluation of landscape function

The use of habitat network modelling to define landscape function in terms of landscape scale species movements is a rapidly expanding area of research (Briers, 2011). Furthermore, there are several different types of model (ibid). The utility and robustness of these models is becoming increasingly important due to pressure from land management activities (especially forestry, agriculture and development) that physically alter landscapes, thereby affecting landscape structure and function (Watts et al, 2005) with implications for biodiversity, ecosystem function and ecosystem services (Jones-Walters, 2009). As such, reliable models are required to support the planning of landscape scale conservation efforts. The objective of this research however is not to critique the various different models, rather data from a given type of habitat network model is used as an input to the tools and models developed in this research (especially the habitat network model described at section 7.4). In this regard, the research has drawn on data from Forest Research's BEETLE – Biological and Environmental Evaluation Tools for Landscape Ecology model (Watts et al, 2005; Smith et al, 2008) which is outlined further at section 5.2.

Forest Research are working on a landscape ecology programme that is developing GIS based tools for measuring landscape structure and assessing functional connectivity of landscapes (Forest Research, 2014b). Data produced through these tools are used as inputs to the habitat network model developed through this research (see section 7.4). More detailed information on the science behind these models is provided at section 5.2. In summary however, the structural tools use land cover data to produce metrics or indicators based on the habitat requirements of certain focal (indicator) species. The functional tools use habitat information from the structural tools to model species movement, to identify potential habitat networks (ibid). In essence, the structural tools measure the landscape by collecting and analysing patch data (see section 5.1.1). In this regard, the landscape can be quantified and mapped using a variety of different landscape metrics such as:

- Total area of habitat
- Mean size of habitat patches
- Mean inter-patch distance
- Variation in patch sizes
- The number of patches linked by a particular piece of new planting or other habitat development or enhancement

5.2 Habitat networks and habitat network modelling

Section 5.1 introduces the key principles of landscape ecology that have informed this research – how we define landscapes for the purposes of planning and management to maintain connectivity for species (see section 5.1.1) and a brief introduction to the tools and models that can be used to measure and evaluate landscape function, in terms of structure and connectivity (see section 5.1.2). Building on the core landscape ecology principles outlined at section 5.1, this section further defines the habitat network concept (section 5.2.1) and provides additional details of the Forest Research BEETLE model, data from which has been used in this research (section 5.2.2). Section 5.2.2 also includes a brief review of the strengths and weaknesses of the BEETLE model in relation to its utility informing land use/management planning for landscape connectivity.

5.2.1 Habitat networks – structural and functional connectivity

A habitat network is "a set of separate areas of habitat that connect together in some way. These connections allow a particular species to be able to move between each individual patch of habitat" (SNH, 2011 p.2). This definition builds on the landscape ecology principles introduced at section 5.1 – i.e. habitats are patches that exist within a matrix. Where the matrix is sufficiently permeable (by way of either a structural or functional connection – see Figures 5.2 and 5.3), the species will be able to move between patches.

Connectivity between habitat patches can been seen in both structural and functional contexts (Watts et al, 2005; Briers, 2011; SNH, 2011). Structural connectivity occurs where habitat patches are directly linked. In this situation, species are able to move directly between patches of habitat without having to traverse an intervening matrix (see section 5.1.1) that may somehow be inhospitable, thereby preventing or reducing movement (ibid). These concepts are illustrated on Figures 5.2 and 5.3.

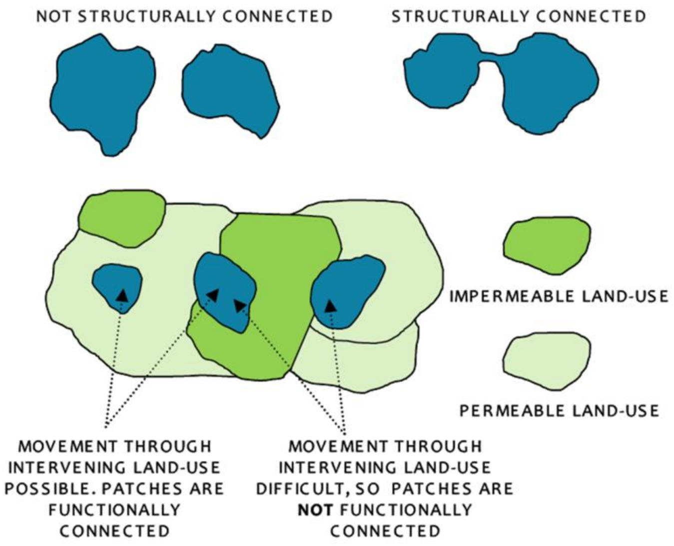


Figure 5.2 Contrast between structural and functional connectivity of habitat patches

(Source: Briers, 2011)

On the other hand, functional connectivity is an important attribute of landscapes related to ecological processes such as the anticipated ability of certain species to move between discrete patches (Watts et al, 2005). In this regard, functional connectivity does not rely on direct connections as long as the distance between discrete patches is not overly far and, crucially, as long as the intervening matrix is sufficiently hospitable to species movements (Briers, 2011; SNH, 2011). The types of factors that can influence matrix hostility include, for example, lack of food and refuge or increased risk of predation (Briers, 2011). In certain types of habitat network modelling (see section 5.2.2) these factors are construed as 'costs' to the species and the higher the 'cost', the less permeable/more hostile the intervening matrix is (ibid). Accordingly, one important strategy for maintaining functional connectivity is to protect areas of 'low cost' land use that exist between important habitat patches (see Figures 5.2 and 5.3). This principle has been considered in the new habitat network model developed through this research (see sections 7.4 and 8.2 and Appendix 6).

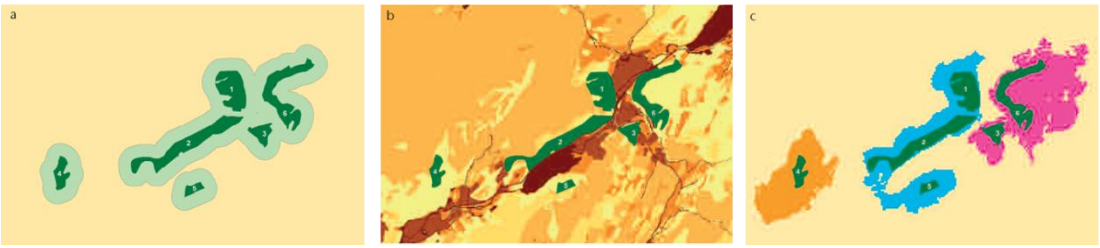


Figure 5.3 Modelling functional connectivity in habitat networks

(Adapted from: Watts et al, 2005)

Note: Map (a) depicts habitat patches (dark green) buffered to illustrate the generic dispersal distance of a given species. Map (b) depicts the permeability of the landscape matrix surrounding the habitat patches – yellow is high permeability and dark brown/red indicates low permeability for the species of interest. Map (c) depicts the functional connectivity of the habitat network – i.e. the dispersal area for the species of interest once the constraints of the landscape matrix are taken into account. In this regard, the structure and configuration of habitat patches in conjunction with the specific nature of the surrounding matrix are such that the habitat patches form three **functional** habitat networks – i.e. the areas marked in orange, blue and pink on map (c). Note how there are no structural connections.

5.2.2 Habitat network modelling and data

Habitat network modelling is a growing area of research and there are many different types of model currently in use and development (Briers, 2011). This includes least-cost models (e.g. Humphrey et al, 2004; Smith et al, 2008; Corbett et al, 2009), graph theory models (e.g. Urban and Keitt, 2011; Pascual-Hortal and Saura, 2006) and spatially explicit population models or SEPMs (e.g. Macdonald and Rushton, 2003; Suter et al, 2009). Habitat network models all share certain characteristics especially the need to define what constitutes habitat (i.e. patch) for the species of interest (e.g. in terms of habitat type and size) and also an estimate of the distances that the species can travel between discrete patches, known as dispersal ability (Briers, 2011). Key differences relate to how functional connectivity (see section 5.2.1 and Figures 5.2 and 5.3) is defined and assessed in the modelled environment (ibid).

As discussed at section 5.1.2 however, the objective of this research is not to critique different models – rather the data from a given type of habitat network model is used as input to the tools and models developed through this research, especially the habitat network model described at section 7.4. In this regard, data from Forest Research’s BEETLE model (see section 5.1.2) has been used. BEETLE is a least-cost type model (see section 5.2.1) and its use in this research has been dictated primarily by data availability. In particular, Forest Research were commissioned to develop an integrated habitat network (IHN) model[60], using the BEETLE suite of tools, for the whole of the Central Scotland Green Network[61] (CSGN) region where Glasgow – the pilot urban centre considered in this research – is located. Furthermore, the use of IHN data (produced through least-cost models such as BEETLE) has been identified as a common method/approach supporting integrated land use/management planning and delivery in Scotland (Phillips et al, 2014). The remainder of this section provides an introduction to least-cost type habitat network models, considers some of their key weaknesses and issues that should be considered when using model outputs and a brief introduction to the spatial data produced through these models.

BEETLE is a least-cost type habitat network model (Watts et al, 2005; Smith et al, 2008; Corbett et al, 2009; Briers, 2011). Least-cost type models are premised on the notion of landscape permeability or resistance whereby the nature of land use will influence a given species' ability to move/permeate through the landscape (ibid) i.e. using functional connections between patches by traversing areas of less hostile matrix. In this regard, "different land uses are assigned different permeability values which reflect the cost or difficulty for a species to travel through that land use. Traversing an area of high-cost matrix will reduce the distance that a species is able to travel and in extreme cases may prevent any movement" (Briers, 2011 p.5). This concept is depicted on Figure 5.4.

As mentioned at the start of this sub-section, the size and configuration of habitat networks (see Figure 5.3) is also a function of species specific requirements. In particular, a given species will have certain habitat requirements (in terms of type and size) and dispersal abilities i.e. the distance the species can move between discrete, non-structurally connected patches as depicted on Figure 5.2 (Smith et al, 2008; Corbett et al, 2009; Briers, 2011). In this regard, a key input to habitat network

---

[60] Spatial data in ArcGIS shapefile format for the entire CSGN IHN model is available for free download from Scottish Natural Heritage's (SNH) data download site (SNH Natural Spaces): https://gateway.snh.gov.uk/natural-spaces/index.jsp [accessed 01/04/14]

[61] The CSGN is a National Development within Scotland's National Planning Framework – the NPF (see section 3.1.1). The remit of the CSGN is to work in partnership across the private and public sector to deliver the CSGN vision: "By 2050, Central Scotland has been transformed into a place where the environment adds value to the economy and where people's lives are enriched by its quality" (CSGN Partnership Board, 2011 p.2). Further information on the CSGN can be found at: http://www.centralscotlandgreennetwork.org/ [accessed 01/04/14]

models (including least cost models such as BEETLE) is data on the ecology of species of interest in terms of habitat requirements and dispersal distances (ibid). This would ideally be based on empirical data on species movements within a range of different landscapes and environments (e.g. data from mark-release-recapture studies) though this sort of information is generally not available (Briers, 2011).

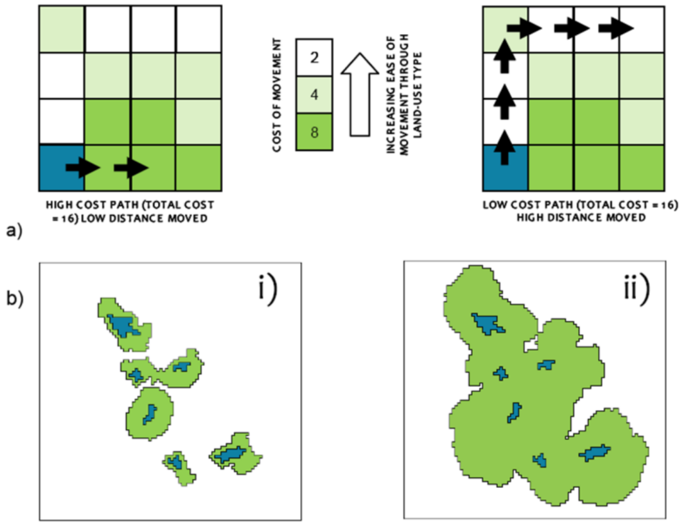


Figure 5.4 Illustration of the principle of least-cost habitat network modelling

(Source: Briers, 2011)

Note: Part (a) of the Figure above illustrates the principle of least-cost habitat network modelling. The blue cell represents patch and other coloured cells the wider land use matrix (the darker green the cell, the higher the cost to the species of moving through that specific land use). In this regard, part (a) shows two different routes through a landscape with the same cumulative cost (16). Although the cumulative cost is the same there are marked differences in the dispersal distance travelled due to the different cost of the land uses travelled through – i.e. dispersal distance is low via the high cost route and high via the low cost route. Part 9(b) depicts this concept spatially – indicating the possible dispersal area in a high cost landscape (i) and low cost landscape (ii).

As a compromise, it is often the case that a generic focal species (GFS) is used (ibid) to "represent key functions of selected habitats and an array of similar species" (Corbett et al, 2009 p.164). A GFS has been defined as "a conceptual or virtual species, whose profile consists of a set of ecological requirements reflecting the likely needs of real species where data are unavailable. GFS are selected to represent particular species, groups of species, habitats, important landscape features or policy objectives" (Smith et al, 2008 p.4). In this regard, the use of GFS can be instrumental in exploring habitat network related land use/management options that can support a diverse range of ‘real’ species e.g. by setting patch requirements to ‘high’ and dispersal distances to ‘low’. An example habitat network model output is shown at Figure 5.5 indicating how the functional connectivity of networks changes as a result of species (e.g. GFS) dispersal ability.

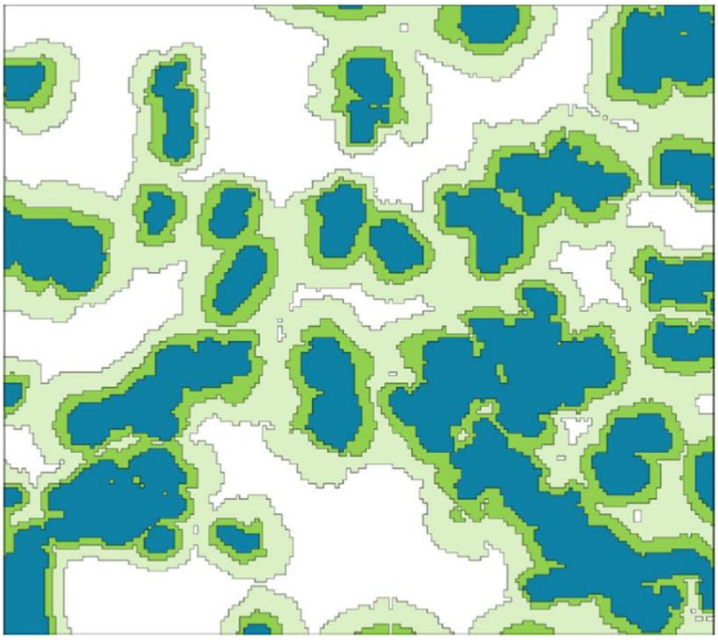


Figure 5.5 Influence of dispersal ability on functional connectivity of habitat networks

(Source: Briers, 2011)

Note: The Figure above depicts the spatial configuration of nested habitat networks generated by varying maximum dispersal distance (e.g. of a generic focal species) to 0.5km (blue polygons), 1km (dark green polygons) and 2km (pale green polygons). Note how the number of contiguous networks decreases (whilst their area increases) as dispersal distance increases – i.e. when dispersal distance is set at 2km nearly all patches are functionally connected.

Briers (2011 p.18) in a review of the evidence base for habitat networks highlights how “habitat networks are one potentially powerful tool for contributing to the conservation of biodiversity through effective landscape management”. Similarly, Smith et al (2008 p.iii) outline how “habitat network modelling has the potential to support and guide the planning process and to target conservation effort by highlighting areas that have the greatest development potential of habitat protection and enhancement”. Despite these positives, Briers (ibid) expresses caution in relation to habitat network use in isolation (i.e. without due consideration of other factors/criteria that can influence land use/management for conservation) as well as highlighting key uncertainties in the use of least-cost modelling techniques. In particular, it is important to recognise that even with perfect data on species ecology (i.e. in terms of habitat requirements and dispersal ability) it would not be possible to define, with any certainty, the exact area of permeable land that defines the connectivity (structural and functional) of a habitat network. In this regard, there is an "inherent fuzziness in resultant habitat network maps that needs to be considered when interpreting the network analyses for land use/management planning" (Briers, 2011 p.15). One way of representing this inherent fuzziness is to use sensitivity analysis in order to test the impact of changing key parameters i.e. habitat requirements and dispersal ability. As outlined at section 7.4, this approach has been adopted in the tools and models developed in this research through the use of habitat networks data representing high and low dispersal ability of the GFS.

Crucially, habitat network model outputs do not themselves identify specific recommendations for land use/management change for increasing landscape connectivity. Rather they provide part of the evidence base and "decision-making system for [land use/management] strategies designed to reduce the impacts of habitat fragmentation and improve habitat connectivity and biodiversity" (Smith et al, p.13). In this regard, habitat network model data requires a degree of user-interpretation in order to identify and define specific land use/management actions. For example, outputs from the Forest Research BEETLE model used in the Glasgow and Clyde Valley Integrated Habitat Networks Project (Smith et al, 2008) are ArcGIS shapefiles depicting the spatial configuration of habitat networks for eight GFS across two dispersal distances – 0.5km and 2km. This includes separate datasets for patches and the functional networks created by these patches (see section 5.2.1 also). The benefit of having the data in this format is that it can be integrated with other compatible datasets (e.g. soils, flood extent, hydrology, access networks etc) in spatial analyses to inform integrated land use/management planning (Phillips et al, 2014) Further information on this data (which has been used in the development of the tools and models in this research – see section 7.4) is provided at section 2.4.2. The integrated use of habitat networks data, in conjunction with other spatial datasets, has been undertaken in this research (see section 8.2).

Scottish Natural Heritage (SNH) have developed a web-based interactive habitat network user tool[62] (SNH, 2014b) that allows users to view maps of existing habitat patches and model the potential impacts of land use/management change on the functional connectivity of habitat networks (e.g. in terms of further fragmentation as a result of development or enhancement as a result of habitat management/creation). In essence, it provides an online scenario planning tool allowing land use/management practitioners to 'go beyond' the static, mapped outputs of habitat network models and input user-defined land use/management preferences to explore changes in functional connectivity. In addition however, it is recommended that the development and enhancement of habitat networks is based on the principles of conservation management (Smith et al, 2008; Corbett et al, 2009) which are listed below in order of priority (noting in particular how the creation of **new** areas of habitat is the lowest priority intervention). These principles have been considered in the new spatial models and guidance developed through this research (see sections 7.4, 8.2 and Appendix 6).

- **Protect** and **manage** areas of high quality habitat
- **Restore** and **improve** sites with restoration potential
- **Improve** and **manage** other sites
- **Improve** the **landscape matrix** by reducing land use intensity
- **Create/recreate new habitat** and semi-natural habitat

5.3 The multiple benefits of urban habitat networks

In terms of the role of biodiversity supporting ecosystem function and the supply of ecosystem services (see section 3.2.1) the development and enhancement of urban habitat networks can be particularly important due to the often inhospitable nature of the urban matrix (SNIFFER, 2008; Corbett et al, 2009; James, 2013; Matthies et al, 2013) as indicated on Figure 5.1. As well as reversing the effect of habitat fragmentation on biodiversity, habitat networks are also regarded as a means of

---

[62] SNH Interactive Habitat Network User Tool: http://www.snh.gov.uk/land-and-sea/managing-the-land/spatial-ecology/habitat-networks-and-csgn/interactive-habitat-network-tool/ [accessed 01/04/14]

delivering a range of other social and environmental benefits i.e. ecosystem services (Corbett et al, 2009). In terms of the PAN65 openspace typology recognised by planners and adopted in Local Development Plans (LDPs), urban habitat and habitat networks can be considered synonymous with natural/semi-natural greenspace (see section 3.1.3 and Table 3.4). When placed in an urban context therefore, well planned and integrated urban habitat and habitat networks have the potential to deliver a broad range of additional urban ecosystem services, depending on the type and size of habitat patches and their management. This has been reflected in the new approaches developed through this research – see section 8.2 and Appendix 6. The importance of urban habitat was also highlighted in the expert interviews in response to question 3.2 (see Appendix 2) – **to your mind, what are the key components of the urban natural environment?** Key responses include:

> *"Fragmented habitats, primarily woodland [...] less intensively managed openspaces [including] grassland meadows and some components of more formal parks"* (I-2)
>
> *"Areas of semi-natural habitat which will exist within parks and public openspaces, infrastructure corridors, water network and river corridors and public useable space such as allotments, cemeteries and school estates"* (I-3)
>
> *"Areas of limited human activity – we try to bring all our vacant and derelict land back into use but it does have a value while it is brownfield – e.g. through natural succession"* (I-4)

As mentioned at section 5.2.1, habitat networks data from the Glasgow and Clyde Valley Integrated Habitat Networks (GCVIHN) Project (Smith et al, 2008; Corbett et al, 2009) has been used in this research in the development of the new tools and models to support urban planning (see sections 7.4 and 8.2). The GCVIHN project (ibid) modelled habitat networks for the following three broad habitats (see section 1.2 for further information the adoption of broad habitats as the unit of analysis within the UK National Ecosystem Assessment – the UKNEA):

- **Unimproved/neutral grassland:** defined as the Phase 1[63] categories unimproved neutral grassland and marshy grassland
- **Wetland:** defined as all wetland habitats identified in the wetland and grassland National Vegetation Classification[64] (NVC) survey ranging from small open waterbodies to wet woodlands
- **Woodland:** defined as all areas of woodland from the OS MasterMap (see section 2.4.2) and Phase 1[65] categories with broadleaved woodland (including ancient broadleaved woodland) identified as a separate group

A further categorisation of these three broad habitats into discrete sub-categories (i.e. in terms of the UKNEA and UK Biodiversity Action Plan) is provided at Table 5.1. In light of this information, it has been possible to identify, in general terms, the range of ecosystem services that these types of broad habitat may provide with reference to key literature. This information has then been fed into the tools and models developed in this research (see Chapters 7 and 8) to ensure that habitat network related land use/management planning actions identified through the modelling can be designed to deliver key ecosystem services, as may be required at a given location (see section 8.2). In this regard, Table 5.2 identifies the potential ecosystem services provided by the three broad habitats considered in this research as well as the importance of the broad habitat for delivery of ecosystem services.

---

[63] The Phase 1 habitat classification and associated field survey technique is intended to provide a relatively rapid system to record semi-natural vegetation and other wildlife habitats. JNCC Phase 1 habitat survey handbook pages: http://jncc.defra.gov.uk/page-2468 [accessed 27/01/14]

[64] The NVC is one of the key common standards used by UK nature conservation agencies. It provides a comprehensive classification and description of the plant communities of Britain, each systematically named and arranged and with standardised descriptions for each: http://jncc.defra.gov.uk/page-4259 [accessed 01/04/14]

[65] Ibid

Table 5.1 Broad habitat types and sub-categories as defined in the UK National Ecosystem Assessment (UKNEA) and UK Biodiversity Action Plan (UKBAP)

(Adapted from: Mace et al, 2011)

UKNEA broad habitat	UKNEA component habitat	UK Biodiversity Action Plan (BAP) priority habitats
Unimproved/ neutral grassland	Neutral grassland	Lowland meadows
	Fen, marsh and swamp	Purple moor grass and rush pastures
Freshwaters – openwaters, wetlands and floodplains	Standing openwaters and canals	• Mesotrophic lakes • Eutrophic standing waters • Oligotrophic and dystrophic lakes • Aquifer fed naturally fluctuating water bodies • Ponds
	Rivers and streams	Rivers
	Bog	Lowland raised bogs
	Fen, marsh and swamp	• Lowland fens • Reedbeds
Woodlands	Broadleaved, mixed and yew woodland	• Lowland beech and yew woodland • Lowland mixed deciduous woodland • Wet woodland
	Coniferous woodland	Native pinewoods

Note: Information in the Table has been extracted from Mace et al (2011) to further define the three broad habitats considered in this research within the new habitat network model (see sections 7.4 and 8.2 and Appendix 6). Specific UKNEA component habitats and UKBAP priority habitats have only been selected for inclusion in the Table where they are either: 1) known to be found in Glasgow[66]; or 2) where there is reasonable potential for the development of the habitat in an urban centre such as Glasgow. Glasgow is the pilot urban centre used in this research (see section 2.1.4).

---

[66] Glasgow Local Biodiversity Action Plan (LBAP) pages:
https://www.glasgow.gov.uk/index.aspx?articleid=6054 [accessed 01/04/14]

Table 5.2 Relationship between broad habitats and ecosystem services

(Adapted from: Haines-Young and Potschin, 2008; Bullock et al, 2011; Mace et al, 2011; Maltby et al, 2011; Quine et al, 2011; UKNEA, 2011)

<table>
<tr><td>Key
<i>importance of broad habitat for delivering the service</i></td><td colspan="2">█ High</td><td>▓ Medium – High</td><td>▒ Medium – Low</td><td>░ Low</td></tr>
<tr><td>Service category</td><td colspan="2">[Final] ecosystem service</td><td>Unimproved/ semi-natural grassland</td><td>Wetland</td><td>Woodland</td></tr>
<tr><td rowspan="6">Provisioning</td><td colspan="2">Crops</td><td>░</td><td>░</td><td>N/A</td></tr>
<tr><td colspan="2">Livestock/ aquaculture</td><td>▒</td><td>░</td><td>░</td></tr>
<tr><td colspan="2">Fish</td><td>N/A</td><td>▓</td><td>N/A</td></tr>
<tr><td colspan="2">Trees, standing vegetation, peat</td><td>▒</td><td>▓</td><td>█</td></tr>
<tr><td colspan="2">Water supply</td><td>░</td><td>█</td><td>▒</td></tr>
<tr><td colspan="2">Wild species diversity</td><td>█</td><td>█</td><td>█</td></tr>
<tr><td rowspan="2">Cultural</td><td colspan="2">Environmental settings – <i>local places</i></td><td>▓</td><td>█</td><td>█</td></tr>
<tr><td colspan="2">Environmental settings – <i>landscapes</i></td><td>█</td><td>█</td><td>▓</td></tr>
<tr><td rowspan="8">Regulating</td><td colspan="2">Climate regulation</td><td>▓</td><td>▒</td><td>█</td></tr>
<tr><td colspan="2">Hazard regulation</td><td>▓</td><td>█</td><td>▓</td></tr>
<tr><td colspan="2">Disease and pest regulation</td><td>░</td><td>▓</td><td>▒</td></tr>
<tr><td colspan="2">Pollination</td><td>█</td><td>N/A</td><td>░</td></tr>
<tr><td colspan="2">Noise regulation</td><td>░</td><td>▒</td><td>▓</td></tr>
<tr><td rowspan="3">Detoxification & Purification</td><td>Water quality</td><td>█</td><td>█</td><td>▓</td></tr>
<tr><td>Soil quality</td><td>█</td><td>▓</td><td>█</td></tr>
<tr><td>Air quality</td><td>▓</td><td>░</td><td>█</td></tr>
</table>

Note: The Table provides an overview of the types of ecosystem service (based on the UKNEA typology) provided by the three broad habitats considered in this research as well as an indication of the relative importance of each habitat for the provision of each ecosystem service (from high – low). More specific information on the ecosystem services provided by each broad habitat (including specific mechanisms by which the services are provided etc) is available at section 3.2 and from the references above. This information has informed the tools and models developed through this research (see Chapters 7 and 8).

Chapter 5 was the last of the ecosystem service specific evidence assessment chapters. Chapter 6 now discusses the evaluation of three existing land use planning frameworks in terms of their ability to operationalise the ecosystems approach.

6. Evaluating existing examples of ecosystems approach based land use planning frameworks – strengths, weaknesses and lessons for wider practice

The overarching aim of this research is to "understand, develop, trial and evaluate new approaches to urban planning that can operationalise key aspects of the ecosystems approach". In order to meet this overarching aim, a substantive evidence assessment has been undertaken as documented in Chapters 3, 4, 5 and 6. This is the last of the evidence assessment chapters and documents the results of the evaluation of existing examples of ecosystems approach based land use planning frameworks under Research Objective No.3 (see Box 1.2). The rationale for this objective recognises that although the ecosystems approach and land use planning are, in effect, separate 'disciplines' with their own discrete theories (see section 2.1.2), there are undoubtedly some existing land use planning frameworks that incorporate aspects of the ecosystems approach, either explicitly or implicitly. Rather than trying to 'reinvent the wheel' therefore, it makes sense to draw on the strengths of existing approaches whilst learning from their weaknesses. The purpose of this section therefore is to summarise the evaluation of existing ecosystems approach based land use planning frameworks. The detailed evaluation is documented at Appendix 7. The specific research questions addressed by this part of the evidence assessment are:

- To what degree have the CBD ecosystems approach principles been considered in the example land use planning frameworks? Which principles have been considered?
- What types of method/approach have the example land use planning frameworks used to consider the CBD principles in their land use/management planning?
- What are the main strengths and weaknesses of the example land use planning frameworks in terms of how they have considered the CBD principles?

The specific methodological approach adopted in the evaluation of example approaches is described at sections 2.2.4, 2.3.1 and 2.4.1. Section 2.3.1 includes an explanation of the rationale behind the selection of example approaches to review. In summary however, the CBD ecosystems approach principles (CBD Secretariat, 2013a) have been used as an evaluation framework i.e. the principles themselves have been deconstructed as evaluation criteria (see Tables 2.3 and 3.8) and then imposed on the example approaches. The evaluation considers the degree to which the principles are met across a three point scale: 1) principle considered; 2) principle considered to a degree; and 3) principle not considered. The more principles met, the greater the potential of the example approach to operationalise the ecosystems approach. Where principles are not met, these are key weaknesses and gaps that arguably need to be met in the development of new approaches, such as the tools, models and guidance developed in this research. The evaluation also helps to identify specific methods, tools and data that may prove helpful for operationalising the ecosystems approach (e.g. as per this research). The remainder of this section summarises the evaluation of each example approach considered. A synthesis of the evaluation overall is provided at section 6.4 including summary findings against the three research questions listed above. The three example approaches considered are:

- Thames Gateway Ecosystem Services Assessment Using Green Grids and Decision Support Tools for Sustainability (THESAURUS) – see section 6.1
- Environmental Capacity in the East of England: Applying an Environmental Limits Approach to the Haven Gateway – see section 6.2
- Glasgow and Clyde Valley Green Network Partnership (GCV Green Network Partnership) Opportunities Mapping – see section 6.3

6.1 THESAURUS ecosystem services assessment and mapping project

THESAURUS was a case study research project that formed part of Defra's Natural Environment Policy Research Programme (Defra, 2009). The research was undertaken by Collingwood Environmental Planning (CEP) Limited[67] and Geodata Institute[68]. The overall aim of the project was "to evaluate the value and appropriateness of using an ecosystem services approach within existing land use planning frameworks, particularly its application through a range of decision support tools using Kent Thameside as a case study" (Defra, 2008 p.7). Key details of the approach adopted in THESAURUS are described at section 6.1.2. A summary of the evaluation of THESAURUS against the CBD ecosystems approach principles (see Tables 2.3 and 3.8) is shown on Figure 6.1.

6.1.1 Evaluation of the THESAURUS approach

The CBD ecosystems approach principles have been grouped on the basis of the broader Scottish Government (2011c) categorisation (see Table 3.8). In terms of the *management of natural systems* principles, the THESAURUS approach has a mixed performance. The approach has considered scale (EsA4) and effects on adjacent ecosystems (EsA1) **to a degree** and the conservation of ecosystem structure and function (EsA2) has been considered **fully** (see Appendix 7). In particular, the THESAURUS approach includes explicit consideration of key ecosystem processes/intermediate services (e.g. hydrological cycle and ecological networks) through the use of network analysis and the spatial representation of proxy

---

[67] Collingwood Environmental Planning is a UK based independent multidisciplinary environmental and sustainability consultancy: http://www.cep.co.uk/ [accessed 27/01/14]

[68] Geodata Institute is a University of Southampton based research institute and consultancy unit specialising in environmental data management and analysis: http://www.geodata.soton.ac.uk/geodata/ [accessed 27/01/14]

ecosystem services at the land parcel level (further information on methods adopted in THESAURUS is provided at section 6.1.2). Ecosystem processes/intermediate services capture the fundamental aspects of ecosystem function that support ecosystem services (see section 3.2.1 and Figure 3.8). In this regard, THESAURUS' comprehensive consideration of these services is supportive of EsA2 on conserving ecosystem structure and function.

Radar Diagram Code	Ecosystem approach principle	Theme
EsA 1	Consider effects on adjacent ecosystems	*Management of natural systems*
EsA 2	Conserve ecosystem structure and function	
EsA 3	Ecosystem management must respect environmental limits	
EsA 4	Adopt the ecosystems approach at appropriate spatial and temporal scale	
EsA 5	Set long term objectives for ecosystem management	
EsA 6	Ecosystem management must recognise that change is inevitable	
EsA 7	Understand and manage the ecosystem in an economic context	*Ecosystem services*
EsA 8	Ensure an appropriate balance between conservation and use of biodiversity	
EsA 9	Objectives for ecosystem management are a matter of societal choice	*Involving people*
EsA 10	Ecosystem management should be decentralised to the lowest appropriate level	
EsA 11	Consider all forms of relevant information including scientific/local knowledge, practice and innovation	
EsA 12	Involve all relevant sectors of society and scientific disciplines	

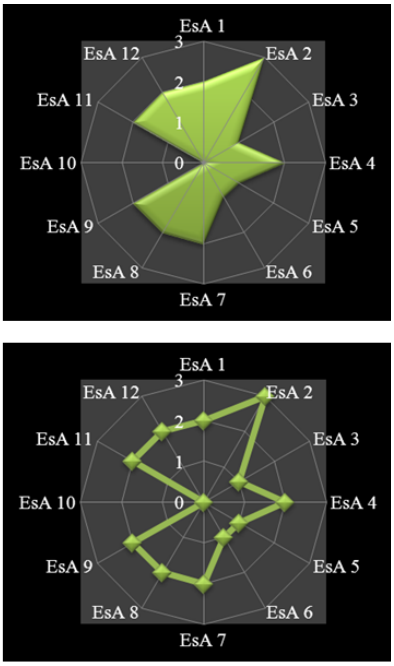


Figure 6.1 THESAURUS – summary of evaluation against Convention on Biological Diversity (CBD) ecosystems approach principles

Note: The Figure summarises the evaluation of THESAURUS against the CBD ecosystems approach principles. The detailed evaluation is provided at Appendix 7. The evaluation assesses each principle in turn in terms of whether the case study has considered the principle **fully** (a score of **3** on the radar diagram), **to a degree** (a score of **2** on the radar diagram) or **not** at all (a score of **1** on the radar diagram). Uncertain assessments are indicated by a score of 0 on the radar diagram (e.g. where consideration of the principle is implicit but not evidenced clearly within the materials reviewed). EsA1 – 6 relate to *management of natural systems* principles against which THESAURUS has a mixed score. THESAURUS' performance against EsA7 and 8, which relate to *ecosystem service* principles is consistent. EsA9 – 12 relate to *involving people* principles against which THESAURUS scores consistently.

Conversely, THESAURUS has **not** considered *management of natural systems* principles on environmental limits (EsA3), setting long term objectives for ecosystem management (EsA5) and recognition that ecosystem change is inevitable (EsA6). In effect, there is no implicit or explicit discussion of these principles in the material reviewed. As a proof of concept study however, THESAURUS was more concerned with trialling and evaluating methodologies as opposed to using these methodologies to develop objectives and deliver land use/management on the ground. In this regard, EsA5 and 6 are perhaps less relevant though EsA3 on environmental limits is critical.

In terms of the *ecosystem service* principles (see Table 3.8), the THESAURUS approach has considered both principles **to a degree** (see Appendix 7). In relation to EsA7 – understand/manage ecosystem in an economic context – the approach recognises the context specific nature of ecosystem service values (either monetary or nominal) and how context in this regard can include costs associated with land management to ensure a given level of service. In relation to EsA8 – appropriate balance between conservation and use of biodiversity – the approach includes specific consideration of biodiversity (and other important elements of biodiversity including habitats and ecological networks) though there is no specific mechanism for balancing the protection of biodiversity with its use.

The THESAURUS approach is relatively consistent across the *involving people* principles (see Table 3.8). In particular, the approach includes a broad definition of stakeholders that the practitioner may wish to engage in the methodology, including in the development of objectives for ecosystem management (EsA9). Furthermore, it is suggested that specific technical steps in the approach (e.g. the weighting of criteria used in the GIS based mapping of proxy ecosystem services) are opened up to a range of stakeholders, supporting the notion that all forms of relevant information should be considered in the planning and delivery of ecosystem management (EsA11). THESAURUS was a research project designed to test the use of the ecosystem services concept within existing land use planning frameworks. As such, the practical application of the approach in terms of informing land management decision-making on the ground was not tested. Accordingly it has not been possible to evaluate the degree to which THESAURUS might be able to support decentralised ecosystem management at the lowest appropriate level, hence why EsA10 is marked as uncertain on Figure 6.1.

6.1.2 The THESAURUS approach – key innovations

The approach adopted in THESAURUS draws heavily on a related Defra Natural Environment Policy Research Programme project that sought to establish and agree what an ecosystems approach might involve in practice as well as the case for adopting the approach in the management of England's terrestrial ecosystems (Haines-Young and Potschin, 2008). As part of an ecosystems approach, Haines-Young and Potschin (ibid) explored three different approaches to assessing ecosystem services: 1) a habitats perspective that would approach the assessment of ecosystem services via consideration of discrete ecological units (i.e. habitats) and the 'bundles' of services that they provide; 2) a services perspective that would assess the services provided by the habitats as opposed to the habitats themselves; and 3) a place-based perspective that seeks to take an integrated view of the habitats, ecosystem services and their interrelationships within a defined area.

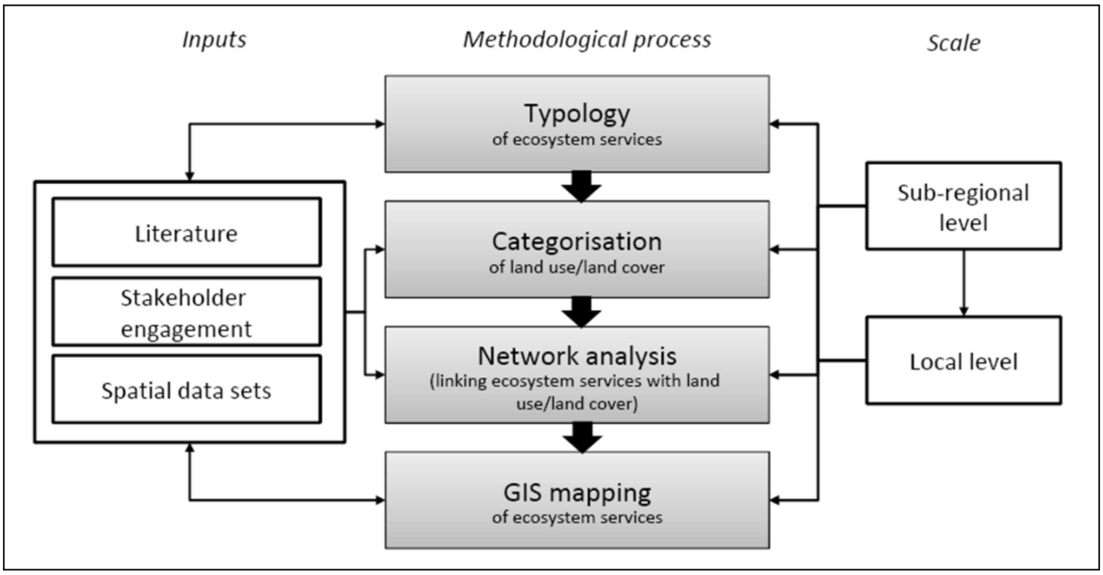


Figure 6.2 THESAURUS – overview of methodological approach

(Source: Sheate et al, 2012)

In effect, THESAURUS has adopted the latter of the three approaches in the assessment of ecosystem services i.e. a place-based approach. Crucially, THESAURUS recognised that the approach adopted must be tailored to the specific decision-making context. In THESAURUS' case therefore, the context is urban/peri-urban land use planning at sub-regional and local scales and it was important to "express the ecosystem services identified in a language and context familiar to planners" (Sheate et al, 2012 p.8). In this regard, a habitats-based approach was considered to be inappropriate primarily as habitats, as a unit of analysis, were felt to be unfamiliar to planners (Sheate et al, 2012). Furthermore, it was felt that the granularity of the available habitats data (e.g. Phase 1 habitats survey[69] data) would not adequately reflect the heterogonous nature of the urban natural environment within the study area (ibid).

The case study area addressed by THESAURUS was Kent Thameside, purportedly the largest brownfield site regeneration project in Europe at the time (Kent Thameside, 2010; Sheate et al, 2012). In line with the area's strategic importance, a green infrastructure strategy had been prepared for Kent Thameside referred to as the 'green grid' (Kent Thameside, 2006). In conjunction with Planning Policy Guidance Note 17 – the then planning policy on openspace, sport and recreation – it was felt that the Kent Thameside Green Grid (KTGG) could provide a "geospatial dataset that encompassed a classification system that was available and familiar to land use and openspace planners" (Sheate et al, 2012 p.11). In this regard, the natural environment type land uses defined within PPG17 and the KTGG (which are similar to those defined in PAN65 – see Table 3.4) then became the unit of analysis for ecosystem service assessment within the overall framing of a place-based approach. Crucially, the land use categories within these two documents would have been familiar to planners in the three planning authorities within the study area. A similar approach to characterisation of the urban natural environment has been adopted in this research (see section 3.1.3 and Chapters 7 and 8).

In adopting a place-based approach, THESAURUS developed some useful methodological innovations that have wider relevance for other urban land use planning contexts, particularly in relation to the *involving people* ecosystems approach principles (see Table 3.8 and Figure 6.1). The overall THESAURUS approach is indicated on Figure 6.2. The approach is premised on the notion that "a typology of ecosystem services can be developed for any location (and at any scale)

---

[69] The Phase 1 habitat classification and associated field survey technique is intended to provide a rapid system to record semi-natural vegetation and other wildlife habitats. JNCC Phase 1 habitat survey handbook pages: http://jncc.defra.gov.uk/page-2468 [accessed 27/01/14]

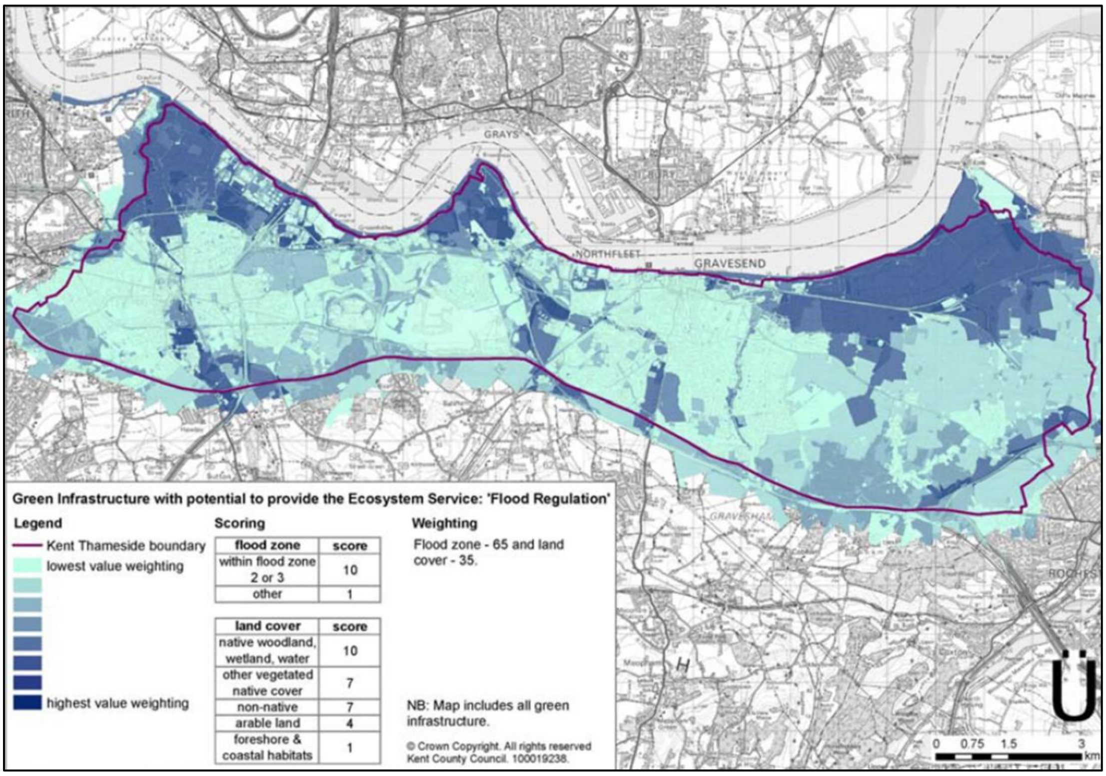
which describes and categorises the ecosystem services provided in that area" (Sheate et al, 2012 p.7). In effect, this recognises that the natural environment in a defined urban location – through its network of greenspace and semi-natural habitats – will be providing a range of ecosystem services. Crucially, THESAURUS' approach to defining the ecosystem service typology draws on several methodological devices (see Figure 6.2): 1) a literature review incorporating literature of wider and more local relevance; 2) stakeholder engagement to validate and refine the literature based typology; and 3) integration of spatial data sets in a GIS to map the spatial representation of proxy ecosystem services (Defra, 2008; Sheate et al, 2012).

The THESAURUS methodological devices mentioned above and shown on Figure 6.2 have the potential to support key CBD ecosystems approach principles. The two tiered approach to literature review for example can support the consideration of all forms of relevant information, including scientific/local knowledge, practice and innovation (EsA11). For example, higher level/more globally relevant literature (e.g. MA, 2005; Mace et al, 2011) can help practitioners to identify a broad/generic ecosystem service typology that can then be refined with consideration of relevant local literature such as existing planning frameworks (e.g. local planning frameworks and masterplans), local biodiversity action plans (LBAPs), evidence in existing consultations and community surveys and literature produced by local interest groups.

Crucially, the stakeholder engagement element provides an important opportunity to validate the literature generated ecosystem service typology. Although THESAURUS adopted a broad definition of stakeholders, the stakeholder engagement element of the project was necessarily quite focussed due to scope and resources, particularly for the sub-regional level/Kent Thameside focussed analysis where the stakeholder engagement was undertaken with technical stakeholders and key agencies only[70] (William Sheate, personal communication, January 29, 2014).

---

[70] THESAURUS also tested the ecosystem service assessment approach at a more local scale in the Ebbsfleet Valley (CEP and Geodata Institute, 2008b). Given the more local nature of this case and the greater accuracy with which the ecosystem service typology could be developed, it was considered appropriate and worthwhile to engage a greater number of stakeholders including affected communities. In this regard, approximately thirty people were engaged as part of a workshop based



Green Infrastructure with potential to provide the Ecosystem Service: 'Flood Regulation'

Legend

Kent Thameside boundary
lowest value weighting
highest value weighting

Scoring

flood zone	score
within flood zone 2 or 3	10
other	1

land cover	score
native woodland, wetland, water	10
other vegetated native cover	7
non-native	7
arable land	4
foreshore & coastal habitats	1

Weighting

Flood zone - 65 and land cover - 35.

NB: Map includes all green infrastructure.

© Crown Copyright. All rights reserved Kent County Council. 100019238.

Figure 6.3 THESAURUS – flood regulation/storage ecosystem service map

(Source: CEP and Geodata Institute, 2008a)

Note: The Figure shows an example ecosystem service map from the THESAURUS project for flood regulation/storage i.e. the ability of the land to store flood water and potentially help to reduce flood risk elsewhere (e.g. central London in the event of a tidal surge). The ecosystem service values shown are nominal – the darker blue the area of land, the greater the value of the flood regulation/storage ecosystem service. The criteria (i.e. causal variables) and scoring used for estimating proxy ecosystem services are shown on the key. These are: 1) adjacency to flood zone; and 2) the water storage capacity of the land use e.g. native woodland and wetland are considered to have a higher storage capacity than arable land.

Following the literature and stakeholder based identification of the ecosystem service typology, THESAURUS also sought to visually represent these services using GIS software (ArcGIS) "so that planners could see which areas were likely to provide which services" (Sheate et al, 2012 p.15). Such an approach can provide a useful visual depiction of the benefits and potential multifunctionality of the existing KTGG as well as offering an insight into how this might change in light of proposed land use change (e.g. the loss or modification of KTGG elements following development). In this regard, ecosystem service maps can be used to steer land use

---

approach to identifying the key uses of the natural environment in the case study area (William Sheate, personal communication, January 29, 2014) planning towards more sustainable decisions e.g. identifying multifunctional elements of the natural environment providing several ecosystem services that should be protected (CEP and Geodata Institute, 2008a; Sheate et al, 2012). An example ecosystem service map from THESAURUS is shown at Figure 6.3. In effect, this thesis thesis has taken the opposite approach – i.e. using spatial models to identify where multiple ecosystem services may be required, rather than where they are already being supplied (see section 8.20.

Table 6.1 THESAURUS – causal variables and data sources for key ecosystem services

(Source: CEP and Geodata Institute, 2008a)

Ecosystem service	**Causal variable/factor affecting service provision**	**Data requirements** (GIS data or data that can be linked to GIS from other models)
Erosion regulation	Soil type	National soils database
	Vegetation cover/cropping patterns	NDVI[71], Landsat data, agricultural census
	Sediment release	PSYCHIC model[72]
	Relief	Topography data
Water and flood regulation	Adjacency to flood zone	Environment Agency or SEPA flood extent data
	Water storage capacity of land use	Habitats data/land cover data
Recreational spaces – active and passive recreation	Adjacency to population	Census data
	Area of site	Greenspace size

Note: Based on key findings from the THESAURUS project, the table above indicates key causal variables that can affect the supply of three example ecosystem services as well as GIS data (or data from other models that can be linked to GIS) that can be integrated with land use/cover data to produce a more refined proxy ecosystem service map. For example, the erosion regulation services provided by an area of land will be affected by soil type, vegetation cover and relief/slope.

Eigenbrod et al (2010) describe two broad approaches for producing ecosystem service maps: 1) methods that incorporate the use of at least some primary data from within the study region; and 2) methods that do not use any primary data – i.e. maps that are based purely on proxies. In their comparative study, Eigenbrod et al (ibid) identified significant variation between ecosystem service maps produced with

---

[71] Normalised Difference Vegetation Index (NDVI) maps are derived from remote sensing data. Maps provide an overview of the status and dynamics of vegetation, providing a measure of the amount of live vegetation cover: Australian Government Bureau of Meteorology (2014) NDVI information http://www.bom.gov.au/climate/austmaps/about-ndvi-maps.shtml [accessed 30/01/14]

[72] PSYCHIC is a process based model of phosphorous and suspended sediment mobilisation in land runoff and subsequent delivery to watercourses: Davison et al (2008) http://www.sciencedirect.com/science/article/pii/S0022169407006233 [accessed 30/01/14]

primary data and those using proxies alone, concluding that proxy maps are likely to provide poor estimates of the actual distribution of ecosystem services. Despite this, proxy based approaches can provide a useful estimate where primary data is lacking (ibid). It is also possible to refine a land cover based proxy approach (i.e. where the mapping of ecosystem services draws on land cover data alone) by integrating the land cover dataset with additional data based on an understanding of causal relationships between ecosystem services and the contextual factors that influence their value/importance. For example, flood storage and recreation services are more valuable in proximity to urban centres i.e. where large numbers of people live (Chan et al, 2006; Eigenbrod et al, 2010). It follows therefore that integrating data on population density can refine a basic land cover proxy layer (ibid).

In essence, THESAURUS adopts this approach whereby proxy ecosystem services are mapped based on a logical combination of likely causal variables. The KTGG land use typology was used as the unit of analysis in this regard with a map of different categories of KTGG type land uses for the area developed using Ordnance Survey MasterMap[73] (OSMM) as a framework for the mapping (Sheate et al, 2012). The particular methodological innovation of interest however was the identification of sample causal variables that can influence ecosystem service provision and the linking of these variables to specific spatial data sets. Crucially, this was identified for the full range of supporting, regulating, provisioning and cultural services identified through the literature and stakeholder processes (see Figure 6.2). In this regard, THESAURUS represents a potentially significant refinement of proxy based ecosystem service mapping methodologies and key aspects of the approach have been adopted in the new tools and models developed through this research (see Tables 2.9 and 7.1 and Chapter 7). Example services, causal variables and data sources from THESAURUS are shown at Table 6.1. A summary of THESAURUS' key methodological innovations is listed below.

---

[73] OS MasterMap is the Ordnance Survey's most comprehensive product. OSMM products pages: http://www.ordnancesurvey.co.uk/business-and-government/products/mastermap-products.html [accessed 30/01/14]

- Effective use of a place-based approach, as an overall framing, in order to define an ecosystem service typology for a given area
- Use of literature review to identify ecosystem services provided within the study area including:
    - Higher level literature of more global relevance (e.g. MA, 2005 and Mace et al, 2011)
    - Local literature of more direct relevant to the study area
- Use of stakeholder engagement to refine and validate proposed ecosystem service typology (i.e. based on literature alone)
- Identification of causal variables and data sources for the full range of ecosystem services within the typology to produce refined proxy ecosystem service maps

The tools and models developed in this research have adopted aspects of THESAURUS' methodological innovations. In particular, the GIS based approach to ecosystem services assessment, especially the use of causal variables to refine proxy assessments and the integration of external qualitative data with spatial datasets, has been used extensively (see Tables 2.9 and 7.1, Chapter 7 and Appendices 8, 9 and 10). The literature review ecosystem service typology and stakeholder engagement aspects (see Figure 6.2) are key methods/approaches that can support the translation of ecosystems approach principles in urban land use/management however they have not been considered in the new approaches developed through this research.

6.2 EERA environmental limits mapping project

Regional Spatial Strategies (RSS) provided regional level planning frameworks for the eight English regions until they were revoked in 2010 as part the new Conservative/Liberal Democrat coalition government's localism agenda (DCLG, 2010). At the examination of the draft East of England RSS, concern was expressed that the scale and location of proposed growth could exceed the environmental capacity of the region, with a risk that environmental limits could be exceeded (EERA, 2008). In response to these concerns, the East of England Regional Assembly (EERA), a body that no longer exists, commissioned a study to develop a new method that could inform spatial planning at regional and sub-regional scales by taking better account of environmental limits (ibid). The study was undertaken by Land Use Consultants[74] (LUC) with inputs from Cranfield University. Key details of the approach adopted in the EERA environmental limits project are described at section 6.2.1. A summary of the evaluation of EERA against the CBD ecosystems approach principles (see Tables 2.3 and 3.8) is shown on Figure 6.4.

6.2.1 Evaluation of the EERA approach

The CBD ecosystems approach principles have been grouped on the basis of the broader Scottish Government (2011c) categorisation (see Table 3.8). In terms of the *management of natural systems* principles, the EERA approach scores consistently fairly well. The approach has considered effects on adjacent ecosystems (EsA1), the conservation of ecosystem structure and function (EsA2) and the setting of long term objectives for ecosystem management (EsA5) **to a degree**. Given the nature of the project it is unsurprising that environmental limits (EsA3) have been considered **fully** (though there are issues with the approach adopted – see sections 6.2.2 and 6.4.1) as has the need to consider the ecosystems approach at appropriate spatial and temporal scales (EsA4). Similarly to THESAURUS (see section 6.1.1), there is no explicit or implicit consideration of the fact that some degree of ecosystem change will be inevitable (EsA 6). See Appendix 7 for further details.

The consideration of environmental limits is approached using environmental state indicators (see section 3.2.1) using readily available environmental data and a two phase model of: 1) within environmental limit; or 2) environmental limit exceeded. The comprehensive consideration of EsA4 relates specifically to the appropriate use of spatial scale (i.e. the approach is designed to inform spatial planning at regional and sub-regional scales, both of which will encompass key natural features such as strategic ecological networks and water catchments) as well as temporal scales. Temporal scale is considered through the assessment of pressures and trends affecting the environmental indicators. In this regard, the assessment can “suggest the likely evolution of the current state of the environment” (EERA, 2008

---

[74] LUC is a UK based environmental planning, design and management consultancy: http://www.landuse.co.uk/ [accessed 01/02/14]

p.37). EERA's approach to mapping environmental limits adopts an environmental topic/issues based approach i.e. environmental state indicators are identified for discrete environmental issues such as water quality, air quality, landscape etc. Whilst this is a useful and practical approach (i.e. the literature identifies environmental state indicators as one approach to defining environmental limits – see section 3.2.1), it does not recognise the integrated nature of ecosystems and ecosystem services including key aspects of ecosystem function as per EsA2. Further details are provided in Appendix 7. The new spatial models developed in this research use ecosystem services type indicators to help address this issue through the consideration of multiple spatial datasets (see Chapter 7).

In terms of the *ecosystem service* principles (see Table 3.8), the EERA approach considers the need to manage ecosystems in an economic context (EsA7) **to a degree** whilst the balancing of conservation and use of biodiversity (EsA8) has **not** been considered (see Appendix 7 also). This latter issue may be particularly significant as there is an emphasis within the EERA approach on the transferability of ecosystem services including reference to "opportunities to import, recreate or substitute the services [provided by the study area]" (EERA, 2008 p.20). As discussed at section 3.2.1 and 3.2.2, a key premise of the ecosystem services concept is the notion that the interactions between an ecosystem's living and non-living components are what determine the "quantity, quality and reliability of ecosystem services" (Mace et al, 2011 p.5). In this regard, the maintenance of biodiversity and other key ecosystem processes/intermediate services (see Figure 3.8) is essential for ecosystem function and ecosystem services. As such, EERA's poor consideration of EsA8, its topic based approach to environmental limits mapping and its focus on the potential transferability of ecosystem services could work against commonly held tenets of ecosystem services and the ecosystems approach in relation to biodiversity and ecosystem function issues. The new models and guidance developed in tis research incorporate specific consideration of biodiversity to address this sort of issue (see section 7.4 and Appendix 6).

Radar Diagram Code	Ecosystem approach principle	Theme
EsA 1	Consider effects on adjacent ecosystems	*Management of natural systems*
EsA 2	Conserve ecosystem structure and function	
EsA 3	Ecosystem management must respect environmental limits	
EsA 4	Adopt the ecosystems approach at appropriate spatial and temporal scale	
EsA 5	Set long term objectives for ecosystem management	
EsA 6	Ecosystem management must recognise that change is inevitable	
EsA 7	Understand and manage the ecosystem in an economic context	*Ecosystem services*
EsA 8	Ensure an appropriate balance between conservation and use of biodiversity	
EsA 9	Objectives for ecosystem management are a matter of societal choice	*Involving people*
EsA 10	Ecosystem management should be decentralised to the lowest appropriate level	
EsA 11	Consider all forms of relevant information including scientific/local knowledge, practice and innovation	
EsA 12	Involve all relevant sectors of society and scientific disciplines	

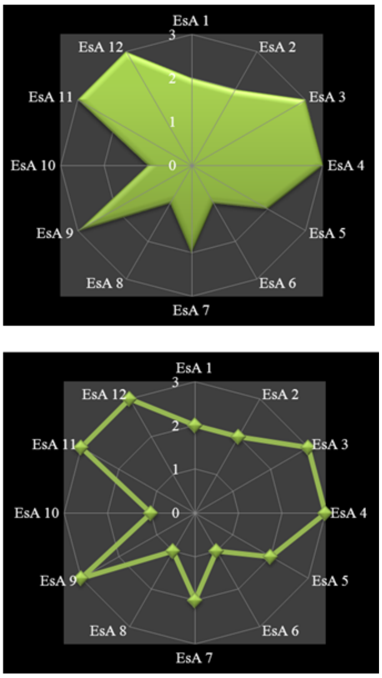


Figure 6.4 EERA – summary of evaluation against Convention on Biological Diversity (CBD) ecosystems approach principles

Note: The Figure summarises the evaluation of EERA against the CBD ecosystems approach principles. The detailed evaluation is provided at Appendix 7. The evaluation assesses each principle in turn in terms of whether the case study has considered the principle **fully** (a score of **3** on the radar diagram), **to a degree** (a score of **2** on the radar diagram) or **not** at all (a score of **1** on the radar diagram). EsA1 – 6 relate to *management of natural systems* principles which EERA scores consistently fairly well against. EERA's performance against EsA7 and 8, which relate to *ecosystem service* principles, is more mixed. EsA9 – 12 relate to *involving people* principles which EERA scores consistently well against with the exception of EsA10.

EERA scores consistently well across the *involving people* principles (see Table 3.8) with all principles except for EsA10 on decentralised ecosystem management considered **fully** (see Appendix 7). In particular, the EERA approach recognises that there are two ways in which environmental limits can be determined (see section 3.2.1) i.e. scientifically based on biophysical thresholds or socially based on societal preferences. In line with this distinction, EERA (2008 p.12) highlights how "environmental limits need to be predetermined and supported by stakeholders". Given resource constraints for the research project, only technical stakeholders were engaged in the determination of environmental limits though if the approach was to be adopted wholesale in RSS planning, the study recommended that the wider public should be engaged, supporting wider consideration of the *involving people* principles.

6.2.2 The EERA approach – key innovations

In line with the findings of the evaluation against ecosystems approach principles (see section 6.2.1), the EERA project has developed a number of key methodological innovations that have wider relevance for other urban (and rural) land use planning contexts. Unlike the THESAURUS case study (see section 6.1) however, EERA's innovations may be more generally applicable. This is borne out on the radar diagrams illustrated at Figure 6.4 which are 'fuller' and more consistent than the THEASURUS diagrams at Figure 6.1. In effect, EERA's methodological innovations arguably have the potential to support the consideration and integration of most of the ecosystems approach principles.

For example, the EERA approach has been designed to add value to existing land use/environmental planning tools, namely strategic environmental assessment (SEA). In particular, the EERA approach can refine assessment processes in SEA by helping to determine the significance of environmental effects. By linking environmental limits/ecosystem services with different pressures (e.g. climate change, land take and population growth) the EERA approach "enables more spatially specific conclusions to be drawn about where within the plan area [significant environmental effects are likely to occur, taking cognisance of environmental limits, and therefore where] environmental mitigation may be required, and for which environmental topics or services" (EERA, 2008 p.14). The focus on integration with SEA may also support consideration of the *involving people* principles (see Table 3.8) as SEA imposes a statutory requirement for public consultation. In this regard, EERA (ibid) highlight how the "process for defining environmental limits takes account not just of scientific knowledge but also local perceptions of the relative value of environmental features or benefits". In essence, the SEA and environmental limits mapping are mutually supportive – the former provides a public engagement platform for the latter whilst the latter adds robustness to environmental assessment and mitigation in the former.

EERA has also developed a workable (though imperfect – see text below and section 6.4.3) methodology for mapping environmental limits for a number of environmental issues/topics. This includes defining environmental limit indicators, identifying suitable spatial datasets and determining environmental limits for each issue/topic considered (with input from key stakeholders). Although the evaluation has identified key weaknesses with this approach (e.g. it was not possible to identify indicators, data or limits for every environmental issue/topic considered), EERA does provide *an* approach for mapping environmental limits for discrete issues/topics (see Figure 6.5) as well as integrating individual maps to produce a composite map (see Figure 6.6). In essence, the composite map can be regarded as an outline spatial strategy for the study area, highlighting broad spatial locations where environmental capacity is likely to be supportive of development/land use change and where it is not (see Figure 6.6).

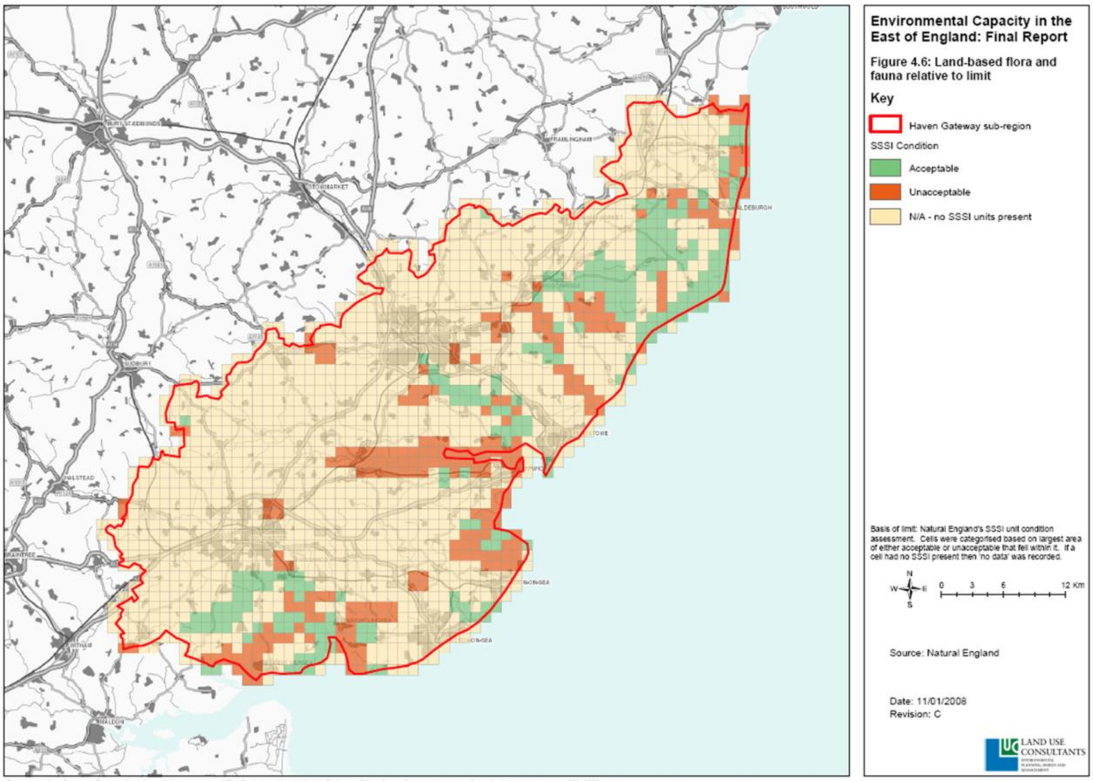


Figure 6.5 EERA environmental capacity project – land based flora and fauna environmental limits map

(Source: EERA, 2008)

Note: The Figure shows the distribution of aggregated 1km x 1km cells where the status of land based flora and fauna is considered to be acceptable or unacceptable with respect to the environmental limit defined through the EERA project. The environmental state indicator used for this specific environmental limit is Site of Special Scientific Interest (SSSI) unit condition. As such, this indicator does not provide a surface for the whole study area as only certain parts of the study area are designated as SSSIs, hence why the map above includes an additional classification for many of the grid squares of "N/A – no SSSI unit present" (i.e. pale yellow cells).

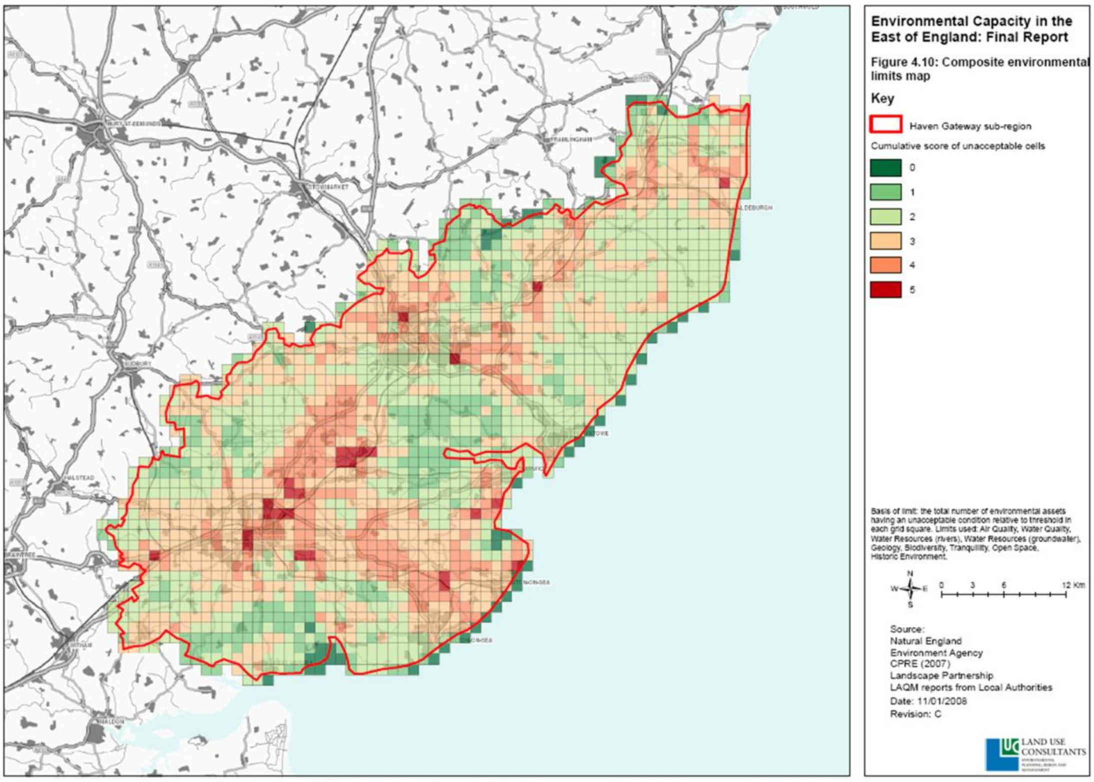

Environmental Capacity in the East of England: Final Report

Figure 4.10: Composite environmental limits map

Basis of limit: the total number of environmental assets having an unacceptable condition relative to threshold in each grid square. Limits used: Air Quality, Water Quality, Water Resources (rivers), Water Resources (groundwater), Geology, Biodiversity, Tranquillity, Open Space, Historic Environment.

Source:
Natural England
Environment Agency
CPRE (2007)
Landscape Partnership
LAQM reports from Local Authorities
Date: 11/01/2008
Revision: C

Figure 6.6 EERA environmental capacity project – composite environmental limits map

(Source: EERA, 2008)

Note: The map above is an overlay of all individual environmental limits maps produced in the EERA project (nine in total). Because all spatial datasets were converted to a 1km x 1km grid, all the layers are compatible and can be overlayed in the GIS to identify cells where more than one environmental limit has been breached. Using simple map algebra, the cumulative score of unacceptable cells can be calculated for each cell. The higher the cumulative score of unacceptable cells (i.e. red coloured cells on the map above), the lower the environmental capacity and *vice versa*.

Whilst there are strengths to the EERA approach, the weaknesses are significant and need to be considered in the future development of ecosystems approach based land use planning methods. A key issue is the highly simplistic nature of the EERA approach. The mapped outputs are 1km x 1km cells that are deemed to be either *acceptable* or *unacceptable* in terms of environmental limits. As shown on the composite map at Figure 6.6, this approach identifies broad areas where the cumulative score of unacceptable cells is high (dark red areas) and low (dark green areas). In simple terms therefore, dark green areas can be construed as having more environmental capacity than dark red areas and therefore may offer more suitable locations for development (i.e. locations with ‘spare’ environmental capacity). As EERA's approach to defining environmental limits focusses on environmental state indicators as opposed to ecosystem service indicators (see section 3.2.1), all of the areas with high cumulative unacceptability scores are clustered around the study area's main urban centres (as this is where cumulative pressure on the natural environment is greatest and therefore where it is most degraded).

Taken in isolation therefore, there is a risk that the composite map might be interpreted in such a way that it steers development away from urban centres towards more rural areas where environmental quality (and ecosystem service provision) is higher. For example, the composite map (see Figure 6.6) suggests that there is a high degree of environmental capacity along the coastal fringe (i.e. the strip of dark green cells) though the natural environment in this area will likely be providing vital ecosystem services that are unlikely to be substitutable (e.g. flood storage, protection against storm surges etc) that should therefore be protected and enhanced. Considering ecosystem services instead of environmental state indicators could help to draw attention to the need for enhanced ecosystem services in urban areas (i.e. to address environmental quality issues) and the protection of high value ecosystem services in more rural areas. In this regard, it could be more appropriate to pursue a spatial strategy of small scale sustainable development in rural areas combined with a development focus in urban centres incorporating environmental improvement projects to enhance urban ecosystem services. A summary of the EERA's key methodological innovations is listed below:

- Adding value to existing environmental and land use planning tools/approaches (SEA)
- Identifying indicators, datasets, limit values and the procedures and methods required to map environmental limits for several discrete environmental topics/issues
- Characterisation of ecosystem services provided by discrete environmental issues/topics (e.g. services provided by water, air, landscape, biodiversity etc)

- Linking environmental limits/ecosystem services with pressures and potential land use planning responses that can be used to mitigate pressures

The tools and models developed in this research have not adopted any aspects of the EERA approach. The research has, however, paid close attention to the key weaknesses of the EERA approach, especially in relation to the use of environmental limit composite maps informing spatial planning (see Figure 6.6). In particular, the consideration of environmental limits in the new tools and models developed in this research uses ecosystem service indicators as opposed to environmental/ecosystem state indicators to help planners think spatially about where land use/management change may be required to enhance ecosystem services and restore degraded ecosystems (see Chapters 7 and 8 and Appendices 8, 9 and 10).

6.3 Glasgow and Clyde Valley (GCV) green network opportunities mapping

The Glasgow and Clyde Valley (GCV) Green Network Partnership[75] is a collaboration between the eight local authorities in the GCV Strategic Development Plan[76] region (see section 3.1.1) as well as other key planning, land use, natural environment and health stakeholders including SNH, FCS, SEPA, Scottish Enterprise and Glasgow Centre for Population Health (GCPH). The overall aim of the partnership is to "make the Glasgow metropolitan region one of Europe's most attractive places to live work and play through the creation of a large functional green network" (GCV Green Network Partnership, 2013a).

The green network is defined as a "network of high quality connected green and open space which delivers a range of multiple benefits […] it is designed and maintained to deliver these benefits into the future" (GCV Green Network Partnership, 2011 p.3). The Partnership (ibid) defines a range of green network components (see Table 6.2), based on landscape ecology theory (see Chapter 5), that comprise any number of types of green and open space as defined in PAN65 (see section 3.1.3 and Table 3.4). The networked nature of the concept relates to the

---

[75] GCV Green Network Partnership homepage: http://www.gcvgreennetwork.gov.uk/ [accessed 03/02/14]

[76] GCV Strategic Development Planning Authority homepage: http://www.gcvsdpa.gov.uk/ [accessed 03/02/14]

notion of green and openspace sites that are linked by paths (for walking and cycling) and other blue/green corridors including natural and manmade watercourses and habitat networks (see Chapter 5). In this regard, there are strong links between the green network concept and the framing of the urban natural environment as per this thesis i.e. 'green' and 'natural' environment type urban land uses forming a network of greenspaces and semi-natural habitats that provide ecosystem services (see sections 3.1.3 and 3.2.1). For example, the GCV Green Network Partnership talk about *green network **benefits*** which, in effect, can be considered synonymous with *urban ecosystem services*.

Table 6.2 Glasgow and Clyde Valley (GCV) green network components

(Adapted from GCV Green Network Partnership, 2011)

Green network component	**Description**
Green network cores/hubs	Large areas of existing or new greenspace which already deliver a wide range of green network benefits. The aim should be to protect and expand these areas, to create new cores/hubs, create visual connections and, critically, to develop corridors to link them
Green network corridors/links	Continuous corridors of greenspace along rivers, disused railways, paths and cycleways and existing railways and roads which serve to connect Green Network Cores/Hubs. Many of these corridors are incomplete, or provide a limited number of functions, so a key aim is to increase the number, continuity, visual interaction and functionality of these corridors
Green network stepping stones	It may not always be necessary or appropriate to create a continuous corridor of greenspace. Many plant and animal species, for example, are able to move short distances between areas of habitat. Historically suburbs had regular public and private squares set amongst densely developed terraces. The development of Green Network Stepping Stones can provide incomplete corridors linking larger areas of greenspace. This could include the planting of street trees, improved roadside verges or garden improvement.
Isolated greenspaces	It is likely that there will always be some isolated greenspaces which are difficult to connect to the wider Green Network. While the functions of such spaces are likely to be more limited, they still have potential to provide considerable benefits to local communities

The GCV Green Network Partnership have developed a GIS based methodology for identifying and mapping spatial green network opportunities (GCV Green Network Partnership, 2011). The approach was originally developed for use as part of the process of developing the GCV Strategic Development Plan (SDP), within which "there was a desire for a spatial representation of the opportunities for delivery of the green network through the planning system" (GCV Strategic Development Planning Authority, 2011 p.7). The approach uses a range of green network related spatial datasets, integrated in a GIS, to identify strategic priority locations for targeting green network delivery through the planning system (e.g. within SDP and LDP policy and Development Management – see section 3.1.1). As per the above, the definition of green network is such that it can be considered synonymous with the 'green' and 'natural environment' type urban land uses considered in this research – i.e. both definitions adopt the PAN65 land use typology as per Table 3.4. Also, green network benefits or functions are, in essence, ecosystem services e.g. attractive locations/environmental settings, recreation, various aspects of climate change adaptation, ecological networks etc (GCV Green Network Partnership, 2011). In this regard, the green network opportunities mapping approach is, in essence, a land use planning tool that adopts key principles of the ecosystems approach. Further details of the green network opportunities mapping approach are described at section 6.3.1. A summary of the evaluation of the approach against the CBD ecosystems approach principles (see Tables 2.3 and 3.8) is shown on Figure 6.7.

6.3.1 Evaluation of the green network opportunities mapping approach

The CBD ecosystems approach principles have been grouped on the basis of the broader Scottish Government (2011c) categorisation (see Table 3.8). In terms of the *management of natural systems* principles, the green network opportunities approach has a mixed performance (see Figure 6.7). The approach has considered effects on adjacent ecosystems (EsA1), the conservation of ecosystem structure and function (EsA2) and the setting of long term objectives for ecosystem management (EsA 5) **to a degree** (see Appendix 7). In terms of EsA2 for example, the focus of the green network approach is very much on conservation management and ecological connectivity – i.e. improving the condition of existing habitat and then developing new habitat mosaics to join up fragmented habitats and improve overall connectivity. The consideration of long term objectives (EsA5) is implicit through the approach's focus on integration of outputs with the LDP process. LDPs within the city regions encompassed by SDPs (see section 3.1.1) are required to plan for a ten year horizon which arguably offers an appropriate timeframe for the delivery of ecosystem scale restoration/improvement projects (this is applicable to the new approaches developed in this research – see section 8.3). The approach has also **fully** considered the need to plan at appropriate spatial and temporal scales (EsA4), mainly as the tool is designed for implementation at the local authority spatial scale and to inform planning across ten year timeframes (see EsA5 also). Conversely, environmental limits (EsA3) and recognition that change is inevitable (EsA6) have **not** been considered at all. Poor consideration of EsA3 is a particular concern given that the approach is designed to input to the LDP process (i.e. there may be scope to inform the scale, location and type of development).

Radar Diagram Code	Ecosystem approach principle	Theme
EsA 1	Consider effects on adjacent ecosystems	*Management of natural systems*
EsA 2	Conserve ecosystem structure and function	
EsA 3	Ecosystem management must respect environmental limits	
EsA 4	Adopt the ecosystems approach at appropriate spatial and temporal scale	
EsA 5	Set long term objectives for ecosystem management	
EsA 6	Ecosystem management must recognise that change is inevitable	
EsA 7	Understand and manage the ecosystem in an economic context	*Ecosystem services*
EsA 8	Ensure an appropriate balance between conservation and use of biodiversity	
EsA 9	Objectives for ecosystem management are a matter of societal choice	*Involving people*
EsA 10	Ecosystem management should be decentralised to the lowest appropriate level	
EsA 11	Consider all forms of relevant information including scientific/local knowledge, practice and innovation	
EsA 12	Involve all relevant sectors of society and scientific disciplines	

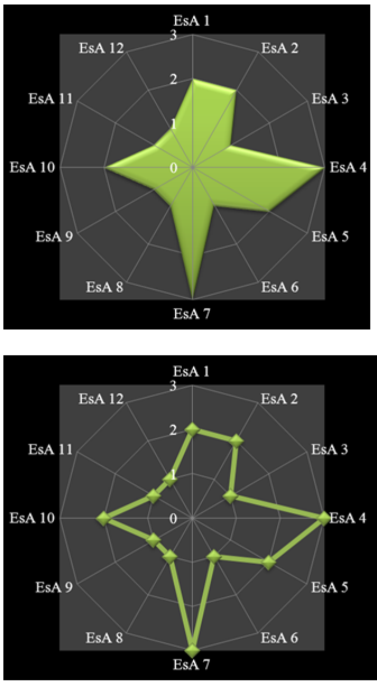


Figure 6.7 Green network opportunities – summary of evaluation against Convention on Biological Diversity (CBD) ecosystems approach principles

Note: The figure summarises the evaluation of GNOM against the CBD ecosystems approach principles. The detailed evaluation is provided at Appendix 7. The evaluation assesses each principle in turn in terms of whether the case study has considered the principle **fully** (a score of **3** on the radar diagram), **to a degree** (a score of **2** on the radar diagram) or **not** at all (a score of **1** on the radar diagram). Uncertain assessments are indicated by a score of 0 on the radar diagram. EsA1 – 6 relate to *management of natural systems* principles against which the approach has a mixed score. The green network mapping tool's performance against EsA7 and 8, which relate to *ecosystem service* principles is mixed. EsA9 – 12 relate to *involving people* principles which the green network opportunities mapping approach generally does not consider.

In terms of the *ecosystem service* principles, the green network approach has a mixed performance (see Figure 6.7). On the one hand, the need to understand and manage ecosystems in an economic context is considered **fully** (EsA7) whereas ensuring a balance between the conservation and use of biodiversity (EsA8) is **not** considered. In terms of EsA7, the approach considers spatial datasets on development and regeneration sites and recognises the role of the planning system driving green network (i.e. green and natural environment land use and ecosystem service) enhancement e.g. through planning policy and planning gain etc (see sections 1.5 and 3.1). In essence, there is a very pragmatic approach to the realities of green network/ecosystem service delivery, recognising that effective delivery requires an appropriate mix of regulation (i.e. planning policy) and incentive (i.e. selling the benefits of integrating green network/ecosystem services thinking to developers). In terms of EsA8, the biodiversity/habitat networks parameter within the GIS tool is considered on an equal footing with the other parameters (i.e. development and regeneration sites, access and recreation).

With the exception of EsA10 on decentralising ecosystem management to the lowest appropriate level which has been considered **to a degree**, the green network approach has **not** considered the *involving people* principles (see Appendix 7). The approach is designed to be integrated with the LDP development process with the green network opportunities identified feeding into the MIR, which will involve extensive public and stakeholder consultation (see section 3.1.2). Despite this, the approach itself has no provision for involving people – in essence it is a technical process designed to be executed by GIS technicians/planners without wider input from the public or affected communities. In terms of EsA10 on decentralisation of ecosystem management, there is strong recognition of the economic practicalities of green network and ecosystem services enhancement projects (see EsA7 also in this regard) and the approach accounts for this, to a degree, by promoting the (implicit) decentralisation of management responsibility to developers, landowners and community groups.

6.3.2 The green network opportunities mapping approach – key innovations

Although overall the green network opportunities mapping approach has a mixed performance against the ecosystems approach principles (see Figure 6.7), there are key areas where principles have been considered fully or to a degree. Linking these areas to specific aspects of the methodology can highlight key innovations that may have wider relevance for other urban (and rural) land use planning contexts. The approach has particular strengths against the *management of natural systems* principles, especially principles that are likely to require a degree of spatial analysis or interpretation – i.e. EsA1, 2 and 4. In this regard, the GIS based approach for identifying strategic green network opportunities may be particularly relevant. The fact that the approach has already been used to inform the development and subsequent adoption of statutory planning policy within the GCVSDP[77] adds weight in this regard. Similarly, the way in which the approach is grounded in reality (i.e. it has been designed with practical utility in mind) is another key strength as outlined further below.

Table 6.3 Green network opportunities mapping – spatial queries, layers and datasets

(Adapted from GCV Green Network Partnership, 2011; GCVSDPA, 2011)

Spatial query	Layers	Spatial dataset(s)
What green network resource currently exists and where are the opportunities to improve the resource?	Layer 1 – core paths network and existing PAN65 openspace resource (including quality scores if available)	• Openspace dataset based on PAN65 typology • Openspace audit qualitative assessment • Core paths network
Where are the priority areas to expand the green network? • For biodiversity habitat networks? • For public access to greenspace?	Layer 2 – habitat network priorities Layer 3 – access network priorities	• Integrated habitat network (IHN) priorities modelling • Networks for people priorities modelling[78]
Where are the major areas of	Layer 4 – land use change and	• Flagship Regeneration

---

[77] The green network priorities identified in the GCVSDP using the opportunities mapping approach are also beginning to influence LDPs within the GCV region e.g. the Glasgow LDP (Gillian Dick, personal communication, February 3rd, 2014) and West Dunbartonshire LDP (WDC, 2013).

[78] This GIS dataset was produced for the GCVSDPA by Forest Research: “the dataset provides a spatial representation of peoples’ access to greenspace by analysing those homes which are within 250m of public greenspace. The threshold distance of 250m is measured using network analysis talks – i.e. distance along paths and pavements rather than as the crow flies” (GCVSDPA, 2011 p.9)

Spatial query	Layers	Spatial dataset(s)
land use change and social need?	social need	Areas • Community Growth Areas • Development and regeneration sites • Scottish Index of Multiple Deprivation

Note: The overall approach to the green network opportunities mapping is to answer three spatial queries (left-hand column) based on an analysis of four GIS layers (central column) created through the use of new and existing spatial datasets (right-hand column). Interrogating the individual GIS layers identifies locations where there are **discrete** green network opportunities or priorities (e.g. green network development/enhancement to support a Community Growth Area, to enhance an existing PAN65 site, to improve connectivity of ecological networks etc). By overlaying all four layers, it is then possible to identify locations where **multiple** discrete opportunities/priorities are coincidental. These then become **strategic green network opportunity areas** for consideration in SDPs and LDPs depending on the context. This process is also indicated on Figure 6.8.

The overall emphasis of the approach is on using spatial datasets and GIS to answer key spatial queries about the available green network resource (i.e. green and natural environment type urban land uses) and its functionality (i.e. the ecosystem services provided). This is indicated at Table 6.3 and on Figures 6.8 and 6.9. The technical aspects of the GIS analysis (i.e. converting vector data to raster data and the integration of different raster layers using simple map algebra[79]) and the use of spatial datasets are not novel. However the approach adopted in the weighting of different layers and individual categories within layers may provide a useful structure for similar analyses in other land use planning contexts.

In the existing green network layer for example (see Table 6.3), different categories of PAN65 site are weighted differently according to the perceived opportunity for enhancement or increased functionality (i.e. enhancement of ecosystem services) and therefore delivery of the green network (GCV Green Network Partnership, 2011; GCVSDPA, 2011). For example, public parks and gardens and natural/semi-natural greenspace are considered to offer more potential for enhanced functionality than school grounds and civic space (see Table 3.4) and are weighted more heavily to reflect this (ibid). Openspace quality assessments, where available, are used in a similar manner – i.e. the poorest quality sites are regarded as offering more potential for enhanced functionality and are weighted

---

[79] ArcGIS online help introduction to map algebra: http://resources.arcgis.com/en/help/main/10.1/index.html#//00p600000003000000 [accessed 05/02/14]

more heavily in the analysis. The GCV Green Network Partnership (ibid) also suggest that different weightings/sensitivity analysis can be used to explore different outcomes from the mapping (e.g. how might the spatial distribution of green network opportunities change if the openspace layer is weighted to focus on natural/semi-natural greenspace only?).

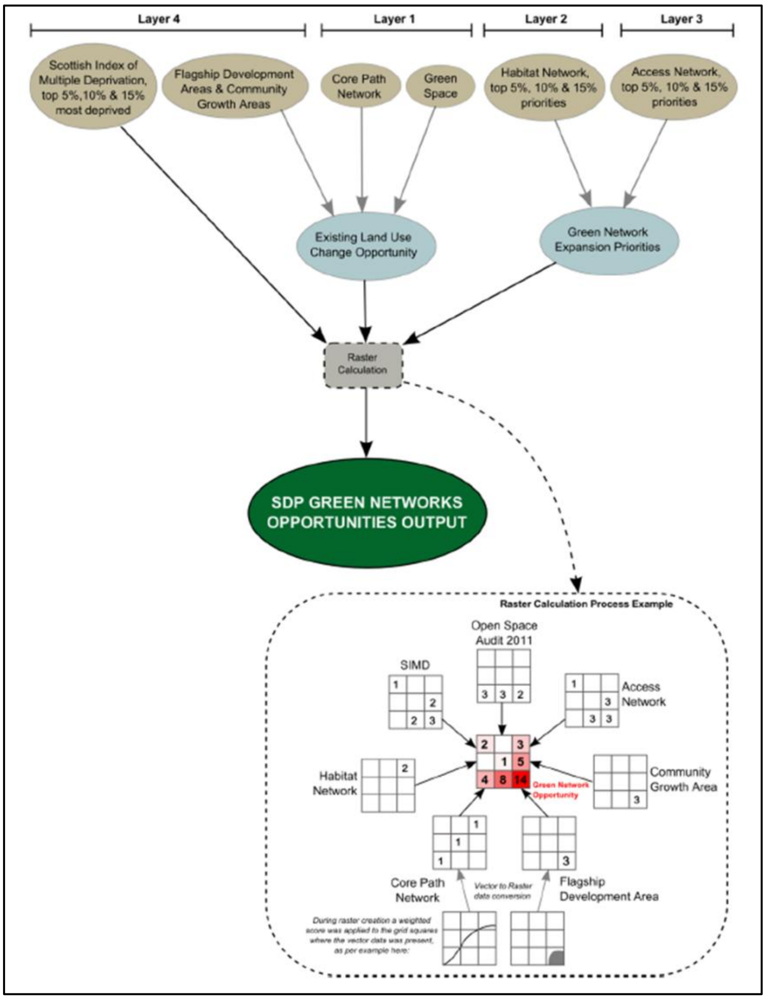


Figure 6.8 Green network opportunities – methodology schematic

(Source: GCVSDPA, 2011)

Note: The Figure depicts the GIS methodology used in the green network opportunities mapping approach. Where required, spatial datasets are converted to raster format to facilitate the integration of different layers using map algebra (i.e. a raster based overlay). As indicated within the box at the bottom of the figure, the different raster layers are then weighted – in effect, this weighting takes account of the **existing** or **potential** ecosystem services provided by the green network (e.g. in the figure above, the importance/value of green network providing, for example, *environmental settings*, *recreation*, *access* etc related ecosystem services within Flagship Development Areas and Community Growth Areas is considered to be high – i.e. these cells are weighted as 3). By integrating the raster layers using map algebra it is then possible to identify which cells are most important/valuable in terms of the green network's existing or potential role providing green network benefits/ecosystem services – the higher the score, the greater the existing or potential importance/value of the green network at this location. Clustering of high value cells then become green network opportunity areas as shown on Figure 6.9.

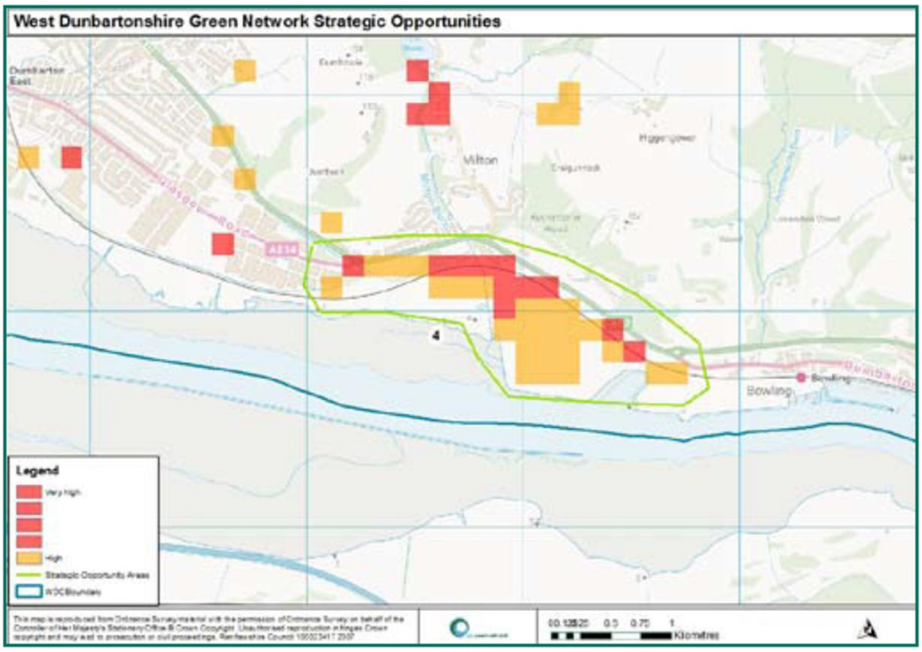


Figure 6.9 Extract from green network opportunities map raster overlay

(Source: GCV Green Network Partnership, 2011)

Note: The Figure shows a raster overlay extract from green network opportunities mapping undertaken by the GCV Green Network Partnership on behalf of West Dunbartonshire Council (WDC). As per Figure 6.8, the raster overlay uses map algebra to calculate a cumulative 'score' for each cell – the higher the score, the greater the **existing** or **potential** importance/value of the green network at this location. This is indicated by dark red cells on the map above. Where clusters of high scoring cells occur (as highlighted within the green line on the figure above), these are regarded as green network opportunity areas due to the number of high scoring cells adjacent to one another. This is in contrast to isolated high scoring cells or smaller clusters of high scoring cells, as shown on the map above to the north and west. A similar approach has been adopted in this research using a concept referred to as multifunctional priority areas or MPAs (see sections 8.2 and 8.3).

As outlined above, the approach integrates individual layers in the GIS using map algebra (i.e. a raster based overlay method). The purpose of this integration, as indicated on Figures 6.8 and 6.9, is to identify locations where the **existing** or **potential** value/importance of the green network is high i.e. locations where green network investment can deliver multiple benefits through enhanced ecosystem services. The nature of the raster based approach in the GIS is that individual cells may score highly in this regard (see Figure 6.8) or there may be clusters of high scoring cells – i.e. locations where multiple high scoring cells are adjacent to one other as shown on Figure 6.9. In essence, these are areas where the existing or potential value/importance of the green network will be particularly high i.e. areas where there is a need for multiple green network benefits/ecosystem services. A similar approach has been adopted in this thesis though using vector based analysis (see section 8.2).

Despite the positives described above, there are also arguably key omissions and weaknesses in the green network opportunities mapping approach. In particular, although consideration of key regulating services is implicit in the approach (e.g. climate change adaptation is listed as a specific function of the green network), the GIS mapping does not include any specific spatial datasets relating to key hazard based climate change adaptation issues e.g. flood risk data or data on slope and vegetation cover as a proxy for soil erosion/landslip risk.

Of the three case study approaches considered in this section, the green network opportunities mapping case has the strongest links to delivery. The THESAURUS and EERA projects are more concerned with researching potential new approaches as opposed to developing tools for immediate use in practical land use/management planning decision-making. Conversely, the green network mapping approach identifies clear delivery mechanisms through the use of planning policy in SDPs and LDPs, integration with masterplans and development proposals as part of an integrated green infrastructure (IGI) approach to development planning and design, effective use of Development Management ensuring that SDP/LDP green network policies are integrated in development and the use of specific green network strategies (GCV Green Network Partnership, 2011; GCV Green Network Partnership, 2013b). In this regard, although there are key weaknesses and omissions with the approach, it is proven and is already informing land use/management decisions and action on the ground in the GCV region through green network policy in the SDP. SDP green network policy is also beginning to exert an influence at the local authority level through LDPs. A summary of GNOM's key methodological innovations is listed below:

- GIS based methodology for identifying green network (ecosystem service) opportunity areas

- Suggested weighting structure for modelling the existing or potential value/importance of green network (ecosystem services) using a raster based approach
- The approach is grounded in reality and has already been used to inform land use policy in the GCV region

The tools and models developed in this research have adopted aspects of GNOM's methodological innovations. In particular, the new spatial models for urban land use/management planning (see Chapters 7 and 8) adopt a demand-led approach – i.e. identifying where land use/management change may be required to deliver new or enhanced ecosystem services – in a similar vein to the GNOM case study. There are key differences though these are more technical than conceptual (i.e. GNOM uses a raster based GIS methodology whereas the new spatial models developed in this research are primarily vector based – see Chapter 7 and section 8.2).

6.4 Synthesis of key findings from the example approaches

In line with Research Objective No.3 (see Box 1.2), sections 6.1 – 6.3 summarised the evaluation of the three example land use planning frameworks that have adopted aspects of the ecosystems approach. This includes a discussion of the particular methodological innovations and strengths that have supported consideration of ecosystems approach principles as well as an outline of potential weaknesses. A more detailed account of the evaluation is provided at Appendix 7. This section draws the evaluation together through a synthesis of key findings based on the three research questions addressed under Research Objective No3.

A visual summary of the evaluation is shown at Tables 6.5. Figures 6.10, 6.11 and 6.12 provide a further illustration of the evaluation results. A 'horizontal' analysis of Table 6.5 (i.e. looking at individual principles) highlights how case study consideration of the suite of twelve ecosystems approach principles is highly variable i.e. some principles have been considered relatively comprehensively whilst for others, consideration has been much less comprehensive. Equally, a 'vertical' analysis of Table 6.5 (i.e. looking at individual example approaches) highlights how consideration of the principles by individual cases is also highly variable (see Figure

6.11 also). Despite this variation it is possible to pull out some key themes, within the bounds of the sample considered, in terms of the research questions addressed under Research Objective No.3. The remainder of this section summarises key findings of the evaluation by research question.

6.4.1 Have the example approaches considered the CDB ecosystems approach principles?

The first research question considered under Research Objective No.3 asks: *"to what degree have the CBD ecosystems approach principles been considered in the example land use planning frameworks? Which principles have been considered?"* As only three example approaches were considered in the evaluation, the results here are purely illustrative – the main intention of Research Objective No.3 in this regard is to identify key strengths, weaknesses and learning points from existing practice to inform the new models, tools and guidance developed through this research (see Chapters 7 and 8). Section 9.1 includes a critical evaluation of the methodology adopted in this research including the evaluation documented in this Chapter.

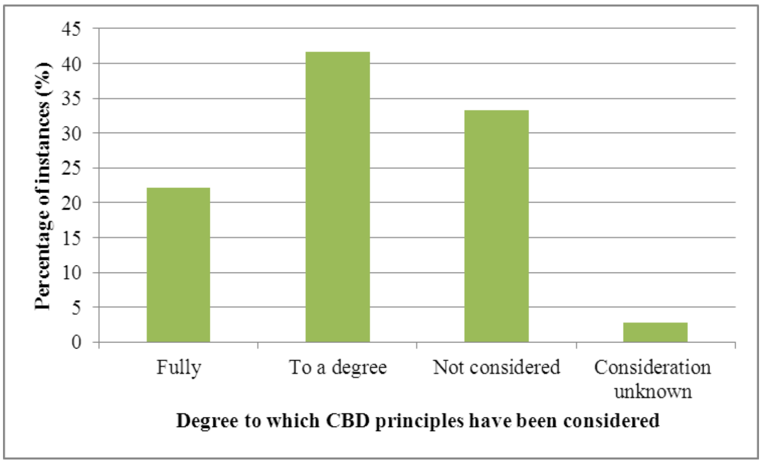


Figure 6.10 Degree to which CBD ecosystems approach principles have been considered – percentage of instances[80] across all case studies

Overall, the Research Objective No.3 evaluation indicates that consideration of the CBD principles by the three example land use planning frameworks has been mixed at best with the principles considered **fully** in only 22% of instances[81].

---

[80] There are 12 CBD ecosystems approach principles (see Table 3.8) and three case studies equating to 36 possible 'instances' where the CBD principles could have been considered (see Table 6.7 for a visual representation of this issue)

[81] Ibid

Principles were considered **to a degree** in 42% of instances and **not** considered at all in 33%. This is indicated on Figure 6.10. At the level of individual example approaches, EERA considered the principles most comprehensively (five principles considered **fully** and four **to a degree**) and GNOM the least comprehensively (two principles considered **fully** and four **to a degree**). Whilst THESAURUS considered the least number of principles **fully** (only one principle), seven principles were considered **to a degree**. This is indicated on Figure 6.11.

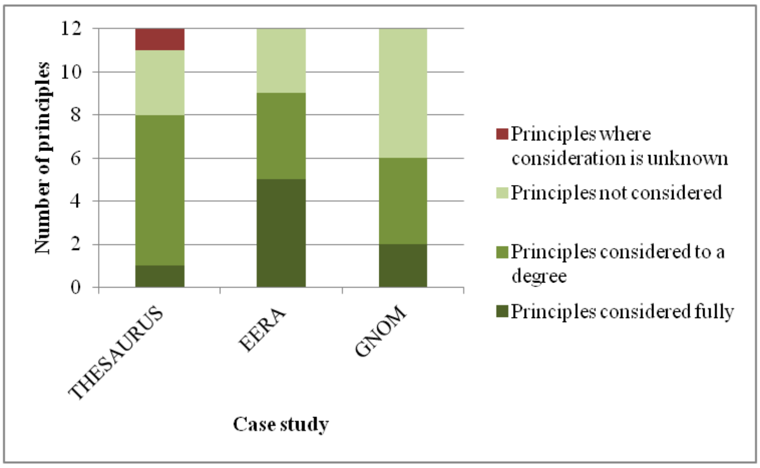
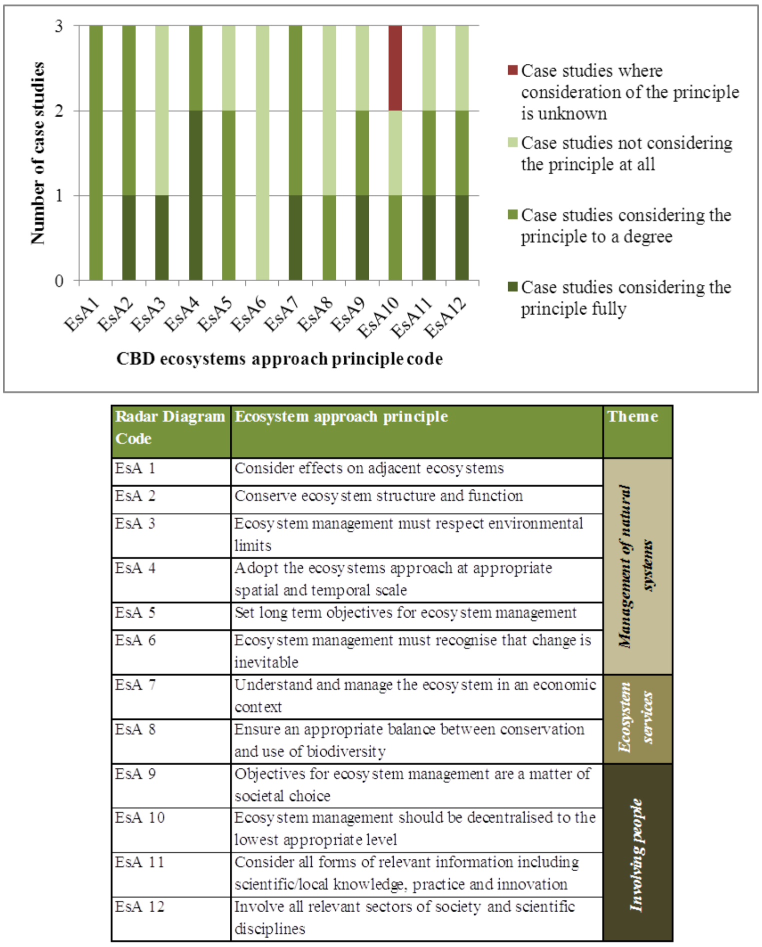


Figure 6.11 Degree to which individual case studies have considered the CBD ecosystems approach principles

At the level of individual CBD principles (i.e. a 'horizontal' analysis of Table 6.5), several principles have been considered and integrated fairly well by the example approaches, namely EsA1 on effects on adjacent ecosystems, EsA2 on ecosystem structure and function, EsA4 on appropriate spatial and temporal scales and EsA7 on management of ecosystems in an economic context which have all been considered either **to a degree** or **fully** (see Figure 6.12). Disregarding the green network opportunities mapping (GNOM) case which has its own particular issues in this regard (see section 6.3.1), all of the *involving people* principles (EsA9 to EsA12) have been considered **fully** or **to a degree** by THESAURUS and EERA with the exception of EsA10 on decentralised management.

As shown on Figure 6.12, EsA4 is the principle that has been considered most comprehensively by the three example approaches. EsA4 focuses on adopting the ecosystems approach at appropriate spatial and temporal scales (see Tables 2.3 and

3.8). The principle was considered **fully** by EERA and GNOM and **to a degree** by THESAURUS. All three of the example approaches are designed to work at broad spatial scales (regional to sub-regional) and this is considered to be an appropriate scale for adopting the ecosystems approach (see section 5.1.1). EERA and GNOM considered EsA4 fully through specific treatment of both spatial and temporal scale issues (THESAURUS only considered spatial scale).



Radar Diagram Code	Ecosystem approach principle	Theme
EsA 1	Consider effects on adjacent ecosystems	*Management of natural systems*
EsA 2	Conserve ecosystem structure and function	
EsA 3	Ecosystem management must respect environmental limits	
EsA 4	Adopt the ecosystems approach at appropriate spatial and temporal scale	
EsA 5	Set long term objectives for ecosystem management	
EsA 6	Ecosystem management must recognise that change is inevitable	
EsA 7	Understand and manage the ecosystem in an economic context	*Ecosystem services*
EsA 8	Ensure an appropriate balance between conservation and use of biodiversity	
EsA 9	Objectives for ecosystem management are a matter of societal choice	*Involving people*
EsA 10	Ecosystem management should be decentralised to the lowest appropriate level	
EsA 11	Consider all forms of relevant information including scientific/local knowledge, practice and innovation	
EsA 12	Involve all relevant sectors of society and scientific disciplines	

Figure 6.12 Degree to which individual CBD ecosystems approach principles have been considered – number of instances across the three case studies

As shown on Figure 6.12, EsA1 has been considered **to a degree** by all three of the example approaches. This principle focuses on ecosystem managers considering the effects of their activities on adjacent ecosystems (see Tables 2.3 and 3.8). All the example approaches are working at the regional to sub-regional scale and although none of the areas encompassed by the example approaches are spatially delineated on the basis of natural features (e.g. water catchments and whole landscapes), they are all of sufficient scale such that they are likely to encompass several natural features, e.g. water catchments and contiguous areas of habitat network. In this regard, all three examples are considered to have the potential to consider effects on adjacent ecosystems, on the basis that the area covered is likely to contain multiple ecosystems. Within the material reviewed in the evaluation however there was no strong evidence that consideration of effects on adjacent ecosystems was happening in practice though the potential to do so is arguably there.

The focus of EsA2 is on the conservation of ecosystem structure and function to maintain ecosystem services (see section 3.2.1 and Table 3.8). As per Figure 6.11, EsA2 was considered **fully** by one example approach (THESAURUS) and **to a degree** by two (EERA and GNOM). In particular, THESAURUS includes a comprehensive analysis of ecosystem processes/intermediate services, i.e. the various aspects of ecosystem function that contribute to ecosystem service supply (see section 3.2.1 and 3.2.2). EERA and GNOM are less comprehensive in this regard, focussing on one or two aspects of ecosystem function only, e.g. land based flora and fauna (EERA) and ecological networks (GNOM). EsA7 focuses on understanding and managing ecosystems in an economic context. This principle was considered **to a degree** by two of the examples (THESAURUS and EERA) and **fully** by one (GNOM). Within the GNOM case, there was a distinct focus on economic drivers for green network enhancement including recognition of the need to ‘sell the benefits’ to developers, the use of spatial datasets on key areas of development and regeneration (i.e. areas of change where there may be a demand for/opportunity to deliver ecosystem services) and also a real focus on the role of the planning system.

The principles considered least well by the example approaches were EsA6 on the importance of ecosystem management recognising that change is inevitable (**none** of the examples considered this principle), EsA3 on environmental limits (**not** considered in two cases) and EsA8 on balancing use and conservation of biodiversity (**not** considered by two of the examples). Poor consideration of EsA3 is a particular concern given the importance of environmental limits for the sustainable management of land and other natural resources (see section 3.2.1). Furthermore, the concept of environmental limits is central within planning (e.g. Scottish Government, 2010b), sustainable development (e.g. Defra, 2005) and environmental (e.g. EC, 2013b) policy in Scotland, the UK and the EU. As described at section 3.2 and Chapter 5, biodiversity is essential for ecosystem function and ecosystem services. In this regard, the poor consideration of EsA8 is concerning, especially in relation to the EERA case which implies a degree of substitutability between ecosystem services, including biodiversity (which is considered as a service).

6.4.2 What types of method/approach have been used?

The second research question considered under Research Objective No.3 asks *"what types of method/approach have the example land use planning frameworks used to consider the CBD principles in their land use/management planning?"* This sub-section describes how a number of potentially useful methods/approaches were identified for each example approach. Section 6.4.3 then provides a discussion of the overall strengths and weaknesses of the example approaches. Findings in both of these sections have played a key role informing the new tools, models and guidance that have been developed in this research (see Chapters 7 and 8).

Phillips et al (2014) identified 20 individual methods/approaches used by land use delivery mechanisms in Scotland to consider and translate the Scottish Land Use Strategy's (LUS) ten principles for sustainable land use. As described at section 3.1.4, there are close parallels between the LUS principles, the ecosystems approach and the tools, models and guidance developed in this research[82]. As such, the methods/approaches identified in Phillips et al (ibid) are considered to provide a useful structure for the analysis of methods used by the example land use planning frameworks evaluated in this Chapter. In particular, Phillips et al's (ibid) analysis of the 20 individual methods/approaches identified seven discrete categories of method which have provided the overall structure for the analysis in this section:

- Spatial analysis
- Environmental assessment
- Ecosystem services

---

[82] Indeed the Glasgow Local Development Plan (LDP) was one of eleven case study land use delivery mechanisms considered in Phillips et al (2014). Furthermore, the Scottish Government have developed a specific guidance note on applying the ecosystems approach to land use, to support the delivery of the national level LUS (Scottish Government, 2011c)

Table 6.4 Evaluation of case study ecosystems approach based land use planning frameworks – qualitative summary

Key to scoring	
Principle considered	■
Considered to a degree	▨
Principle not considered	□

Ecosystems approach principle		**Case study ecosystems approach based land use planning frameworks**			
		THESAURUS	**EERA**	**Green Network Opportunities Mapping (GNOM)**	**Summary comments**
Management of natural systems	EsA 1. Consider effects on adjacent ecosystems	▨	▨	▨	Principle considered by all case studies **to a degree** e.g. consideration of key transboundary ecosystem processes (THESAURUS) and broader scale issues beyond the study area boundaries (EERA)
	EsA 2. Conserve ecosystem structure and function	■	▨	▨	Principle considered at least to a degree. THESAURUS considers the principle **fully** through a comprehensive ecosystem service typology covering all ecosystem processes/intermediate services
	EsA 3. Ecosystem management must respect environmental limits	□	■	□	Mixed consideration. Environmental limits **not considered** by THESAURUS or GNOM. EsA 3 type issues are the central premise of EERA where the principle has been considered fully
	EsA 4. Adopt the ecosystems approach at appropriate spatial and temporal scale	▨	■	■	Principle considered **fully** by EERA and GNOM both of which operate at a broad spatial scale (i.e. likely to encompass key natural features) and consideration of planning up to 10 year horizon
	EsA 5. Set long term objectives for ecosystem management	□	▨	▨	Mixed consideration. Considered **to a degree** by EERA and GNOM but **not considered** by THESAURUS. For EERA and GNOM, similar issues apply as per EsA 4
	EsA 6. Ecosystem management must recognise that change is inevitable	□	□	□	Poor consideration across all case studies – no explicit or implicit references found to EsA 6 type issues in any of the material reviewed in the evaluation
Ecosystem services	EsA 7. Understand and manage the ecosystem in an economic context	▨	▨	■	Principle considered at least to a degree. GNOM **fully considers** the principle – in particular there is a strong emphasis on the role of the planning system delivering green network/ecosystem services
	EsA 8. Ensure an appropriate balance between conservation and use of biodiversity	▨	□	□	Mixed consideration. EsA 8 is **not considered** by EERA and GNOM. In particular EERA places an emphasis on the potential substitutability of ecosystem services, including biodiversity
Involving people	EsA 9. Objectives for ecosystem management are a matter of societal choice	▨	■	□	Mixed consideration. EERA considers EsA 9 **fully** by focussing on socially based approaches to defining environmental limits. GNOM is designed to be implemented by GIS technicians/planners
	EsA 10. Ecosystem management should be decentralised to the lowest appropriate level	**?**	□	▨	Mixed consideration. GNOM considers EsA 10 **to a degree** through its focus on the economic realities of green network/ecosystem service delivery and consideration of local level delivery models
	EsA 11. Consider all forms of relevant information	▨	■	□	Mixed consideration. Similarly to EsA 9, EERA considers this principle **fully**. THESAURUS recognises that there are opportunities to consider wider information though this was not acted on
	EsA 12. Involve all relevant sectors of society and scientific disciplines	▨	■	□	Mixed consideration – similar issues to EsA 11

- Partnerships and governance
- Engagement and awareness-raising
- Planning and design
- Grants and incentives

All three of the example approaches used **spatial analysis** techniques as a key component of their overall approach to land use/management planning. Phillips et al (2014 p.68) identified three specific applications of spatial analysis and highlighted how "given the inherently spatial nature of land use/management planning it is unsurprising that several of the [land use delivery mechanism] case studies have used spatial analysis and spatial data to varying degrees in their [land use/management planning] activities". In terms of the example approaches considered in this research, THESAURUS used spatial analysis and multiple spatial datasets to map proxy ecosystem services (see section 6.1.2). Similarly, EERA used multiple spatial environmental datasets aggregated to 1km x 1km grid squares to map environmental limits for a range of discrete environmental media e.g. air quality, water quality, groundwater resources and tranquility (see section 6.2.2). GNOM used spatial datasets and specific spatial queries and weightings to identify areas where land use/management intervention may be required to deliver multiple benefits (see section 6.3.2). All three cases used GIS technology to facilitate their spatial analyses.

All three of the example approaches used the **ecosystem services** concept as a key part of the methodological approach within their land use/management planning activities. Phillips et al (2014 p.75) identified two specific applications of ecosystem services highlighting how this ranged from "comprehensive ecosystem service assessments to using ecosystem services more generally as a framing to communicate the benefits of the natural environment to stakeholders". In terms of the example approaches considered in this research, THESAURUS used landcover data and additional 'causal variable' datasets (see Table 6.1) to map proxy ecosystem services (see section 6.1.2 and Figure 6.3). The ecosystem service assessment aspect of THESAURUS' approach was also informed by a literature review and stakeholder engagement to identify a typology of ecosystem services for the study area (see

Figure 6.2). GNOM and EERA's use of ecosystem service approaches/methods was less comprehensive than THESAURUS. For example GNOM used integrated habitat network (IHN) data, within the overall spatial analysis approach, to identify where green network intervention may be required to improve ecological connectivity as one aspect of multifunctional land use.

THESAURUS and EERA used aspects of **engagement and awareness-raising** techniques as a component of their wider approach. Phillips et al (2014 p.82) identified four specific engagement and awareness-raising techniques including the use of "more novel approaches to encourage engagement in land use/management decision-making". Both THESAURUS and EERA used stakeholder engagement as a key input to technical aspects of spatial analysis and ecosystem service assessments. In THESAURUS' case, stakeholder input helped to validate the literature based ecosystem service typology prior to the collation of data on causal variables and spatial analysis (see section 6.1.2 and Figure 6.2). In EERA's case, stakeholder input was used to define environmental limits based on social preferences (see sections 3.2.1 and 6.2.2).

The EERA approach was designed to support **environmental assessment** processes, namely strategic environmental assessment (SEA), recognising that SEA and environmental assessment (EA) more generally can be a key input to land use/management planning. Phillips et al (2014 p.72) identified three specific applications of environmental assessment in land use/management planning highlighting how information from assessments "will often be useful for understanding how the plan or project might influence sustainable land use outcomes". In the case of EERA, the environmental limits mapping and SEA of regional land use/development plans were found to be mutually supportive. The environmental limits mapping supported the evaluation of significance in SEA and SEA provided a platform for public and stakeholder engagement e.g. to identify environmental limits based on social preferences.

Finally, GNOM has a key focus on the use of regulation (i.e. planning policy, Development Management and enforcement) as a driver for land use/management intervention. The use of regulation in this regard is considered to align with the **grants and incentives** methods/approach category i.e. regulation is the 'stick' to the ‘carrot’ of grants and incentives. Phillips et al (2014 p.87) identified three specific approaches for the use of grants and incentives in land use/management delivery highlighting how “grant and incentive mechanisms can have a significant impact on land use/management in a variety of different contexts”.

Key aspects of the methods/approaches highlighted in this section have informed the tools, models and guidance developed in this research. In particular, the new spatial models have drawn on lessons from the spatial analysis and ecosystem service methods utilised by the case studies (see Chapters 7 and 8). Furthermore, the suite of overarching ecosystems approach guiding principles, where relevant, have drawn on all of the methods/approaches identified in this section (see Appendix 3).

6.4.3 What are the main strengths and weaknesses of the example approaches?

The third research question under Research Objective No.3 asks *“what are the main strengths and weaknesses of the example land use planning frameworks in terms of how they have considered the CBD principles?”* A summary of the main strengths and weaknesses in this regard is provided at Table 6.6. This includes an indication of which example approach (or approaches) the strengths and weaknesses relate to. Where relevant, the strengths and weaknesses identified in Table 6.6 have informed the new tools, models and guidance that have been developed in this research (see Chapters 7 and 8 and Appendices 3, 4, 5, 6, 8, 9 and 10). In particular, the strengths and weaknesses have played a key role informing the development of the suite of guiding principles for ecosystems approach based urban land use planning (see Appendix 3) as well as the overarching guidance for interpreting and acting on spatial model outputs (see Chapters 7 and 8) in the development of integrated urban land use/management strategies (see Appendices 4, 5 and 6).

The strengths and weaknesses were identified through an analysis of all data produced during the evaluation of example approaches as summarised in sections 6.1 – 6.3. The approach taken to the analysis of qualitative data is described at section 2.4.1. As a general observation it is interesting to note that strengths are more prominent than weaknesses in terms of the three example approaches considered in the Research Objective No.3 evaluation. As per Table 6.6, some of the strengths and weaknesses are only applicable to one example approach, reflecting the focus of this research question on identifying the **main** strengths and weaknesses (i.e. it was sometimes the case that a strength or weakness evidenced in only one case study was felt to be significant in its own right).

Table 6.5 Summary of the main strengths and weaknesses of example ecosystems approach based land use planning frameworks

Details of strength or weakness	Applicable example(s)
Strengths	
1. Relatively comprehensive consideration of ecosystem processes/intermediate services: EsA2 focuses on the conservation of ecosystem structure and function. This is a key premise of the ecosystems approach as sustainable supplies of essential ecosystem services are reliant on healthy ecosystems (see section 3.2). THESAURUS considered all ecosystem processes/intermediate services as part of a network analysis approach. GNOM and EERA both considered some key aspects of ecosystem function though not as comprehensively as THESAURUS e.g. in GNOM the focus was on the use of IHN data to model ecological connectivity	THESAURUS EERA GNOM
2. Effective consideration of spatial and temporal scale: EsA4 requires that the ecosystems approach is adopted at appropriate spatial and temporal scales. All three example approaches considered spatial scale effectively. EERA and GNOM also considered temporal scale issues but in different ways – EERA analysed trends and associated pressures to understand how the baseline environment may evolve in order to identify key issues that land use/management should consider. The GNOM approach is aligned to the SDP and LDP mechanisms which have their own statutory planning and revision timescales	EERA GNOM
3. Disaggregation of the natural environment using management units that are familiar to planners and decision-makers: Disaggregating the natural environment into discrete spatial units can be a useful device for ecosystems approach based land use/management planning. THEASURUS evaluated a range of approaches and settled on the management unit that would be most familiar to planners and decision-makers (effectively different 'green' and 'natural environment' type land uses as per the local green infrastructure strategy and relevant national level planning guidance)	THESAURUS
4. Use of stakeholder input to validate technical modelling processes: As described at section 6.4.2, all of the example approaches used elements of spatial analysis and ecosystem service assessment in their land use/management planning activities. The expert-focussed and often technical nature of these approaches is such that non-technical stakeholders (such as the public and local communities) can be excluded from participation. THESAURUS and EERA both included specific stakeholder engagement stages within their methodologies to validate technical aspects of the approach e.g. the ecosystem service typology in the former and proposed environmental limits in the latter. This is relevant to all of the *involving people* ecosystems approach principles, especially EsA9, 11 and 12	THESAURUS EERA

Details of strength or weakness	Applicable example(s)
5. Visual presentation of spatial land use/management issues to communicate key messages to planners and decision-makers: All three of the example approaches used visual presentation of spatial data to communicate messages to planners and key land use/management decision-makers. In the case of THESAURUS for example, ecosystem service maps (i.e. a map for each service considered) were used to demonstrate the benefits provided by existing land use. Considering the maps together therefore highlighted where existing land use/management is providing multiple benefits and also where there may be a shortfall of ecosystem services	THESAURUS EERA GNOM
6. Using a multi-staged mixed methods approach to refine a proxy based approach for ecosystem service assessment and mapping: In the absence of comprehensive primary data, proxy based approaches can be used to assess and map ecosystem services e.g. using landcover data to estimate ecosystem service provision. THESAURUS used a proxy based approach but added several additional inputs to refine and improve the output maps. This included literature review to identify a typology of ecosystem services for the study area as well as stakeholder input to validate the literature based typology (see Strength 4 also). The mapping of proxy ecosystem services was refined through the use of supporting datasets to better understand the causal relationships between ecosystem services and the contextual factors that influence their value/importance	THESAURUS
Weaknesses	
1. Poor consideration of environmental limits: EsA3 focuses on ecosystem management that respects environmental limits. Only one of the example approaches considered environmental limits (EERA) though there are concerns about how the environmental limits maps produced by this case study might be interpreted by land use/management stakeholders (see Weakness 3). Poor consideration of EsA3 is a particular issue given the importance of environmental limits for the sustainable management of land and other natural resources (see section 3.2.1)	THESAURUS EERA GNOM
2. Poor/mixed consideration of biodiversity: EsA8 highlights the importance of striking an appropriate balance between the conservation and use of biodiversity. Whilst all three of the example approaches considered biodiversity within their land use/management planning activities, none have a mechanism in place to balance use and conservation objectives (e.g. a specific principle on the primacy of biodiversity objectives). Furthermore, EERA's approach implies a degree of transferability between biodiversity and other environmental topics/issues considered within the environmental limits mapping	THESAURUS EERA GNOM
3. Potential for misinterpretation of environmental limits maps: The EERA case produced environmental limits maps based on environmental state indicators (see section 3.2.1). With this approach, limits are exceeded where current or historic pressures have degraded the environment such that key indicators of environmental quality fall below some identified threshold. In this regard, areas where limits have been exceeded tend to cluster around heavily developed areas where pressure is greatest i.e. urban areas primarily. The corollary of this is also true – areas where limits have not been exceeded tend to be areas of better environmental quality away from development pressure. This is illustrated on Figure 6.6. Without interpretation therefore, this type of environmental limits map could be seen as promoting development in rural areas instead of using land use/management intervention in degraded urban areas to help restore damaged ecosystems and improve environmental quality. In reality of course a development strategy incorporating elements of	EERA

Details of strength or weakness	Applicable example(s)
both approach would likely be preferential	
4. Limited consideration of regulating services: The GNOM case features limited consideration of regulating services such as flood and erosion control and noise regulation. Instead, the approach has a strong focus on cultural services with some consideration of ecosystem processes/intermediate services (especially ecological connectivity). As outlined at section 3.2, a balanced approach to land use/management is likely require consideration of all categories of ecosystem services, including ecosystem function issues	GNOM

Chapter 6 was the last of the three evidence assessment Chapters that have provided the technical basis for the development of new approaches to urban planning that can operationalise the ecosystems approach. Chapter 7 now discusses the three new spatial models that have been developed through this research.

7. Developing new spatial models for urban planning: how do we know where urban ecosystem services are required?

The overarching aim of this research is "to understand, develop, trial and evaluate new approaches to urban planning that can operationalise key aspects of the ecosystems approach" (see section 1.4). In meeting this overarching aim, a substantive evidence assessment has been undertaken as documented in the four preceding Chapters – Chapters 3, 4, 5 and 6. The evidence assessment has played a crucial methodological role by fulfilling Research Objectives Nos. 2 and 3 (see Box 1.2). In this regard, the evidence assessment has collated, analysed and synthesised material that provides the technical basis for developing new urban planning approaches in line with Research Objective No.4 (see Box 1.2).

This is the first of two Chapters documenting results under Research Objective No.4. It describes the three new spatial models for urban planning that have been designed to help practitioners identify where land use/management intervention may be required to deliver new or enhance existing ecosystem services. Readers should note that all Figures within this Chapter are also provided in a standalone document that is available on the CD-ROM enclosed with this thesis. The new models are:

1. The **Flood control model:** identifies where flood storage ecosystem services are required in the floodplain (see Chapter 4 and section 7.2)
2. The **Hydrological cycle model:** identifies where runoff reduction and storm water storage services are required in the wider catchment (see Chapter 4 and section 7.3)
3. The **Habitat network model:** identifies where ecological connectivity services are required at all locations (see Chapter 5 and section 7.4)

The methodological approach adopted in the development of the new models is described at sections 2.2, 2.3.3 and 2.4.2. This involved elements of an action research based approach whilst the author was working at Glasgow City Council (GCC) whereby the new spatial models were used to inform the development of a specific GCC urban greenspace project (see sections 2.2.6 and 2.3.3 and Appendix 12). The utility of the new models was then tested and evaluated in this regard in collaboration with other Council personnel. The models are also supported by new guidance for interpreting and acting on model outputs in the development of integrated urban land use/management strategies (see Appendices 4, 5 and 6) as well as a new suite of guiding principles for ecosystems approach based urban land use planning more generally (see Appendix 3). Both the guidance and the principles have been informed by the evidence assessment described at Chapters 3, 4, 5 and 6. The guidance and principles are explained fully in Chapter 8.

7.1 Overall approach to the new spatial models for urban planning

The technical aspects of the new spatial models are described in sections 7.2, 7.3 and 7.4. Appendices 8, 9 and 10 provide more detailed step-by-step instructions, aimed at practitioners, including geoprocessing notes/instructions for the ArcGIS based operations. In summary however, the models integrate a range of spatial datasets to understand and map the causal relationships between ecosystem services and the contextual factors that influence their value/importance. In essence, outputs from the new models show locations where land use/management **may** be required to deliver new or enhanced ecosystem services – i.e. locations where there is a potential demand for or shortfall of ecosystem services. This type of approach (see section 6.1.2) is recommended by Eigenbrod et al (2010) and has been used in a number of studies (e.g. CEP and Geodata, 2008; Countryside Council for Wales, 2011; Sheate et al, 2012) and in practical decision-making contexts (e.g. Bellamy and Winn, 2013; Hölzinger et al, 2013).

Whilst the new models developed in this research have drawn on existing approaches from the literature (ibid) and the example ecosystems approach based land use planning frameworks considered under Research Objective No.3 (see Chapter 6), the models incorporate several key innovations that add value to and set them apart from existing approaches. This issue is addressed further in Chapter 9. Table 7.1 lists the ecosystem services considered in the three new models along with the causal variables or contextual factors that have been considered in the modelling in order to understand the potential value/importance of the ecosystem services in a given location. This is also illustrated on Figures 7.1, 7.16 and 7.28. Further information on how qualitative causal variables have been integrated with existing spatial datasets in the new spatial models is provided at section 2.4.2.

Table 7.1 Ecosystem services/causal variables considered in the spatial models

Ecosystem service	Causal variable/contextual factor affecting service provision
Flood storage – see section 7.2	• **Fluvial flood risk:** flood extent and receptors affected under 1/200 year event, anticipated location of flooding within the catchment • **Morphology:** presence and location of culvert and realignment pressures • **Floodplain vegetation**: type and location of existing vegetation cover, ecological potential to create new natural/semi-natural habitat – floodplain woodland and wetland • **Floodplain topography**: floodplain cross-section gradient, presence and location of fine scale topographical features in the floodplain
Runoff reduction – see section 7.3	• **Pluvial flood risk:** flood extent under 1/200 year event • **Topography:** location of steeply sloped ground • **Surface waterbodies:** location, immediate catchment area • **Impermeable ground:** location, immediate catchment area
Ecological networks – see section 7.4	• **Habitat patches:** location, size • **Functional habitat networks:** location, size • **Ecological potential of land for habitat establishment:** location, value

7.2 The flood control model – where are flood storage services required?

This section describes the structure, process and function of the flood control model that has been developed through this research. The purpose of the flood control model is to identify sites and possible land use/management based interventions that can enhance flood storage ecosystem services (see section 3.2). The development of the flood control model has been informed by the material collated, analysed, synthesised and documented in Chapter 4 (see sections 4.2, 4.4, 4.5 and 4.6 in particular) as part of Research Objectives Nos. 2 and 3 (see Box 1.2). The overall structure of the flood control model is indicated on Figure 7.1 and summarised at Table 7.2.

The utility of the flood control model lies in its use scoping sites and developing broad concepts for land use/management based interventions that can provide flood storage ecosystem services, thereby enhancing natural flood management (NFM) capacity within urban catchments. The focus of the flood control modelling is on the identification of sites and interventions within the floodplain that have the potential to increase fluvial flood storage. This is in contrast to the hydrological cycle model (see section 5.2) which focuses on the identification of measures in the wider catchment, primarily outwith the floodplain. In line with this distinction, the flood control model draws on the key floodplain based NFM measures analysed in Chapter at sections 4.5, 4.6 and 4.7. Table 7.3 highlights where these key NFM measures have been considered within the flood control model.

As indicated on Figure 7.1, the flood control model is made up of two screening processes and a constraints analysis/scenario development stage. The first screening stage is comprised of three steps (Steps 1, 2 and 3), the second screening stage comprises two steps (Steps 4 and 5) and the constraints analysis/scenario development stage comprises three steps (Steps 6, 7 and 8). Key information on individual steps in the flood control model is provided at sections 7.2.1 – 7.2.8 with additional detail and geoprocessing instructions for the GIS based operations provided at Appendix 8. In line with Research Objective No.5 (see Box 1.2), an evaluation of the tools and approaches developed through this research is provided at section 9.2.4 and Appendix 11.

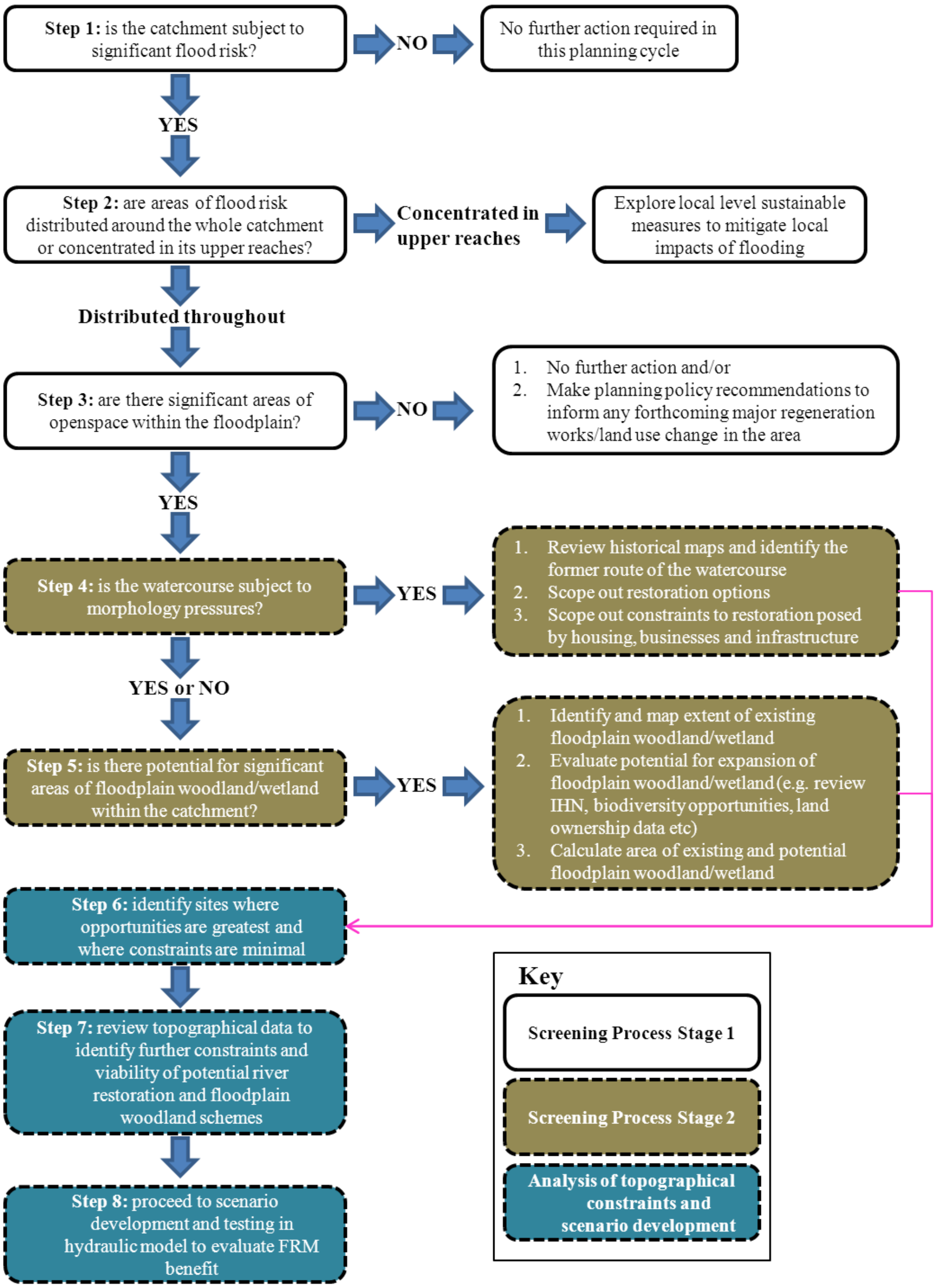


Figure 7.1 Overall structure of the flood control model

Note: Figure also available within standalone CD-ROM.

Table 7.2 Flood control model – description of key stages

Stage	Objectives/purpose
Screening process stage 1	Identifies catchments that are subject to significant flood risk where the flood risk is (at least in part) located in the lower reaches of the catchment. Where this is the case, there may be potential to develop floodplain based NFM measures in the upper catchment that increase flood storage and reduce flood risk downstream. This stage also models the extent of the floodplain and identifies the extent and location of openspace within that floodplain i.e. 'floodplain openspace'. The area of floodplain openspace is then expressed as a percentage of the area encompassed by the catchment – where this is equal to or more than 2% it is considered reasonable for practitioners to progress to the second screening stage
Screening process stage 2	Identifies opportunities for specific floodplain based NFM measures within the study catchment: river restoration and floodplain woodland and wetland restoration and enhancement. Opportunities are identified with reference to spatial data on key morphology pressures and woodland/wetland habitat networks and opportunity areas. In summary, this screening stage considers the viability of floodplain based NFM measures within the study catchment and produces the input data for the scenario development stage
Constraints analysis and scenario development stage	Appraises data produced in the second screening stage to identify sites where opportunities are greatest and constraints minimal. It then reviews topographical data to further characterise constraints and inform optimal strategies for woodland creation. Finally, this stage produces scenarios (in the form of outline land use/management strategy plans) for testing in an appropriate hydraulic model

The flood control model has been designed in such a way that the practitioner would start at the beginning and work their way through to the end (see Figure 7.1). The premise of this approach is that as the various steps in the model are progressed, the sophistication of the analysis increases in line with the potential FRM benefit of the outputs. Conversely, the cumulative area of the outputs decreases as the model is progressed, as the screening criteria become more onerous and less beneficial sites are screened out. The final step of the flood control model (Step 8 – see section 7.2.8) involves the development of integrated NFM scenarios that could be tested in an appropriate hydraulic model.

The flood control model should be applied on a catchment by catchment basis, across the local authority area. Where a waterbody has a catchment area extending beyond the boundaries of the local authority, the flood control model can be applied to identify potential sites and scenarios (see Step 8 at section 7.2.8) though the scenarios must be tested in a hydraulic model covering the whole catchment. Importantly, this type of catchment by catchment approach can inform the development of NFM measures that can help to desynchronise flood flows to the main channel (see section 4.6).

Table 7.3 Where are individual NFM measures considered in the flood control model?

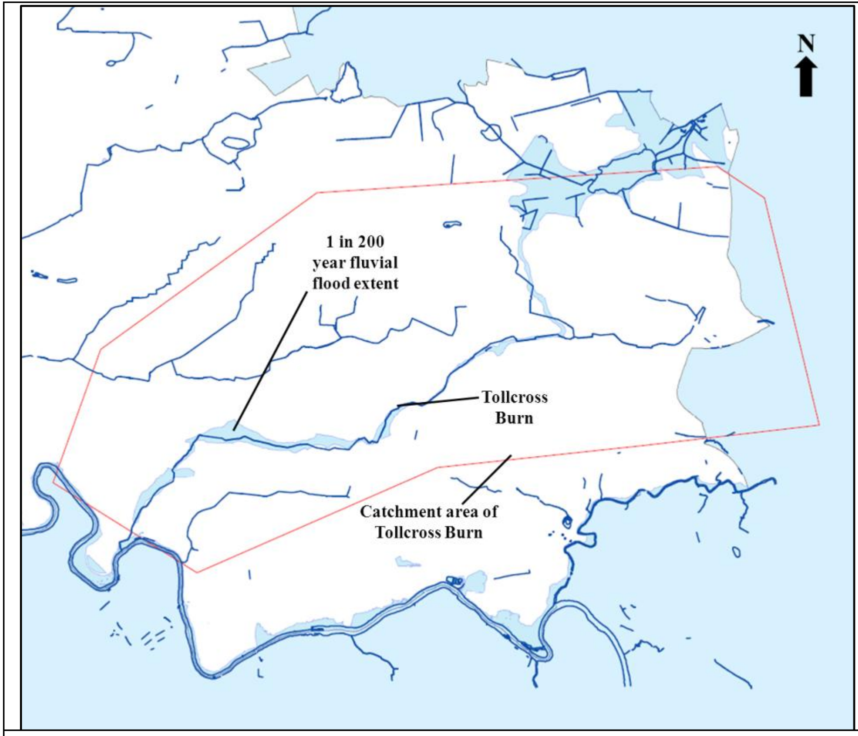
Measure	**Flood control model reference**	**Chapter 4 reference**
1. River restoration	Step 4 – see section 7.2.4	Section 4.5
2. Floodplain/riparian zone woodland planting and restoration	Step 5 – see section 7.2.5	Section 4.6
3. Creation, restoration and enhancement of floodplain wetland features	Step 5 – see section 7.2.5	Section 4.7
4. Temporary inundation of openspace/increased flood storage using low level bunds	Step 3 – see section 7.2.3	Section 4.7
5. Integrated land use/management led fluvial flood storage measures	Step 6 – see section 7.2.6 Step 7 – see section 7.2.7 Step 8 – see section 7.2.8	N/A

Note: This table indicates where the key *floodplain* based NFM measures considered in the evidence assessment have been integrated with the flood control model. The synthesised technical information developed through the evidence assessment (in line with Research Objectives Nos. 2 and 3 – see Box 1.2) has been crucial informing the parameters and functionality of the flood control model.

7.2.1 Step 1 – is the catchment subject to significant flood risk?

The purpose of Step 1 in the flood control model is **to identify whether the catchment being investigated is subject to significant flood risk**. Individual tasks to be undertaken in Step 1 of the flood control model are described in Appendix 8. An example Step 1 output is shown on Figure 7.2, other example outputs are provided in Appendix 8. The 1 in 200 year return period is equivalent to a 0.5% probability of flooding in any given year. In terms of the Scottish Planning Policy (SPP) risk framework (see section 4.3), areas falling within the 1 in 200 year flood extent are defined as ‘medium-high risk’ as the likelihood of being flooded in these areas is relatively high. Where the 1 in 200 year flood extent data encompasses receptors such as homes, businesses and infrastructure, the risk of flooding can be considered significant given the likelihood of a flood taking place and the consequences of that flood (see section 4.3).

Scotland's National Flood Risk Assessment (SEPA, 2011b) assessed flood risk by combining flood extent data (i.e. data on the likelihood of flooding) with a quantitative assessment of the number of receptors that may be impacted (i.e. data on the consequences of flooding). This included an assessment of impacts on people (number of residential properties), community services (number of hospitals, schools, GP practices etc), businesses, transport infrastructure and agriculture (ibid). In effect, the higher the number of receptors within the floodplain, the higher the overall flood risk. A similar approach has been adopted in Step 1 of the flood control model (see Appendix 8).



Summary details of example output	
Model	Flood control
Step	1
Step title	Is the catchment subject to significant flood risk?
Tasks	1.1 and 1.2
Note: Figure also available within standalone CD-ROM.	

Notes: This example flood control model above shows the hydrology and fluvial flood extent of the Tollcross Burn catchment.

Figure 7.2 Flood control model Step 1, Tasks 1.1 and 1.2 – example model output

7.2.2 Step 2 – what is the distribution of flood risk areas across the catchment?

Step 1 clarifies whether or not the catchment is subject to significant flood risk given where flooding is likely to occur under the 1 in 200 year flood event and the receptors affected. Where the answer to Step 1 is "yes" (see Figure 7.1), the purpose of Step 2 in the flood control model is **to add another layer of refinement by identifying how this flood risk is distributed around the catchment**.

In particular, this step is intended to scope catchments where there are significant areas of flood risk in the lower reaches. In these situations, there may be the potential to develop floodplain NFM measures in the mid-upper reaches of the catchment that can provide increased flood storage and help to reduce flood risk downstream in more vulnerable areas (e.g. by taking properties and infrastructure out of flood risk). The viability of potential floodplain NFM measures is appraised in subsequent steps, especially Steps 6 – 8 (see sections 7.2.6 – 7.2.8).

Step 2 is approached by simply referencing a GIS output such as that shown at Figure 7.2. Where there are clear areas of flood risk in the lower reaches of the catchment (such as those at Tollcross and Braidfauld detailed in the examples in Appendix 8), the answer to Step 2 would be "yes – flood risk is distributed throughout the catchment" and the practitioner would move on to Step 3. Where the answer is "no – flood risk is concentrated in the upper reaches of the catchment"[83], it is advisable that local land use/green infrastructure measures are sought to help mitigate flooding impacts at source.

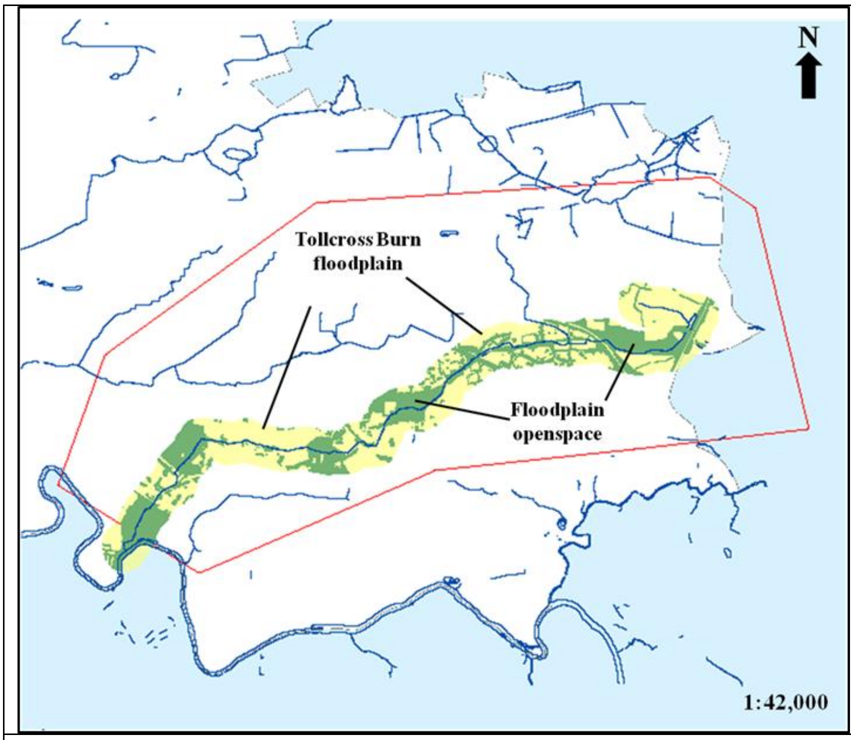
7.2.3 Step 3 – are there significant areas of openspace within the floodplain?

Openspace is the 'currency' by which the floodplain based NFM measures considered in this research and described at sections 4.5 and 4.6 are built. Accordingly, the purpose of Step 3 in the flood control model is **to identify the floodplain openspace resource that may be available for the development of floodplain NFM measures**. Additionally, Step 3 marks the end of the first screening stage in the flood control model (see Figure 7.1) and practitioners may wish to cease their investigations here (e.g. outputs from this stage could usefully inform urban land use planning in their own right – see section 8.3). Alternatively, practitioners

---

[83] This situation could arise, for example, where the lower reaches of a catchment is protected throughout with flood defences that have been designed to accommodate a 1 in 200 year or more event. In this instance, flooding may occur in the upper reaches but even high flows associated with a 1 in 200 year event (or more) would not be expected to overtop flood defences in the lower reaches of the catchment. The sustainability of such an approach is questionable however given the likely maintenance burden of the flood defences, the lack of resilience (the defences could potentially be overtopped by high flows beyond their design capacity) and the impact further downstream or in the main channel due to the lack of flood storage – see section 4.5.

may wish to progress to the second screening stage and the development/testing of NFM scenarios. Individual tasks to be undertaken in Step 3 of the flood control model are described in Appendix 8 including geoprocessing notes for the ArcGIS based operations. An example Step 3 output is shown on Figure 7.3. A full schedule of Step 3 outputs is provided at Table 7.4.



Summary details of example output	
Model	Flood control
Step	3
Step title	Are there significant areas of openspace within the floodplain?
Task	N/A
Note: Figure also available within standalone CD-ROM.	

Notes: This example flood control model output shows the modelled floodplain for the Tollcross Burn (the pale yellow polygon) and areas of floodplain openspace (green polygons).

Figure 7.3 Flood control model Step 3 – example model output

Step 3 is premised on the use of GIS to model an approximation of the floodplain in the catchment being studied. The floodplain is modelled by using GIS to 'buffer' the waterbody being studied. The size of the buffer used will vary depending on the size of the watercourse being studied (and therefore the size and characteristics of the catchment) though for small burns (such as those examined in this thesis), a general value of 250m is suggested. This will give a floodplain cross-section of approximately 500m for most stretches of the watercourse. The dimensions chosen for the buffering operation reflect the common morphological characteristics of small urban watercourses, the nature of their response to flows under a 1 in 200 year rainfall event and the likely flood extent associated with these flows (see section 4.3 and Appendix 8 for further information). Naturally these three parameters will vary between different watercourses, catchments and urban contexts though for many small urban catchments, flooding under a 1 in 200 year event would arguably be well contained within a floodplain cross-section of 500m (unless the gradient of the floodplain was particularly gentle). In any event, the buffering operation in Step 3 of the flood control model is only required to *approximate* the floodplain in order to identify floodplain openspace that could *potentially* be used to support the development of floodplain NFM measures. The viability of these potential measures is then tested through the latter steps of the flood control model (see sections 7.2.6 – 7.2.8). The floodplain modelled for the Tollcross Burn (north-east Glasgow) as part of this research is shown on Figure 7.3. The buffer operation is undertaken for the whole watercourse, including stretches subject to morphology pressures that are not currently connected to their floodplain (see section 7.2.4 for further information in this regard).

Once the floodplain has been modelled, the next task is to identify the openspace resource falling within this area. This is achieved simply by clipping the PAN65 openspace data to the newly created floodplain polygon in the GIS. This operation will identify all those PAN65 openspace sites that fall within the floodplain. The outputs of this step for the Tollcross Burn are shown on Figure 7.3. Further information on PAN65 openspace and related data is provided at sections 2.4.2 and 3.1.3.

The two geoprocessing tasks described above provide the necessary data to ascertain whether or not there are ‘significant’ areas of openspace within the floodplain. In line with the literature (see section 4.6) it is considered appropriate to use a quantified threshold for defining significance, as an aid to decision-making. For the purposes of this research, significant areas of floodplain openspace are considered as those greater than or equal to 2% of the catchment area being investigated. The GIS can be used to obtain and calculate both figures as explained further at Appendix 8. Depending on the specific planning context, practitioners may wish to progress to the second screening process (i.e. Step 4 onwards) even if the cumulative area of floodplain openspace is less than 2% of the catchment area. As described above, the process of modelling the floodplain is, by design, an arbitrary process and the 2% target is suggested as a guideline only

In the case of the Tollcross Burn example indicated at Figure 7.3, floodplain openspace is considered to be significant in terms of the 2% threshold as 5.1% of the catchment area is comprised of floodplain openspace (see Appendix 8 for further information). Where the response to Step 3 is negative and cumulative floodplain openspace is considered to be insignificant, the practitioner could choose to take no further action or to make planning policy recommendations aimed at informing any forthcoming regeneration and/or major land use change (i.e. regeneration and/or land use change could be designed to create new areas of floodplain openspace).

Table 7.4 Flood control model Step 3 – schedule of model outputs

Output	Type of output	Description of output
1. Shapefile of floodplain openspace	Spatial (polygon ArcGIS feature class)	The location and extent of all areas of floodplain openspace within the study catchment
2. Total area of floodplain openspace (ha)	Metric	This output describes the cumulative area of floodplain openspace within the study catchment. Floodplain openspace is the 'currency' by which land use/management based NFM measures are progressed hence the importance of this metric
3. Percentage of catchment comprised of floodplain openspace (%)	Metric	This output describes the cumulative area of floodplain openspace as a percentage of the total area of the study catchment

7.2.4 Step 4 – is the watercourse subject to morphology pressures?

The purpose of Step 4 in the flood control model is **to identify whether the watercourse being investigated is subject to the types of morphology pressure that lend themselves to being addressed as part of land use/management based NFM schemes**. Individual tasks to be undertaken in Step 4 of the flood control model are described in Appendix 8 including geoprocessing notes for the ArcGIS based operations. A full schedule of Step 3 outputs is provided at Table 5.4.

As described at section 4.5, Step 4 focusses on two key morphology pressures of concern – culverts and bed and bank reinforcements/river realignments. For these types of pressure, it may be possible to develop feasible restoration scenarios that have the potential to deliver FRM and other multiple benefits including water environment improvements. Accordingly, a key aspect of Step 4 is identifying where pressures are located and the types of pressure present. In Scotland, spatial data on morphology pressures is available as a download from SEPA (see section 2.4.2).

Step 4 comprises 4 tasks. Task 4.1 adds the morphology pressures data to ArcMap[84]. A typical output from Task 4.1 is shown at Figure 7.4. The morphology pressures data is then overlayed with the floodplain openspace layer (i.e. the output from Step 3 – see section 7.2.3) to identify where morphology pressures are located within areas of floodplain openspace (see Figure 7.4). Where this is the case, it may be possible to develop restoration projects that address the identified morphology pressures whilst also delivering FRM and other multiple benefits. In effect, the floodplain openspace can provide the physical space for restoration works – especially the reinstatement of a functional floodplain (see section 4.5). The remaining three tasks in Step 4 analyse potential restoration constraints with a view to scoping plausible restoration scenarios. These are then fed into Steps 6 – 8 (see sections 7.2.6 – 7.2.8).

Where morphology pressures are found to be located within areas of floodplain openspace, Task 4.2 identifies potential restoration options. Where possible, the restoration approach adopted in this research is predicated on restoring watercourses to their original route, including the reinstatement of a functioning floodplain to provide increased flood storage ecosystem services and associated FRM benefits (see section 4.5). Artificial changes to watercourses, such as culverting and realignment, generally simplify watercourse morphology[85] and the characteristics of a modified waterbody (especially its course) are likely to be

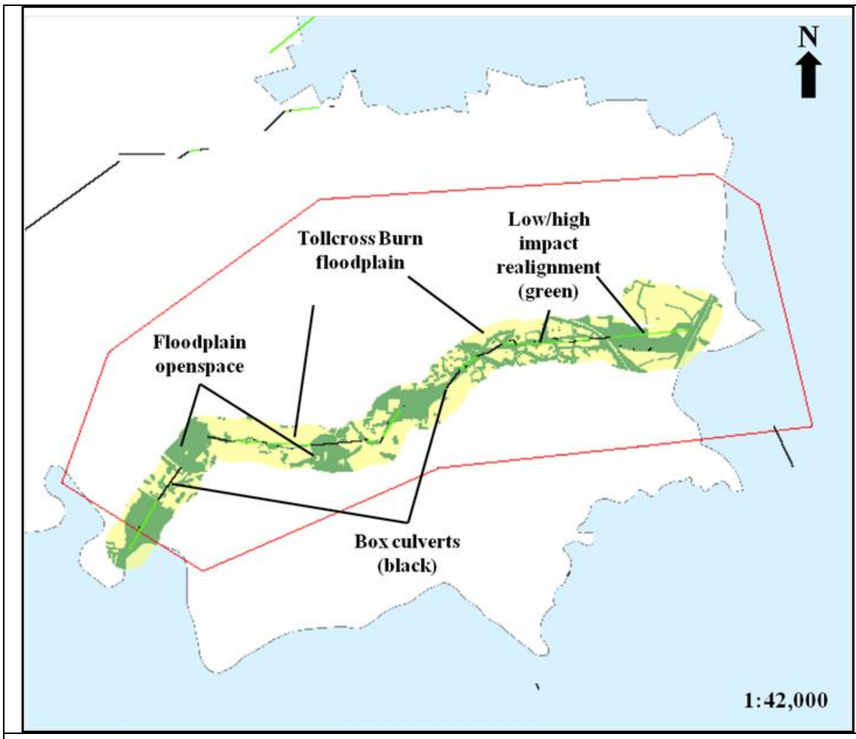
---

[84] Depending on the format of the data used, it may be necessary to extract specific data on culvert and realignment (canalisation) pressures, as these are the pressures of interest for green infrastructure led NFM schemes

[85] For example, straightening out meanders and creating narrow, deep channels. Such modifications can result in greater flow rates, rivers that respond more quickly to rainfall events (flashy rivers) and a shorter lag time between the rainfall event and peak flows

significantly different to when it was in its original state. Accordingly, Task 4.2 is a historic map review to identify the watercourse's original route prior to modification.

Figure 7.5 shows a plan of what is now the Sandyhills Park area of Tollcross (located roughly in the middle of the Tollcross Burn catchment – north-east Glasgow) overlayed with 1860s base mapping. The figure also shows the approximate (SEPA data) and actual (Glasgow City Council data) location of the modern box culvert at Sandyhills Park that this reach of the Tollcross Burn currently flows through. As part of this task, the historic route of the watercourse at the site being investigated is digitised in the GIS. Once digitised, the historic route of the watercourse can be manipulated in the GIS with other data sets to identify the presence of any restoration constraints.

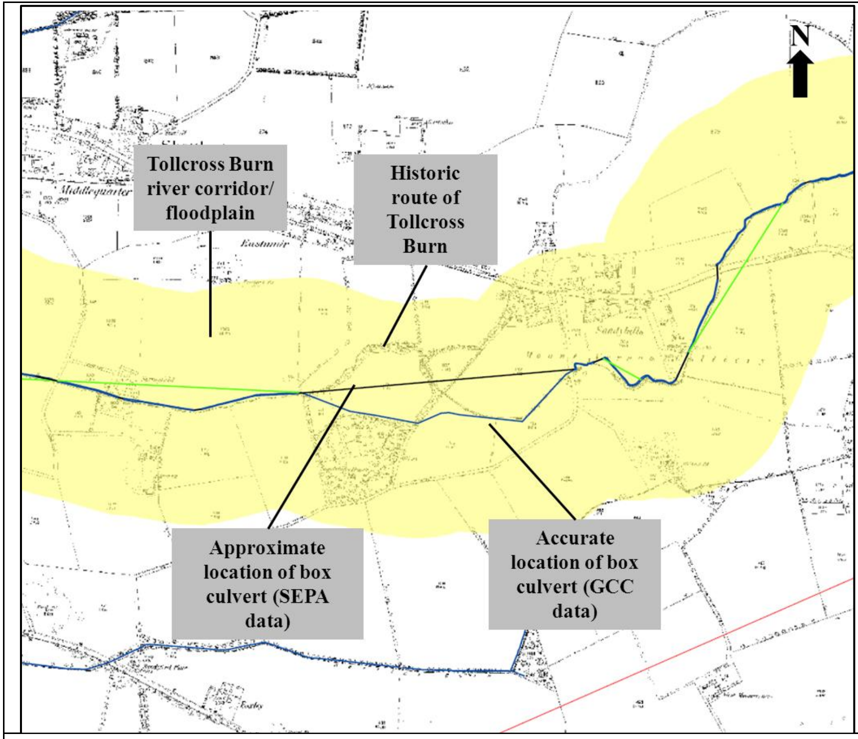


Summary details of example output	
Model	Flood control
Step	4
Step title	Is the watercourse subject to morphology pressures?
Task	4.1
Note: Figure also available within standalone CD-ROM.	

Notes: This example flood control model output shows floodplain openspace and the approximate location of culvert pressures (black lines) and realignment pressures (bright green lines).

Figure 7.4 Flood control model Step 4, Task 4.1 – example model output

Task 4.3 scopes out potential constraints to restoration. As described above, this research is based on a preferred restoration option whereby the watercourse is restored to its original route and a functional floodplain reinstated. For this task, the digitised historic route of the watercourse is added to ArcMap and overlayed with modern base mapping to identify constraints and help scope the feasibility of restoring the watercourse to its original route. The key constraints considered in Task 4.3 are housing, other buildings (e.g. shops, community facilities, schools etc) and roads infrastructure[86]. Figure 7.6 provides an example of Task 4.3.



Summary details of example output	
Model	Flood control
Step	4
Step title	Is the watercourse subject to morphology pressures?
Task	4.2
Note: Figure also available within standalone CD-ROM.	

Notes: This example flood control model output shows the location of a specific culverted reach of the watercourse under investigation relative to 1860s base mapping. Note that the 1860s base mapping shows the historic route of the watercourse including detail of a significant meander to the north that has been straightened out by the modern culvert.

Figure 7.5 Flood control model Step 4, Task 4.2 – example model output

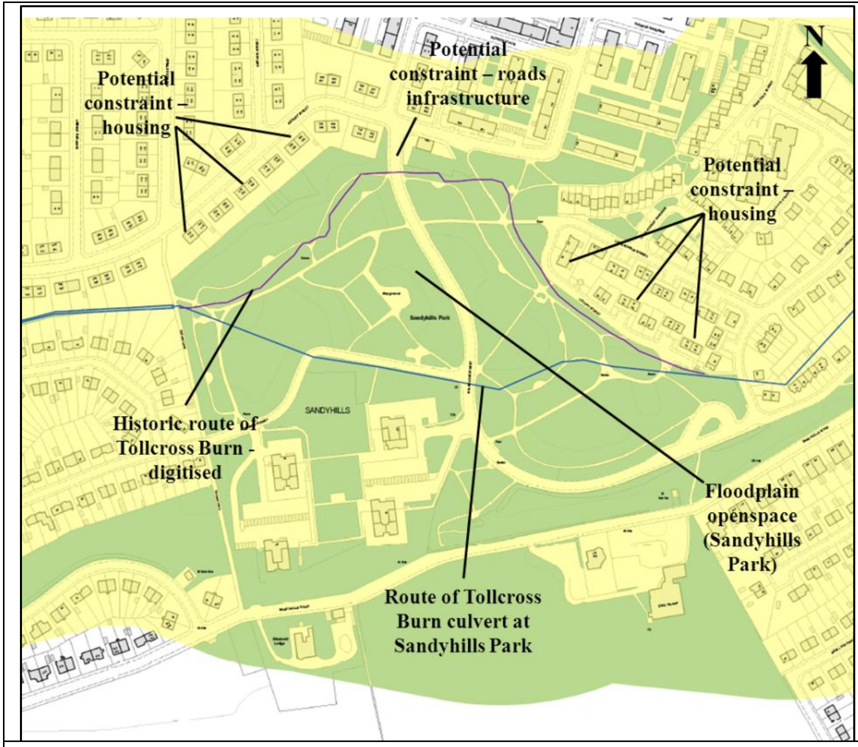
The constraints analysis undertaken during Task 4.3 also considers how any identified housing and infrastructure constraints may impact the cross-section of a reinstated functional floodplain. Where the floodplain is constrained such that it can only be relatively narrow for example, the engineering and design constraints are such that the main channel is likely to be steep sided and deep with the floodplain steeply sloped and relatively narrow also[87]. This sort of channel-floodplain cross-section configuration would put significant constraints on other land

---

[86] There are a range of additional constraints to river restoration that need to be considered in more detailed site level planning and design. Key constraints in this regard include underground infrastructure such as foul, surface water and combined sewers.

[87] Where the floodplain is constrained and narrow, a steep and deep channel cross-section is required to provide the cross-sectional area necessary to accommodate anticipated water volumes under high flow conditions

use/management based NFM measures (such as floodplain woodland establishment – see section 4.6 and Appendix 4), potentially reducing the FRM and wider multiple benefits of the scheme.



Summary details of example output	
Model	Flood control
Step	4
Step title	Is the watercourse subject to morphology pressures?
Task	4.3
Note: Figure also available within standalone CD-ROM.	

Notes: This example flood control model output indicates potential restoration constraints were the watercourse to be restored to its original route i.e. reinstating the sizeable meander to the north. Under this restoration scenario, key constraints are housing and roads infrastructure.

Figure 7.6 Flood control model Step 4, Task 4.3 – example model output

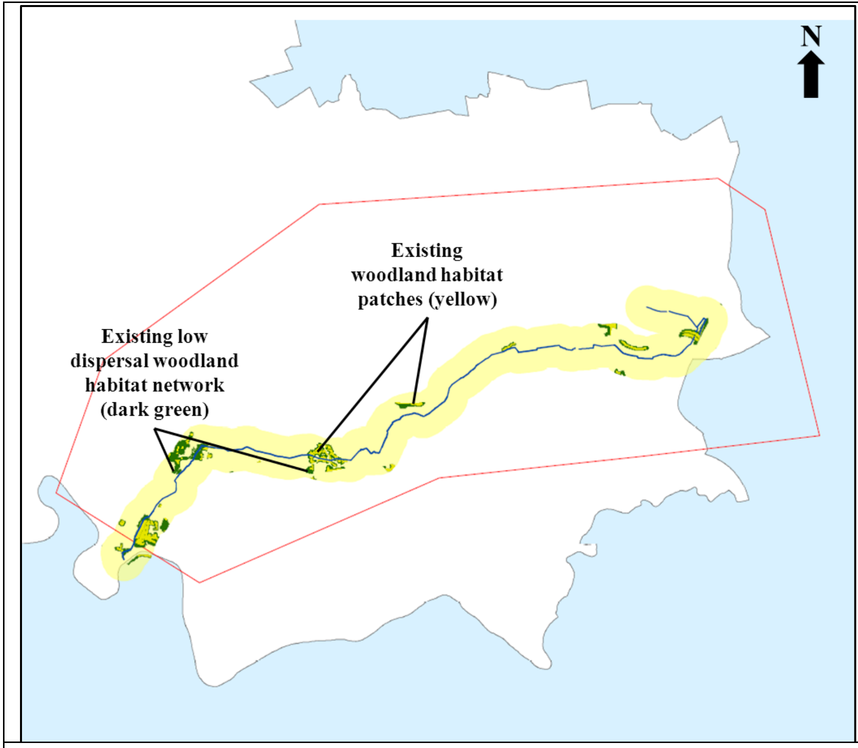
Finally, Task 4.4 requires practitioners to document the outputs of the constraints analysis thus far. This includes using ArcGIS to digitise the approximate area within the study site that may be available for floodplain reinstatement and a summary schedule of the constraints identified (see Appendix 8). At this stage in the flood control model, the practitioner will only have considered constraints associated with housing, other buildings and roads infrastructure. At Step 7, topographical constraints are introduced and the area within the site that is potentially available for floodplain reinstatement may be reduced. As with Step 3 however, practitioners may wish to cease their investigation at the end of Step 4 and key outputs should be documented to support future work. Tasks 4.2 – 4.4 are repeated for each instance where morphology pressures are found to be located within an area of floodplain openspace.

Table 7.5 Flood control model Step 4 – schedule of model outputs

Output	Type of output	Description of output
1. Shapefile of watercourse restoration opportunities	Spatial (line ArcGIS feature class)	For areas of floodplain openspace where: a) the watercourse under investigation flows through the openspace; and b) the watercourse is subject to either a culvert or realignment pressure, this output depicts the historic route of the burn as a digitised ArcGIS feature class (lines)
2. Shapefile of potential floodplain reinstatement area	Spatial (polygon ArcGIS feature class)	Where restoration of morphology pressures has been identified as a desirable course of action (see above), this output depicts land that could potentially be used for reinstating a functional floodplain as a digitised ArcGIS feature class (polygons). The digitised areas account for key infrastructure constraints (e.g. roads, houses etc)
3. Total potential increase in watercourse length (m/km)	Metric	Where restoration of morphology pressures has been identified as a desirable course of action (see above), this output details the approximate increase in watercourse length that may be possible if all modified stretches are restored to their historic routes. This metric can also be represented as a percentage increase in length over the watercourse's current modified length
4. Total potential increase in functional floodplain area (ha)	Metric	Where restoration of morphology pressures has been identified as a desirable course of action (see above), this output details the total potential increase in the area of functional floodplain available for flood storage (i.e. the sum of all outputs identified under item 2 above)

7.2.5 Step 5 – is there potential for significant areas of floodplain woodland and wetland?

The purpose of Step 5 in the flood control model is **to identify whether existing or potential areas of floodplain woodland and wetland within the study catchment are significant in NFM terms**. Individual tasks to be undertaken in Step 5 of the flood control model are described in Appendix 8 including geoprocessing notes for the ArcGIS based operations. The analysis of floodplain woodland and wetland provision is undertaken with reference to habitat patches, habitat network and habitat opportunities data (see section 2.4.2 for further information on the data used). Further information on landscape ecology, habitat networks and associated ecosystem services can be found in Chapter 5. The potential impacts of floodplain woodland design on NFM function is considered in Steps 6, 7 and 8 (see section 7.2.6 – 7.2.8).

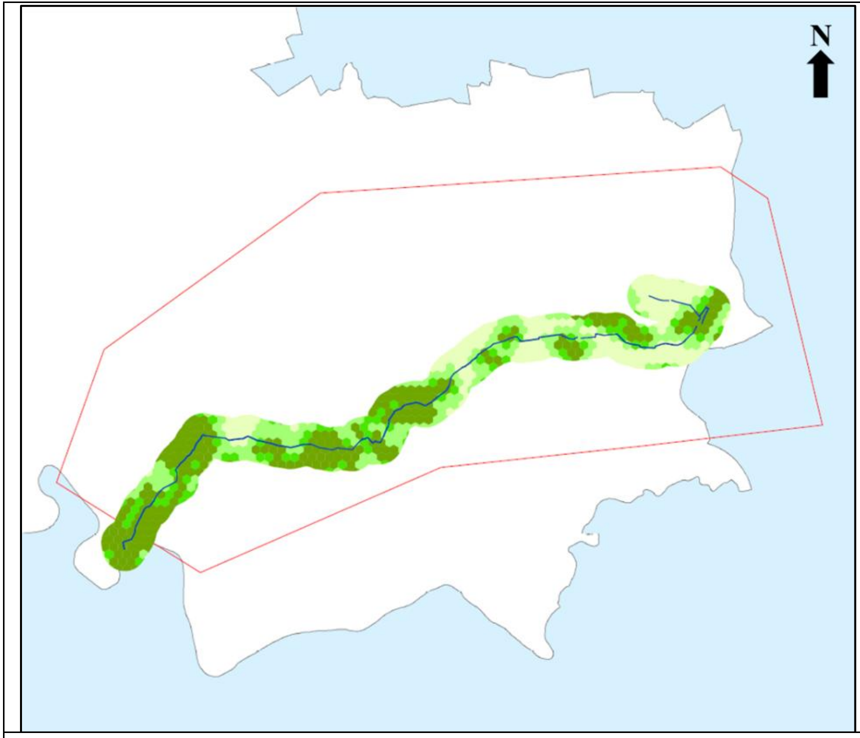


Summary details of example output	
Model	Flood control
Step	5
Step title	Is there potential for significant areas of floodplain woodland and wetland?
Task	5.2
Note: Figure also available within standalone CD-ROM.	

Notes: This example flood control model output shows the extent and distribution of existing floodplain woodland habitat patches (yellow polygons) and habitat networks (green polygons) within the Tollcross Burn catchment.

Figure 7.7 Flood control model Step 5, Task 5.2 habitat patches and habitat networks in the floodplain – example model output

The key purpose of Step 5 is to understand the existing and potential extent and distribution of floodplain woodland and wetland within the study catchment. Step 5 comprises three tasks. Task 5.1 adds the various habitat datasets to ArcMap. Task 5.2 then clips the habitats data added at Task 5.1 down to the area of interest – i.e. the modelled floodplain defined during Step 3 (see Figure 7.3). This provides the necessary data for calculating key habitat metrics in Task 5.3. Figure 7.7 shows existing floodplain woodland habitat patches and their associated low dispersal habitat networks. Figure 7.8 shows the woodland habitat opportunities data for the Tollcross Burn floodplain (see section 5.2 for further information on habitat networks). Similar outputs are produced for floodplain wetland.



Summary details of example output	
Model	Flood control
Step	5
Step title	Is there potential for significant areas of floodplain woodland and wetland?
Task	5.2
Note: Figure also available within standalone CD-ROM.	

Notes: Further information on the biodiversity opportunities data is available at section 2.4.2. In summary however, darker green areas indicate land with greater ecological potential to support the establishment of broadleaved woodland habitat. The biodiversity opportunities model developed by Forest Research (Smith et al, 2008) underpinning this data considers a range of parameters including existing land use/land cover and the ecological connectivity afforded by existing habitat patches.

Figure 7.8 Flood control model Step 5, Task 5.2 floodplain woodland opportunity areas – example model output

Task 5.3 calculates three key habitat metrics to quantify the existing and potential area of floodplain woodland and wetland within the study catchment. All the metrics can be obtained easily from the GIS. The metrics are also expressed as a percentage of the total catchment area (see Table 7.6). The three metrics are:

- **Metric 1:** total area of habitat patches within the floodplain
- **Metric 2:** total area of habitat networks within the floodplain
- **Metric 3:** potential area available for habitat expansion within the floodplain i.e. the difference between metrics 1 and 2 (see section 5.2)

Example habitat metrics for the Tollcross Burn catchment are shown at Table 7.6. As part of this research, a simple model for calculating Metric 3 based on Metric 1 and 2 input data has been created using Microsoft Excel (see Appendix 8 for further information). As shown in Table 7.6, based on the habitat metrics data alone, there would arguably be significant potential for increasing the cover of both floodplain woodland and wetland habitat within the Tollcross Burn catchment. On the basis of the literature however (see section 4.6), it is suggested that floodplain woodland – as a stand-alone strategy for NFM – is only considered where the existing or potential floodplain woodland is equivalent to 2% or more of the whole catchment area. In the case of the Tollcross Burn catchment therefore, the *potential* area of floodplain woodland, at 1.34% of the catchment area would not be considered sufficient as a 'stand-alone' NFM strategy.

Table 7.6 Flood control model Step 5, Task 5.3 – example model output

Habitat type	**Metric 1: total area of existing habitat patches (ha)**	**Metric 2: total area of existing habitat networks (ha)**	**Metric 3: area potentially available for habitat expansion (ha)**
Woodland	12.3	36.14	23.84
Wetland	1.68	5.98	4.3
Catchment scale analysis: Tollcross Burn catchment area = 2621.5ha			
Percentage of Tollcross Burn catchment **currently** comprised of **woodland habitat**: 0.47%		Percentage of Tollcross Burn catchment **currently** comprised of wetland habitat: 0.06%	
Percentage of Tollcross Burn catchment that could **potentially** comprised of **woodland habitat**: 1.34%		Percentage of Tollcross Burn catchment that could **potentially** comprised of wetland habitat: 0.23%	

Note: The table shows floodplain woodland and wetland habitat metrics for the Tollcross Burn catchment.

In instances such as this, where the potential area of floodplain woodland is below the 2% threshold, there may be still be beneficial options for floodplain woodland expansion as part of an integrated NFM strategy that incorporates several of the measures considered in this research. It may be the case for example that a combined strategy featuring channel restoration (see sections 4.5 and 7.2.4) in conjunction with relatively minor woodland expansion works could have a significant impact on downstream flood flows, when tested in a hydraulic model. In addition, the habitat networks data used in the flood control model is based on a low dispersal network (see sections 2.4.2 and 5.2). In effect, this allows for the identification of optimal habitat expansion sites only where ecological potential is particularly high. It may be appropriate in some cases to use habitat networks data based on a high dispersal network and/or to consider more marginal sites for habitat expansion and put more time and investment into site preparation. These types of decision will require a careful weighing up of costs and benefits that are beyond the scope of the model developed through this research. Additional guidance on the consideration of marginal sites for floodplain woodland expansion is provided at Appendix 8.

Table 7.7 Flood control model Step 5 – schedule of model outputs

Output	Type of output	Description of output
1. Shapefile of optimal sites for floodplain woodland/wetland expansion	Spatial (polygon ArcGIS feature class)	Areas of land in the floodplain of optimal suitability for the expansion of floodplain woodland and wetland habitat as a strategy for NFM
2. Shapefile of sub-optimal sites for floodplain woodland/wetland expansion	Spatial (polygon ArcGIS feature class)	Areas of land in the floodplain of sub-optimal suitability for the expansion of floodplain woodland and wetland habitat as a strategy for NFM
3. Total area of existing habitat patches (ha)	Metric	Total area of *existing* floodplain woodland and wetland habitat patches. This metric will give an indication of the degree to which existing floodplain woodland/ wetland provision may already be providing flood storage ecosystem services. This metric can also be presented as a percentage (i.e. % of the study catchment area *currently* comprised of habitat)
4. Total area potentially available for habitat expansion (ha)	Metric	Total area of floodplain land of optimal suitability for woodland and wetland *expansion*. This metric will give an indication of the degree to which potential floodplain woodland/wetland provision may be able to provide flood storage ecosystem services. This metric can also be presented as a percentage (i.e. % of the study catchment area that could *potentially* be comprised of habitat)

Outputs from Step 5 are highly useful in their own right in that they identify optimal sites where floodplain woodland and wetland expansion could potentially be undertaken to contribute positively to sustainable FRM in the study catchment. The habitat metrics identified at Task 5.3 provide useful quantitative data for understanding the scale of potential expansion and also the potential viability of floodplain woodland and wetland as 'stand-alone' NFM measures. In addition however, the spatial outputs from Step 5 (in terms of the ArcGIS shapefiles produced at Task 5.2) can also be used either as a stand-alone tool to inform policy-development across a range of issues (e.g. FRM, surface water management, land use, biodiversity, parks and openspace, landscape etc) or in multiple overlays with other data or outputs from other spatial ecosystem service models (see sections 7.3 and 7.4) to identify ecosystem service priority areas for multifunctional land use/management intervention. This is discussed further at section 8.2.

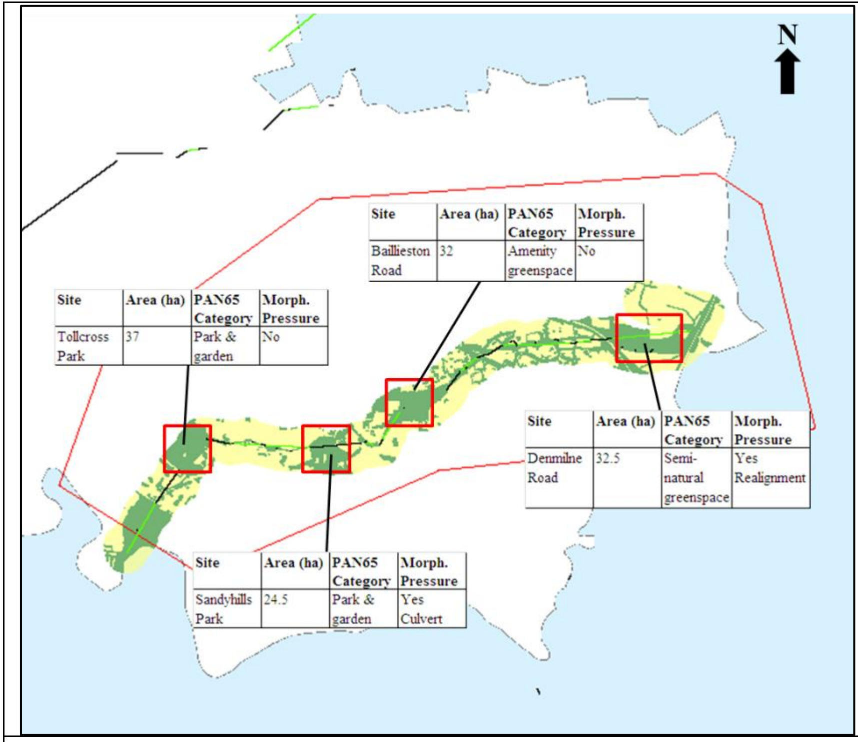
7.2.6 Step 6 – identify sites where opportunities are greatest and constraints minimal

Based on outputs generated in Steps 3, 4 and 5 (see Tables 7.4, 7.5 and 7.7), the purpose of Step 6 in the flood control model is **to identify, rank and prioritise floodplain NFM measures that have the potential to deliver the greatest FRM benefit with the minimum of constraint**. Constraint in this regard includes delivery cost which is a key issue as discussed further below. Outputs from Step 6 are then used to prioritise action in the final two steps (detailed analysis of topographical constraints and development of scenarios for testing in an appropriate hydraulic model). Individual tasks to be undertaken in Step 6 of the flood control model are described in Appendix 8.

Step 6 is premised on the identification of floodplain sites and potential interventions that are likely to be able to deliver the greatest FRM benefit through the use of the key floodplain based NFM measures considered in this research (see sections 4.5, 4.6 and 4.7). The flood control model construes FRM benefit in this regard as a function of the Manning's **n** or 'roughness' value for the floodplain and the channel under different land use/management regimes (see section 4.4). In effect, appropriate land use/management measures in the floodplain (e.g. floodplain woodland creation – see section 4.6) or environmental engineering measures in the channel (e.g. river restoration – see section 4.5) will alter Manning's **n** for the channel/floodplain, increasing surface roughness and potentially contributing to enhanced flood storage ecosystem services. Different NFM measures or combinations of measures will provide differing FRM benefits, depending on the degree to which the proposed measure(s) alters surface roughness. In summary however, non-wooded floodplain openspace (e.g. parks, gardens, sports pitches, amenity greenspace etc) will have lower values of Manning's **n** whereas fully integrated NFM schemes incorporating channel restoration, floodplain woodland/wetland establishment and site engineering (e.g. bund construction etc) are 'rougher' and will have higher values. These principles are illustrated on Tables 4.6 and 4.7. Further information on key hydraulic principles for urban land use planning and water management are provided at section 4.4.

Step 6 in the flood control model comprises four tasks. Task 6.1 identifies potential floodplain openspace sites where NFM measures of a significant scale may be viable. Further information and guidance on defining significance in this regard is provided in Appendix 8. This research has focused on sites that already have or could potentially have a direct hydraulic connection with the watercourse under investigation. In effect, this equates to floodplain openspace sites that the watercourse flows through – be that on the surface in an unmodified condition or underground or channelised in a modified condition. Figure 7.9 depicts this concept for the Tollcross Burn catchment in north-east Glasgow. This approach has purposefully avoided potential measures that might create artificial surface water conveyance routes (i.e. for connecting the watercourse with floodplain openspace sites that aren't hydraulically connected) given the additional technical modelling that would be required (see section 4.7.3).

Within Task 6.1, sites where the watercourse is subject to a morphology pressure are considered to be 'high cost' as a degree of river restoration will normally be required to secure an FRM benefit. This research has not attempted to quantify the potential costs of river restoration at these sites, rather they are simply assigned the qualitative descriptor 'high cost' which is used as an input to the Multi Criteria Analysis (MCA) in Task 6.4 (see below). This approach is considered appropriate given that the purpose of the flood control model is to identify sites and possible land use/management based interventions that can enhance flood storage ecosystem services (i.e. it is not intended to develop costed proposals for NFM measures). The use of broad information on potential river restoration costs (i.e. 'high cost' and 'low cost') is considered fit for purpose where the purpose is supporting the prioritisation of sites and potential NFM measures



Site	Area (ha)	PAN65 Category	Morph. Pressure
Baillieston Road	32	Amenity greenspace	No

Site	Area (ha)	PAN65 Category	Morph. Pressure
Tollcross Park	37	Park & garden	No

Site	Area (ha)	PAN65 Category	Morph. Pressure
Denmilne Road	32.5	Semi-natural greenspace	Yes Realignment

Site	Area (ha)	PAN65 Category	Morph. Pressure
Sandyhills Park	24.5	Park & garden	Yes Culvert

Summary details of example output	
Model	Flood control
Step	6
Step title	Identify sites where opportunity is greatest and constraint minimal
Task	6.1
Note: Figure also available within standalone CD-ROM.	

Notes: This example output shows floodplain openspace sites that have been selected for further analysis due to their size (ha), existing land use and existing hydrological connection to the study watercourse. Sites where the watercourse is subject to a morphology pressure are considered ‘high cost’ as some degree of river restoration activity is likely to be required. Sites without morphology pressures are considered ‘low cost’ as key NFM measures (e.g. floodplain woodland) can be progressed without the need for any river restoration activity.

Figure 7.9 Flood control model Step 6, Task 6.1 – example model output

Tasks 6.2 to 6.4 should be undertaken for each site identified through Task 6.1. Task 6.2 helps to identify potential NFM measures for each scoped in floodplain openspace site from Task 6.1. Task 6.2 is distinctly spatial in nature and involves an overlay of key spatial outputs from Steps 3, 4 and 5 (see Tables 7.4, 7.5 and 7.7) to help identify the full range of measures that may be possible at each of the scoped in sites. The flood control model spatial outputs overlayed in the GIS are:

- **Floodplain openspace** (Step 3, Output 1, Table 7.4)
- **Watercourse restoration opportunities** (Step 4, Output 1, Table 7.5)
- **Potential floodplain reinstatement areas** (Step 4, Output 2, Table 7.5)
- **Optimal sites for floodplain woodland and wetland expansion** (Step 5, Output 1, Table 7.7)

Figure 7.10 depicts a typical Task 6.2 overlay that has been undertaken for the Tollcross Burn catchment. As shown on Figure 7.10, each of the floodplain openspace sites identified and scoped in at Task 6.1 become NFM opportunity areas. NFM opportunity areas No.1 and No.3 are likely to be 'low cost' sites as the watercourse is unmodified at these locations whereas No.2 and No.4 are more likely to require some degree of restoration and are therefore considered to be 'high cost'.

Site level analysis of the various layers in the Task 6.2 overlay (see Figure 7.10) gives an indication of the types of NFM measure that may be possible. For example, at NFM opportunity area No.1 (Tollcross Park), there is a sizeable area of floodplain openspace with the PAN65 land use category 'Park and Garden' (see Table 3.4) and the site is hydrologically connected to the watercourse. In addition, the site contains a substantial woodland habitat network and several optimal sites for floodplain woodland expansion[88] (see section 4.6). Further guidance on how to interrogate Task 6.2 outputs to identify NFM measures that may be viable at each site is provided in Appendix 8.

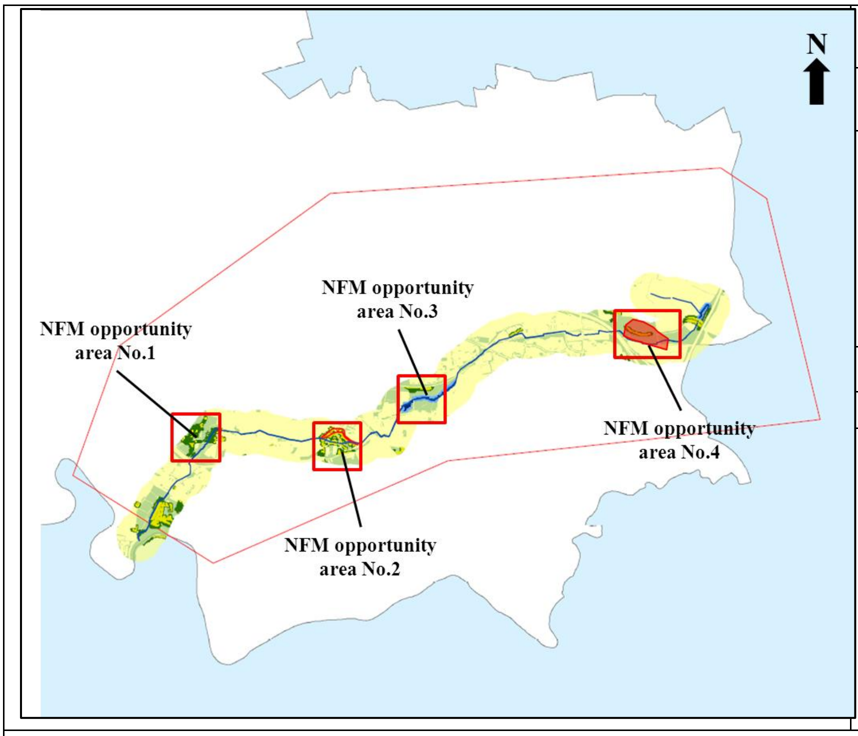
Task 6.3 of the flood control model requires practitioners to collate a schedule of potential NFM measures for each of the scoped in opportunity areas. Example schedules of measures for NFM opportunity areas No.1 and No.2 are provided at Table 7.8 (schedules for opportunity areas No.3 and No.4 are provided at Appendix 8). As indicated in Table 7.8, potential NFM measures should be ranked on the basis of their likely FRM benefit (see section 4.4 and Tables 4.6 and 4.7). In task 6.3, potential NFM measures are ranked purely on the basis of their likely FRM benefit (i.e. their potential to positively alter Manning's **n** values by increasing channel and/or floodplain roughness). In addition to FRM benefit however, there are also several other criteria that will influence the intervention's potential viability as a sustainable FRM scheme. Accordingly, once all potential interventions have been

---

[88] Tollcross Park is one of Glasgow's finest designed landscapes. Accordingly, any NFM measures pursued at this site would need to be designed carefully for sensitive integration with the existing landscape, management and use of the park. These issues are reflected to a degree in Step 8 of the flood control model (see section 7.2.8) and are discussed at sections 8.2 and 8.3. At this stage of the flood control model however, the focus is on identifying potential sites and measures of a scale that could deliver significant FRM benefits.

identified for a given site through Task 6.3, a more sophisticated evaluation is required to rank the alternatives in terms of wider sustainability criteria[89]. These are:

1. The number or total area of sites where the NFM measure is likely to be viable
2. The likely cost of intervention
3. The likely impact on Manning's n and associated FRM benefit



Summary details of example output	
Model	Flood control
Step title	Identify sites where opportunity is greatest and constraint minimal
Step	6
Task	6.2
Note: Figure also available within standalone CD-ROM.	

This example output illustrates the use of combined flood control model outputs from Steps 3-5 to identify potential NFM opportunities for scoped in floodplain openspace sites from Task 6.1. The very light green polygons are floodplain openspace sites, the red polygons are areas that may be available for floodplain reinstatement following river restoration, the yellow and green polygons are woodland habitat patches/networks and the dark/pale blue polygons are wetland habitat patches/networks.

Figure 7.10 Flood control model Step 6, Task 6.2 – example model output

---

[89] Although the criteria considered in the Task 6.4 MCA are wider than those considered in Task 6.3, there are still a broad range of significant issues that are not considered in the analysis. These include amenity, landscape, biodiversity as well as the views of stakeholders and local communities. These wider sustainability issues are picked up further in Step 8 of the flood control model (see section 7.2.8) and discussed at sections 8.2 and 8.3.

Table 7.8 Flood control model Step 6, Tasks 6.2 and 6.3 - example schedules of potential natural flood management (NFM) measures

Site details		**Potential NFM measures available**
Site	Tollcross Park	1. Leave the site as is and zone in LDP as flood storage area 2. Engineering/bunding of the site to increase flood storage capacity 3. Expansion of floodplain woodland 4. Fully integrated scheme incorporating LDP zoning, engineering/bunding of the site and floodplain woodland expansion
NFM Opportunity No	1	
PAN65 Category	Park and Garden	
Area (ha)	37	
High/low cost	Low cost	
Site	Sandyhills Park	1. Leave the site as is and zone in LDP as flood storage area[90] 2. Restore channel and functional floodplain and reconnect watercourse with floodplain[91] 3. Channel/functional floodplain restoration + engineering/bunding of the site 4. Channel/functional floodplain restoration + floodplain woodland expansion 5. Fully integrated scheme incorporating channel/floodplain restoration, engineering/bunding of the site and floodplain woodland expansion
NFM Opportunity No	2	
PAN65 Category	Park and Garden	
Area (ha)	24.5	
High/low cost	High cost (culvert)	

Note: NFM measures in the table above are listed in increasing order of FRM benefit. At the Tollcross Park site for example, measure 1 – *leave the site as is and zone in LDP as flood storage area* – will have a lesser FRM benefit than measure 3 – *expansion of floodplain woodland*.

Task 6.3 identifies a schedule of potentially viable NFM measures or combination of measures that could be delivered at a given site based on outputs from earlier steps of the flood control model. At this stage therefore, there is a need to prioritise this list of potential measures in order to recommend a specific measure (or combination of measures) to take forward for consideration in Steps 7 and 8 of the flood control model, for each site (see sections 7.2.7 and 7.2.8). This decision-making process could be undertaken in a number of ways e.g. group discussions/workshops with relevant personnel from the municipality (e.g. planners, civil engineers, ecologists etc), a wider process of stakeholder engagement (potentially including members of the public in affected areas) or with reference to

---

[90] In its current configuration, the site at Tollcross Park is not currently providing any flood storage ecosystem services as the watercourse is culverted along this reach and therefore has no connection with the floodplain. This zoning measure would ensure that the site is protected for potential future development of NFM measures (including river restoration).

[91] All other potential NFM measures at this site are predicated on the delivery of this measure to reconnect the watercourse with its floodplain.

key strategic plans and policies in order to evaluate the degree to which potential NFM measures align or conflict with relevant strategic objectives and targets. However as the flood control model has been designed for use by individual practitioners, a less deliberative approach is favoured to ensure its ease of use by individuals[92]. Given the nature of the outputs from Task 6.3 and the potentially limitless criteria that define the sustainability of NFM measures, a Multi Criteria Analysis (MCA) approach has been favoured. MCA is an umbrella term describing a collection of formal approaches that seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter (Belton and Stewart, 2002). Crucially, it has the benefit of offering a process that leads to rational, justifiable and explainable decisions (Belton and Stewart, 2002; Mendoza and Martins, 2006). MCA can use quantitative, qualitative or mixed data. Indeed Kenyon (2007 p.80) used qualitative, participant-led MCA to evaluate FRM options in Scotland noting how the use of a "visual, structured and progressive method delivered a package of outputs offering the precise result so often required by policy-makers".

For each NFM opportunity area, Task 6.4 uses MCA to evaluate the range of possible NFM measures or combinations of measures identified for the site through Task 6.3. A simple model for conducting the MCA evaluation has been developed in Microsoft Excel. The MCA evaluation considers 'low cost' and 'high cost' sites separately as 'high cost' sites will always require river restoration to reconnect the watercourse with its floodplain. The full range of possible NFM measures or combinations of measures considered in the MCA is indicated in Table 7.9. The MCA evaluates each measure or combination of measures against FRM sustainability criteria to calculate a final score accounting for the likely availability of the measure within the catchment[93], its cost and its FRM benefit. These criteria[94]

---

[92] This thesis envisages that recommendations from individual and integrated spatial model outputs (see section 8.2) would be tested through stakeholder and public consultation as part of the process of developing Local Development Plans (LDPs) – see section 8.3.

[93] Some measures are likely to be more available within catchments than others and are scored higher in the MCA as a result. For example, **all** floodplain openspace could be protected through planning policy to maintain existing levels of flood storage ecosystem services – i.e. the 'leave the site as is and zone in LDP as flood storage area' measure. In principle therefore, this measure could be rolled out across all floodplain openspace as it is not reliant on the presence of any other features (e.g. habitat

have been identified from the literature (see section 4.4 and Tables 4.6 and 4.7) as well as the author's professional knowledge and experience working in urban land use planning/management at Glasgow City Council (GCC).

Table 7.9 Flood control model Step 6, Task 6.4 – natural flood management (NFM) measures considered in multi criteria analysis (MCA) evaluation

Low cost site NFM measures	High cost site NFM measures
1. Leave the site as is and zone in LDP as flood storage area 2. Engineering/bunding of the site 3. Floodplain woodland expansion 4. Floodplain wetland expansion 5. Fully integrated NFM scheme	1. Restore channel/floodplain and reconnect watercourse with floodplain 2. High Cost Measure No.1 + floodplain woodland expansion 3. High Cost Measure No.1 + floodplain wetland expansion 4. High Cost Measure No.1 + engineering/bunding of the site 5. Fully integrated NFM scheme incorporating High Cost Measure No.1

Note: 'High cost' sites will always require river restoration to reconnect the watercourse with its floodplain. At high cost sites therefore, this initial intervention must always be undertaken before any of the other measures can usefully be put in place, hence why all measures at these sites are considered to be 'high cost'.

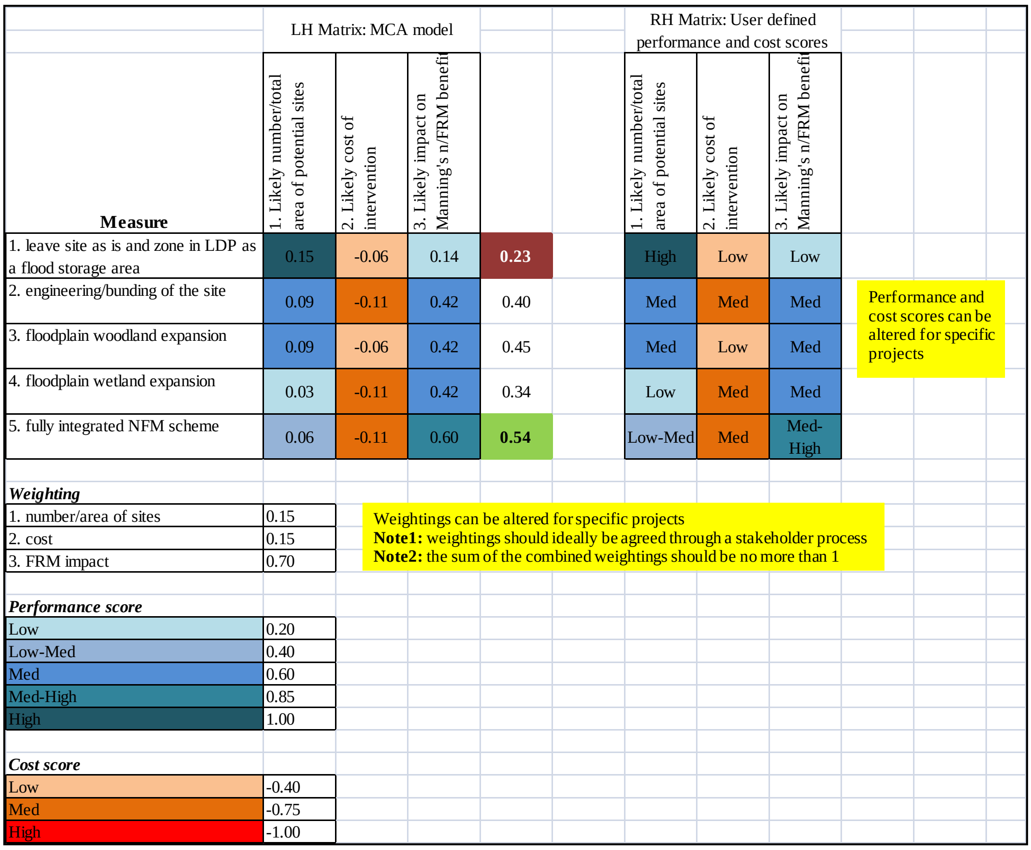
The practitioner can alter key parameters in the MCA including *performance* scores (for the likely availability/prevalence and FRM benefit criteria – a positive number) and a *cost* score (for the likely cost of intervention criterion – a negative number). The three criteria can also be weighted, allowing the practitioner to express preferences concerning *costs* and *benefits*. For example in instances where cost is less of an issue, the weighting could be designed to favour high performing measures with a strong FRM benefit (e.g. more expensive fully integrated schemes – see Table 7.9). Practitioners may also wish to run a number of scenarios, using different performance scores, cost scores and weightings, to explore different cost/benefit preferences. The MCA evaluation will then numerically rank the alternative measures or combinations of measures available at each site, providing key evidence to inform decision-making when progressing to Steps 7 and 8 of the flood control

---

patches). Conversely, the 'expansion of floodplain woodland/wetland' measure is reliant on the presence of existing habitat or at least good ecological potential for habitat establishment

[94] The nature of the MCA approach at Task 6.4 is such that additional FRM sustainability criteria can be added in subsequent iterations of the flood control model to improve the richness and depth of analysis. The three criteria used in this iteration are considered appropriate and fit-for-purpose given the objectives and proposed utility of the flood control model but this is a key area for future research as discussed at section 9.3.

model. Further details and practical guidance on using the MCA approach developed through this research is provided at Appendix 8. Example MCA outputs are shown at Figures 7.11 and 7.12.



	LH Matrix: MCA model				RH Matrix: User defined performance and cost scores		
Measure	1. Likely number/total area of potential sites	2. Likely cost of intervention	3. Likely impact on Manning's n/FRM benefi		1. Likely number/total area of potential sites	2. Likely cost of intervention	3. Likely impact on Manning's n/FRM benefi
1. leave site as is and zone in LDP as a flood storage area	0.15	-0.06	0.14	**0.23**	High	Low	Low
2. engineering/bunding of the site	0.09	-0.11	0.42	0.40	Med	Med	Med
3. floodplain woodland expansion	0.09	-0.06	0.42	0.45	Med	Low	Med
4. floodplain wetland expansion	0.03	-0.11	0.42	0.34	Low	Med	Med
5. fully integrated NFM scheme	0.06	-0.11	0.60	**0.54**	Low-Med	Med	Med-High

Performance and cost scores can be altered for specific projects

Weighting	
1. number/area of sites	0.15
2. cost	0.15
3. FRM impact	0.70

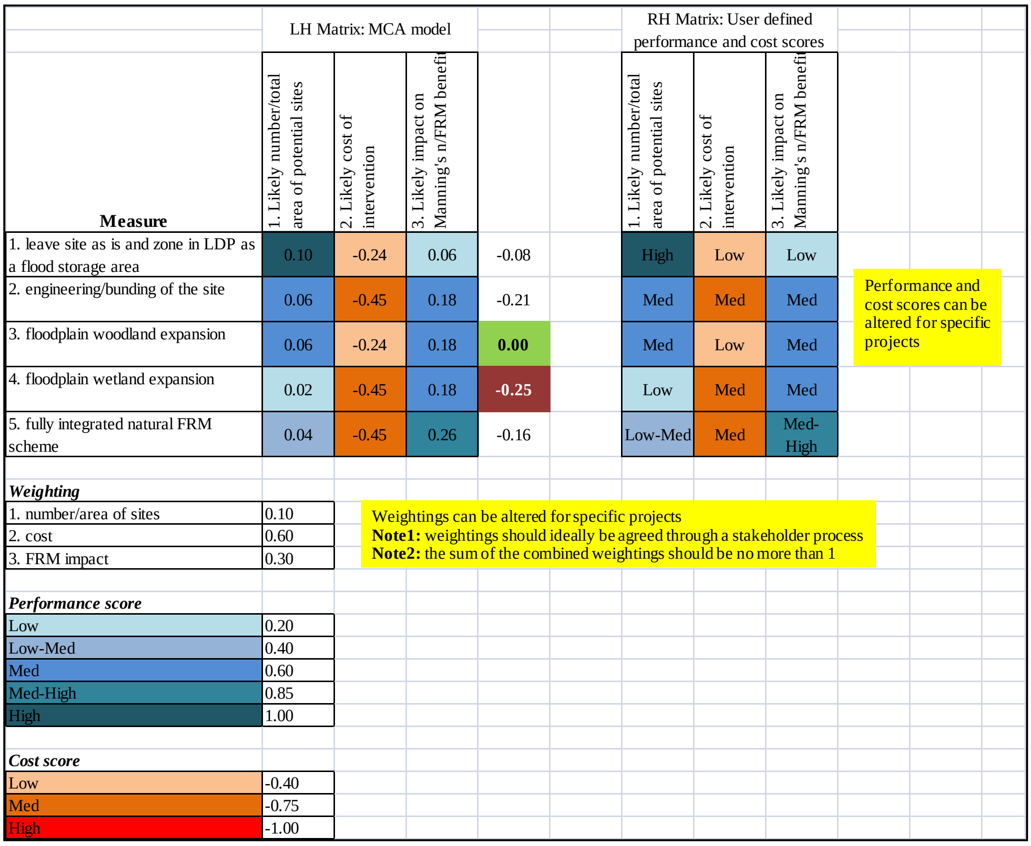
Weightings can be altered for specific projects
Note1: weightings should ideally be agreed through a stakeholder process
Note2: the sum of the combined weightings should be no more than 1

Performance score	
Low	0.20
Low-Med	0.40
Med	0.60
Med-High	0.85
High	1.00

Cost score	
Low	-0.40
Med	-0.75
High	-1.00

Figure 7.11 Flood control model Step 6, Task 6.4 – example multi criteria analysis (MCA): low cost site/weighting scenario 1

Note: The figure above (also available on standalone CD-ROM) shows an example MCA output for a ‘low cost’ site – i.e. a site that does not require river restoration. The five NFM measures listed on the left-hand matrix (i.e. the MCA model) are identical to those listed at Table 7.9 under the ‘low cost site NFM measures’ column. For each **measure**, the practitioner has the option of altering the performance and cost scores (right-hand matrix). For example, measure 1 – *leave site as is and zone in LDP as a flood storage area* – is applicable to all floodplain openspace sites and has been allocated a *high* performance score against this criterion. Conversely, it is likely to have a minimal FRM benefit as channel and floodplain roughness will be low. It has therefore been allocated a *low* performance score against this criterion (see right-hand matrix). No physical intervention is required under this measure so the cost criterion has been scored as *low*. For each **criterion**, the practitioner has the option of altering the weighting applied to that criterion in the MCA model (left-hand matrix). In the scenario indicated in the Figure above, the emphasis is placed very much on FRM benefit which has been allocated a weighting of 0.70. The other two criteria are considered less important each with a weighting of 0.15. For each measure, the MCA model (left-hand matrix) then multiplies each cost/performance score against its relevant weighting. Weighted scores are then summed to give an overall ‘FRM sustainability’ score for the measure (final column in the left-hand matrix). Given the preferences expressed in the figure above therefore, measure 5 – *fully integrated NFM scheme* – scores highest (0.54) as it has a strong FRM benefit and similar costs to a number of other measures. Unsurprisingly, measure 1 scores lowest (0.23) due to its low score against the FRM benefit criterion.



	LH Matrix: MCA model				RH Matrix: User defined performance and cost scores		
Measure	1. Likely number/total area of potential sites	2. Likely cost of intervention	3. Likely impact on Manning's n/FRM benefi		1. Likely number/total area of potential sites	2. Likely cost of intervention	3. Likely impact on Manning's n/FRM benefi
1. leave site as is and zone in LDP as a flood storage area	0.10	-0.24	0.06	-0.08	High	Low	Low
2. engineering/bunding of the site	0.06	-0.45	0.18	-0.21	Med	Med	Med
3. floodplain woodland expansion	0.06	-0.24	0.18	**0.00**	Med	Low	Med
4. floodplain wetland expansion	0.02	-0.45	0.18	**-0.25**	Low	Med	Med
5. fully integrated natural FRM scheme	0.04	-0.45	0.26	-0.16	Low-Med	Med	Med-High

Performance and cost scores can be altered for specific projects

Weighting	
1. number/area of sites	0.10
2. cost	0.60
3. FRM impact	0.30

Weightings can be altered for specific projects
Note1: weightings should ideally be agreed through a stakeholder process
Note2: the sum of the combined weightings should be no more than 1

Performance score	
Low	0.20
Low-Med	0.40
Med	0.60
Med-High	0.85
High	1.00

Cost score	
Low	-0.40
Med	-0.75
High	-1.00

Figure 7.12 Flood control model Step 6, Task 6.4 – example multi criteria analysis (MCA): low cost site/weighting scenario 2

Note: Further details of the functionality of the MCA are provided in the notes to Figure 7.11. The figure above indicates MCA results using a different weighting scenario to that shown in Figure 5.11 (note that the performance and costs scores are the same in both scenarios). In the scenario indicated in the figure above, the emphasis is placed on cost which has been allocated a weighting of 0.60. The other two criteria are considered less important with the number/area of sites criterion allocated a weighting of 0.1 and the FRM benefit criterion 0.30. Given the preferences expressed in the figure above therefore, measure 3 – *floodplain woodland expansion* – scores highest (0.00) as it is one of only two low cost measures and is scored medium on the number/area of sites and FRM benefit criteria. Measure 4 scores lowest (-0.25) due to its relatively high cost score and fairly low performance scores. Figure also available within standalone CD-ROM.

As indicated on Figures 7.11 and 7.12, the MCA can be used to evaluate a number of different scenarios. In Figure 7.11, weightings have been set up to focus on the FRM benefit criterion whereas in Figure 7.12, the focus is on cost. The outputs of the MCA can subsequently be used to rank and prioritise potential measures (or combinations of measures) at individual sites to carry forward to steps 7 and 8 of the flood control model (see sections 7.2.7 and 7.2.8). For example, MCA outputs shown at Figures 7.11 and 7.12 are for ‘low cost’ sites. Table 7.8 indicates the range of potential NFM measures that may be available at Tollcross Park which is a low cost site (see Figure 7.9). Under the FRM *benefit* focussed scenario (see Figure 7.11), the MCA suggests that pursuing a fully integrated NFM scheme would be the best option for Tollcross Park. On the other hand, outputs from the *cost* focussed scenario (see Figure 7.12) suggest that the single measure floodplain woodland expansion option would be preferential. This example illustrates how different cost/benefit preferences can be used to explore sensitivity when a range of possible NFM measures are available for a given site.

7.2.7 Step 7 – topographical analysis to identify further constraints/viability of measures

The purpose of Step 7 in the flood control model is **to estimate the gradient of the floodplain cross-section at key locations within NFM opportunity areas in order to identify further constraints on the development of NFM schemes**. Individual Step 7 tasks are described in more detail in Appendix 8.

Steeply sided floodplains can place particular constraints on channel and floodplain restoration and floodplain woodland and wetland expansion based NFM measures as discussed at section 4.6 and Appendix 4. For example, restoring a functional floodplain through the creation of a two stage channel[95] where existing gradients are steep would likely necessitate significant and potentially costly earthworks in order to realise desired gradients in the floodplain. Given the wider benefits[96] associated with channel and floodplain restoration, the costs associated with earthworks etc may be considered reasonable in this regard. On the other hand, undertaking such earthworks to reduce gradients and improve the performance of a floodplain woodland expansion project would be harder to justify.

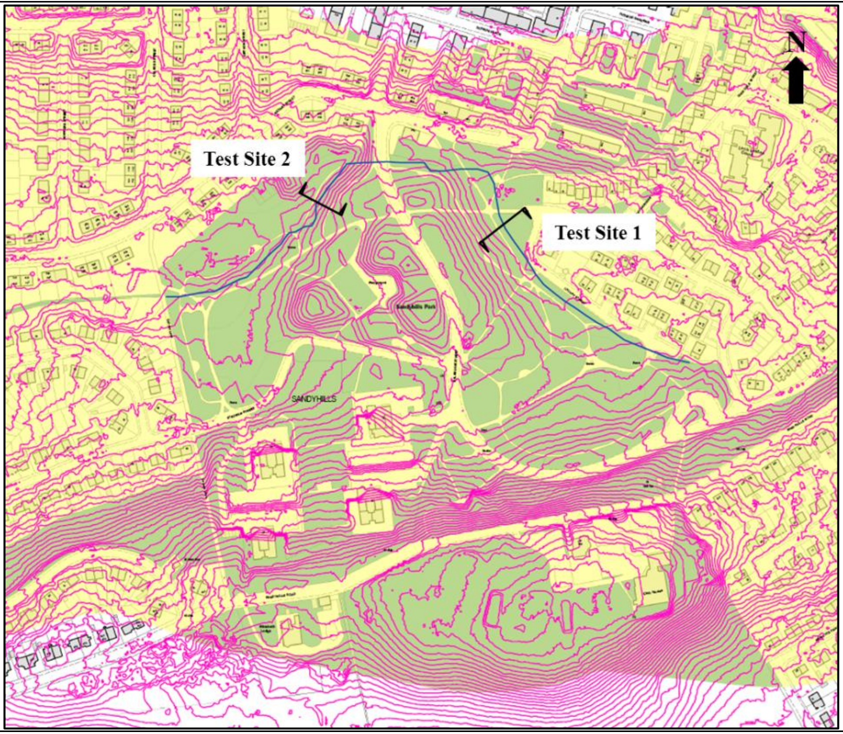
In Step 7 therefore, practitioners undertake a final analysis of constraints to gain a more refined understanding of where topography has the potential to negatively impact the FRM benefit of prioritised NFM measures carried forward from Step 6 (see section 7.2.6). The analysis in Step 7 is applied to both ‘low cost’ and ‘high cost’ sites though, as mentioned above, costly earthworks may be easier to justify at ‘high cost’ sites where channel/floodplain restoration will contribute

---

[95] Such as that discussed at section 4.5 and shown on Figures 4.7 and 4.8

[96] And also relevant legal drivers that require morphology pressures to be addressed, such as the Water Framework Directive (WFD) in the European Union (EU): http://ec.europa.eu/environment/water/water-framework/ [accessed 08/12/13]

towards wider water environment objectives etc[97]. At 'low cost' sites, Step 7 undertakes gradient estimation at test sites along the watercourse's *existing* route to identify potential constraints to floodplain woodland and wetland expansion. At 'high cost' sites, gradient estimation is undertaken at test sites along the *proposed* route of the restored watercourse (as per Step 4 Task 4.3 – see section 7.2.4) to identify potential constraints to watercourse/channel restoration and floodplain woodland and wetland expansion.



Summary details of example output	
Model	Flood control
Step	7
Step title	Topo. Analysis to identify further constraints and viability of measures
Task	7.1
Note: Figure also available within standalone CD-ROM.	

Notes: The figure above shows Sandyhills Park – NFM opportunity area No.2 from Step 6. It is a 'high cost' site. The pink lines are topographical contours at 0.5m intervals. The blue line is the proposed route for restoring the watercourse (as identified at Step 4) which is culverted along this stretch. The black lines indicate the locations of proposed floodplain gradient test sites – i.e. the two steepest sections of the *proposed* floodplain within this NFM opportunity area.

Figure 7.13 Flood control model Step 7, Task 7.1 – example model output

Step 7 comprises four tasks and should be undertaken for each of the NFM opportunity areas identified at Step 6. Task 7.1 identifies key steep sections within the *existing* or *proposed* floodplain at each of the NFM opportunity areas from Step 6. These sections then become test sites where the gradient of the floodplain cross-

---

[97] Ibid

section is estimated. The approach adopted in Step 7 is predicated on the use of a LiDAR topographical contours data set (see section 2.4.2) which is overlayed with the watercourse restoration opportunities and floodplain reinstatement area data (from Step 4) for 'high cost' sites and the existing watercourse data for 'low cost' sites. This overlay will identify particularly steep sections of the *existing* or *proposed* floodplain which become test sites for gradient estimation. Depending on the size of the NFM opportunity area being investigated, two to three test sites should be identified in this manner as indicated on Figure 7.13.

Task 7.2 collects data from the GIS that are required for estimating the gradient of the floodplain cross-section at the test sites selected in Task 7.1. Gradient calculations rely on the following data: 1) the 'rise' or difference in elevation between the lowest and highest points; and 2) the 'run' or the horizontal distance between the lowest and highest elevations. Distances are measured for both banks of the existing/proposed floodplain, noting that these two measurements are the 'run' data used in the gradient calculations. The difference in elevation is obtained simply by counting the number of contour lines crossed within the floodplain cross-section and multiplying this by the contour interval[98]. These two measurements are the 'rise' data used in the gradient calculations[99]. Further information and guidance on the measurement of gradient in Step 7 is provided in Appendix 8.

Task 7.3 estimates the gradient of the floodplain at each of the test sites, noting that gradient is calculated separately for each bank of the *existing* or *proposed* floodplain. A simple model has been created using Microsoft Excel for estimating gradient based on input data from Task 7.2 (see Appendix 8 for further information). Table 7.10 summarises the gradient estimation carried out at NFM opportunity area No.2 (Sandyhills Park) – see Figure 7.10.

---

[98] Noting that contour interval will vary depending on the specific topographical data set used. For the Step 7 analysis it is recommended that a fine scale topographical data set is used (e.g. 0.5m contour intervals as a minimum) wherever possible – see Appendix 8 for further information

[99] It should be noted that the figure for 'rise'/ difference in elevation is a relative rather than absolute figure. The elevation at the *actual* location of an existing channel ('low cost' sites) or the *potential* location of a restored channel (high cost sites) is taken as 0m. Heights above ordnance datum (AOD) are not necessary for the calculation of slope in this step of the flood control model

Table 7.10 Flood control model Step 7, Task 7.3 – example model output

Test site No.	Rise (m)	Run (m)	Slope info.
Test site 1: south-west bank	1.5	20	• 7.5% • 1 in 13 • Moderate to gentle
Test site 2: south-east bank	2.5	12	• 20.8% • 1 in 5 • Moderate to steep
Test site 3: north-west bank	2	12	• 16.7% • 1 in 6 • Moderate to steep

Note: Refer to Figure 7.13 for location of test sites and orientation of the floodplain at these sites. At test site 1, gradient estimation has only been undertaken for the south-west bank as the bank to the north-east is broadly flat i.e. gradient is considered to be insignificant as a constraint to the development of NFM measures.

As with other steps and tasks in the flood control model, Task 7.4 requires practitioners to make informed decisions on the basis of data and information generated through subsequent steps in conjunction with their own expertise and local knowledge. Task 7.4 is one decision-making juncture out of many and an overly prescriptive approach was considered inappropriate. Given that the key purpose of Step 7 is to refine the constraints analysis, introducing quantified gradient constraint thresholds to steer practitioners to specific conclusions was considered unnecessary. Rather, broad categories of constraint have been developed as a guide for practitioners, to be used in conjunction with their own expertise, local knowledge and advice from other relevant specialists where relevant. This categorisation is shown at Table 7.11.

At Task 7.4 therefore, practitioners are required to review the floodplain cross-section gradient estimation data from Task 7.3, contrast this to the broad categories of gradient constraint shown at Table 7.11 and then form a view as to the potential severity of the gradient constraint at the NFM opportunity areas under investigation. For example, where the floodplain is steep/highly constrained (e.g. gradients of between 1:3 and 1:1 – see Table 7.11), it may only be economically viable to carry out the necessary earthworks where the proposed scheme (e.g. channel restoration in conjunction with floodplain woodland expansion) has demonstrable wider benefits as well as strong legislative drivers (e.g. addressing morphology pressures to meet WFD targets). Conversely, undertaking these earthworks as part of a scheme that solely involves floodplain woodland expansion would be less economically viable[100].

Table 7.11 Categorisation of potential gradient constraint on floodplain NFM measures

Gradient (quantitative)	Gradient (qualitative)	Potential constraint on floodplain NFM measures
2.5% or 1:40	Very gentle	🟩 **Less constrained**
5% or 1:20	Gentle	🟩
10% or 1:10	Moderate	🟨
20% or 1:5	Moderate-steep	🟨
33% or 1:3	Steep-moderate	🟧
50% or 1:2	Steep	🟧
100% or 1:1	Vey steep	🟥 **Highly constrained**

In the case of NFM opportunity area No.2 (Sandyhills Park) outlined at Table 7.10 and shown on Figure 7.13 (and in further detail at Appendix 8), test site 1 is arguably unconstrained – one bank has a moderate to gentle gradient and the other bank is broadly flat – whilst test site 2 is moderately constrained – both banks are moderate to steep. Given that this is a 'high cost' site and that proposed intervention will involve an element of channel/floodplain restoration (deculverting of the watercourse), the whole site is arguably relatively unconstrained in terms of topography. Accordingly, the recommendation would be for this site to proceed to scenario development in Step 8 of the flood control model.

7.2.8 Step 8 – scenario development

The purpose of Step 8 in the flood control model is **to translate the proposed outline NFM measures from Steps 6 and 7 into more detailed scenarios**. Individual tasks to be undertaken in Step 8 of the flood control model are described in Appendix 8. The scenarios developed in Step 8 are intended to provide an outline indication of proposed land use/management based NFM schemes for each NFM opportunity area scoped in at Step 6 and subsequently carried forward after the

---

[100] It should be noted however that a floodplain woodland expansion scheme of this kind could arguably go ahead without earthworks/reduction in floodplain gradients. Although the FRM benefit of floodplain woodland is greater where the floodplain is less steep, planting-up steep floodplains may still have a significant FRM benefit (though this would need to be validated using an appropriate hydraulic model). In addition, the floodplain woodland scheme would potentially deliver a range of wider amenity, biodiversity and landscape benefits i.e. FRM benefit is only one consideration.

topographical constraints analysis at Step 7 (see section 7.2.7 and Appendix 8). The scenarios *do* include broad recommendations for the location, scale, design and management of key land use/management based NFM measures. However the scenarios *do not* include detailed technical drawings, engineering design, bill of quantities etc[101].

For integrated NFM schemes that involve two or more different NFM measures (see Table 7.9), scenario outputs from Step 8 will include plans for each individual measure (e.g. channel restoration, floodplain woodland etc) as well as an overall strategy plan that outlines all of the components required to deliver the integrated scheme. In essence, the overall strategy plan is an indicative land use/management plan for the NFM opportunity area, detailing the NFM schemes's various components as well as a broad indication of their anticipated location across the site. Indicative floodplain cross-sections are prepared to provide a better understanding of scale and interaction between the individual NFM measures and components that constitute the overall scheme (e.g. to show the difference in levels between channel, bank and floodplain - see section 4.5). Taken together, the various plans and sections can provide the basis for discussion with other relevant specialists, as required, to progress the technical design development prior to scenario testing in an appropriate hydraulic model (see Chapter 7). For discrete NFM schemes involving only one FRM measure (see Table 7.9), scenario outputs from Step 8 will include one FRM strategy plan and indicative cross-sections as required.

Step 8 involves six tasks. Building on outputs from Steps 6 and 7 (Tasks 6.4 and 7.4 – see Appendix 8), Task 8.1 clarifies the scope of the NFM measure(s) under consideration i.e. it identifies whether any changes to the scope are required in light of topographical constraints. In the case of NFM opportunity area No.2 for example (see Figure 7.10 and Table 7.8), the topographical constraints identified at Step 7

---

[101] This issue is particularly important in relation to any proposed profile changes to the channel and floodplain – whilst the hydraulic impact of vegetation changes can be modelled by changing the value of Manning's **n** for the affected component, proposed alterations to the physical make-up of the channel and floodplain (i.e. its geomorphology) can require highly skilled input to make the corresponding alterations in the modelled environment (e.g. altering the DEM in a GIS). Accordingly, further technical input and technical design development is required before the scenarios can be tested in an appropriate hydraulic model. This is likely to include land surveys to obtain accurate elevations for the site, exemplifying the scope of technical activity required before a scenario is ready for testing in the hydraulic model.

(see Figure 7.13 and Table 7.10) are considered to be acceptable given that NFM opportunity area No.2 is a 'high cost' site. Accordingly, no alternations are required and the integrated NFM scheme proposed at Step 6 is carried through as is: **channel restoration AND floodplain woodland expansion**. Additionally, Task 8.1 should establish clear and ambitious objectives that articulate the vision for the NFM scheme. Example objectives are provided at Appendix 8.

Task 8.2 involves a further review of topographical data to identify the presence (or not) of fine scale topographical features in the floodplain that may constrain or enhance the overall design of the scheme. In particular, the presence of relic side channels in the floodplain may have the effect of diverting flood flows back into the main channel (partially negating the flood storage benefit afforded by the floodplain itself and other NFM measures under consideration) whereas relic ponds and depressions can increase floodplain roughness as well as providing the three dimensional space necessary for flood storage (see sections 4.5 and 4.6). In addition, areas of broadly flat ground may provide an opportunity for the creation of floodplain scrapes if these areas are at a similar (or lower) elevation to the banks of the watercourse (RRC, 2002). In essence, the flood control model generally construes relic side channels as a constraint to NFM measures whereas depressions, relic ponds and flat areas are more likely to provide an opportunity. The significance of the constraint/opportunity will be depend on the overall topography of the floodplain and the relative levels of the channel, banks and fine scale topographical features of interest. Additionally, it may be possible to engineer relic side channels to enhance flood storage ecosystem services as outlined at sections 4.5 and 4.6. Further guidance on undertaking Task 8.2 is provided at Appendix 8.

Task 8.3 considers the profile of the *existing* floodplain (low cost sites) or *proposed* floodplain (high cost sites), to identify where earthworks may be necessary in order to realise the desired floodplain profile. For low cost sites, shallower floodplain gradients can enhance the FRM benefit of key measures (e.g. floodplain woodland – see section 4.6 and Appendix 4) and some earthworks may be desirable to positively alter the floodplain. Unlike high cost sites however, floodplain remodelling at low cost sites is not essential (i.e. some degree of FRM benefit is still likely to be achievable) and the costs associated with earthworks may be harder to justify. Task 8.3 therefore simply reviews the topographical data already considered at Step 7 (see Figure 7.13) to identify key areas where floodplain gradients are steep and where earthworks may be required to remodel the floodplain. The desired outputs from Task 8.3 therefore are recommendations detailing where earthworks may be required. This then feeds into Task 8.4 which develops the outline geomorphology and land engineering strategy for the site, as part of the overall strategy plan. The recommendations should differentiate between essential earthworks (e.g. those required to reinstate the floodplain at a high cost site) and desirable earthworks (e.g. those that would be advantageous at a low cost site but non-essential). Figure 7.14 details the output of Task 8.3 analysis for NFM opportunity area No.2 (Sandyhills Park).

Informed by recommendations from Task 8.3, Task 8.4 identifies outline areas where earthworks may be required to realise a desirable floodplain profile in terms of maximising the FRM benefit of the wider scheme. Earthworks may be necessary in order to create the suitably shallow floodplain/bank/channel gradients required to encourage out of bank flows (e.g. the creation of two stage channels, flat berm areas etc) and also any land engineering works in the floodplain to increase surface roughness and/or to provide increased flood storage (e.g. floodplain scrapes, creation of wetland mosaic etc). Proposals for land engineering works in the floodplain should also be informed by the review of fine scale topographical features undertaken at Task 8.2 (e.g. the identification of flat areas at a suitable elevation for the construction of floodplain scrapes).

At this level of analysis, defining exact gradients for the floodplain, bank and channel is not necessary and the Task 8.4 analysis should focus on the identification of broad areas where earthworks *may* be required. A more detailed analysis of channel bed, bank and floodplain elevations will be required at subsequent stages[102] of project planning and design to ensure that strategic ecosystem service priorities identified in the flood control model (see section 8.2) can be effectively translated

---

[102] Providing input data to model the watercourse/floodplain response to a variety of different flow conditions. This type of detailed approach helps to ensure that the designed landform of the channel/bank/floodplain responds to flood flows in a predictable and planned manner – for example, different engineered compartments of the floodplain are inundated in a specified order as individual compartments are progressively inundated and overtopped.

into action on the ground. The outputs of Task 8.4 analysis, including delineation of proposed earthworks areas, should be collated on an outline geomorphology and land engineering strategy plan, an example of which is provided at Appendix 8.

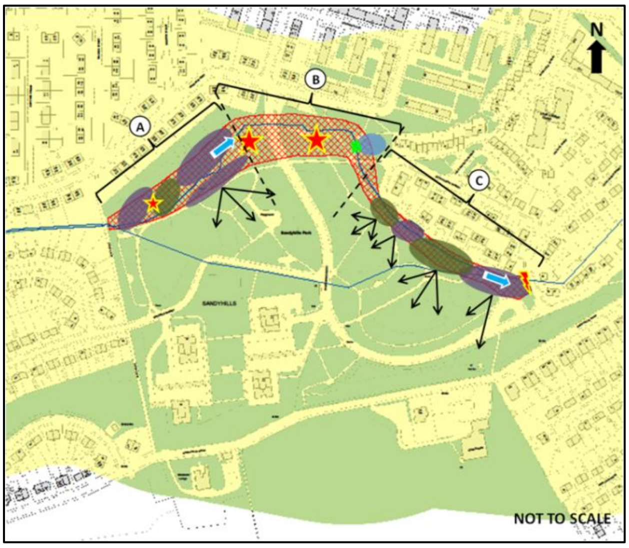
Summary details of example output	
Model	Flood control
Step	8
Step title	Scenario development
Task	8.3
Note: Figure also available within standalone CD-ROM.	

Notes: The figure above details locations at NFM opportunity area No.2 (Sandyhills Park) where earthworks *may* be required to realise a desired floodplain profile. Proposed earthworks denoted with the number '1' are likely to be essential due to floodplain gradients at these locations. Proposed earthworks denoted with the number '2' are desirable but non-essential.

Figure 7.14 Flood control model Step 8, Task 8.3 – example model output

Task 8.5 is focussed on the development of strategies for the habitat related NFM measures: 1) floodplain and riparian zone woodland planting/restoration (see section 4.6); and 2) creation, restoration and enhancement of floodplain wetland features (see section 4.7). Accordingly, Task 8.5 is informed by an analysis of key outputs from Step 5 (see section 7.2.5), especially the spatial data on existing floodplain habitat patches/networks (see Figure 7.7 and Appendix 8) along with spatial data on optimal and marginal sites for habitat expansion (see Figure 7.8 and Appendix 8). For each of the scoped in NFM opportunity areas, Task 8.5 identifies habitat creation/restoration opportunities within the floodplain.

As per the principles of conservation management (see section 5.2.2 and Appendix 6), the preferred approach to habitat related works is to consolidate and enhance *existing* habitat patches. Existing habitat patches are identified through Task 5.2 (see section 7.2.5). In the case of floodplain woodland, this equates to management interventions to improve the FRM benefit of existing habitat patches. Various management measures for achieving this objective are outlined at Appendices 4 and 6. Once recommendations for enhancing the FRM benefit of all *existing* habitat patches have been identified, the preferred approach for subsequent action is to create *new* habitat within the floodplain to further increase the roughness of the land and to provide increased flood storage ecosystem services. Optimal sites for the creation of new habitat are likely to be within the habitat network formed by existing habitat patches as these areas will be part of a contiguous network and therefore already functionally connected (see section 5.2). Appendices 4 and 6 provide guidance for the establishment of floodplain woodland in urban areas.



Summary details of example output	
Model	Flood control
Step	8
Step title	Scenario development
Task	8.6

KEY

Ⓐ FRM zone – FRM benefit provided by floodplain woodland and two stage channel
Ⓑ FRM & Amenity zone – FRM benefit provided by two stage channel
Ⓒ FRM zone – FRM benefit provided primarily by floodplain woodland
● Floodplain scrape
🟩 Spillway
➡ Anticipated backing up of flood waters caused by floodplain woodland
⚡ Potential increased flood risk due to flood waters backing-up
★ Anticipated area of major earthworks to achieve required floodplain profile
★ Anticipated area of minor earthworks to achieve required floodplain profile
● Woodland establishment within existing woodland habitat network
● Interplanting and restocking of existing woodland habitat patches
← Integration of new/enhanced woodland with adjacent woodland habitat networks

Notes: The proposals on Figure 5.15 have been informed by the strategies for individual NFM measures detailed above in section 5.1.8. The broad locations for major and minor earthworks and the proposed floodplain scrape have been informed by the outline geomorphology and land engineering strategy plan (see Figure 5.14 and Appendix 4). The proposals for floodplain woodland management and establishment have been informed by the floodplain woodland enhancement strategy plan (see Appendix 4). Figure also available within standalone CD-ROM.

Figure 7.15 Flood control model Step 8, Task 8.6 – typical model output

The final task in Step 8 (Task 8.6) is the development of an overall strategy plan for the site. This integrates the various strategies for each separate NFM measure under consideration to identify broad location, scale, design and management recommendations for land use/management based NFM schemes. The development of the overall strategy plan involves the sequential consideration of all individual NFM strategies for the site (see above) to identify potential constraints and synergies. An example strategy plan output for NFM opportunity area No.2 (see Figures 7.9 and 7.10) is shown at Figure 7.15. One of the key issues addressed in the development of this example is the substantial earthworks proposed for the central stretch of the reinstated channel and floodplain marked as ‘Strategy Zone B’ on Figure 7.15. Given the potential scale of the earthworks that may be required at this location, existing woodland habitat would likely be removed, potentially just leaving key specimen trees (marked as ‘Proposed Intervention 3’ at Appendix 8). The focus for this part of the site is therefore as a joint FRM and Amenity Zone – the edges of the new floodplain are pulled right back to create shallow gradients and flat berm areas that are inundated by flood waters whilst facilitating safe access to the water under low flow conditions (e.g. for recreational/educational purposes). For this reason, the floodplain woodland works are diverted to the other two Strategy Zone areas upstream and downstream.

7.3 The hydrological cycle model – where are runoff reduction services required?

This section describes the structure, process and function of the hydrological cycle model that has been developed through this research. The purpose of this model is to identify sites where appropriate land use/management intervention can be used to enhance runoff reduction ecosystem services (see section 3.2) i.e. sites and interventions that can help to restore the more natural functioning of water catchments by supporting and enhancing the natural drainage processes that underpin hydrological cycle function (see section 4.7). In this regard, the model is designed to work in concert with the flood control model described at section 7.2. The model can be run for a range of different geographies and scales in urban areas including those defined by natural features (e.g. water catchments) and administrative units (e.g. local development framework areas). Some of the key implications of scale, e.g. in terms of data use and management, GIS processing time etc, are discussed at Appendix 9. The development of the hydrological cycle model has been informed by the material collated, analysed, synthesised and documented in Chapter 4 (see sections 4.2, 4.4 and 4.7 in particular) as part of Research Objective No.2 (see Box 1.2). The overall structure of the hydrological cycle model is shown on Figure 7.16 and described at Table 7.12.

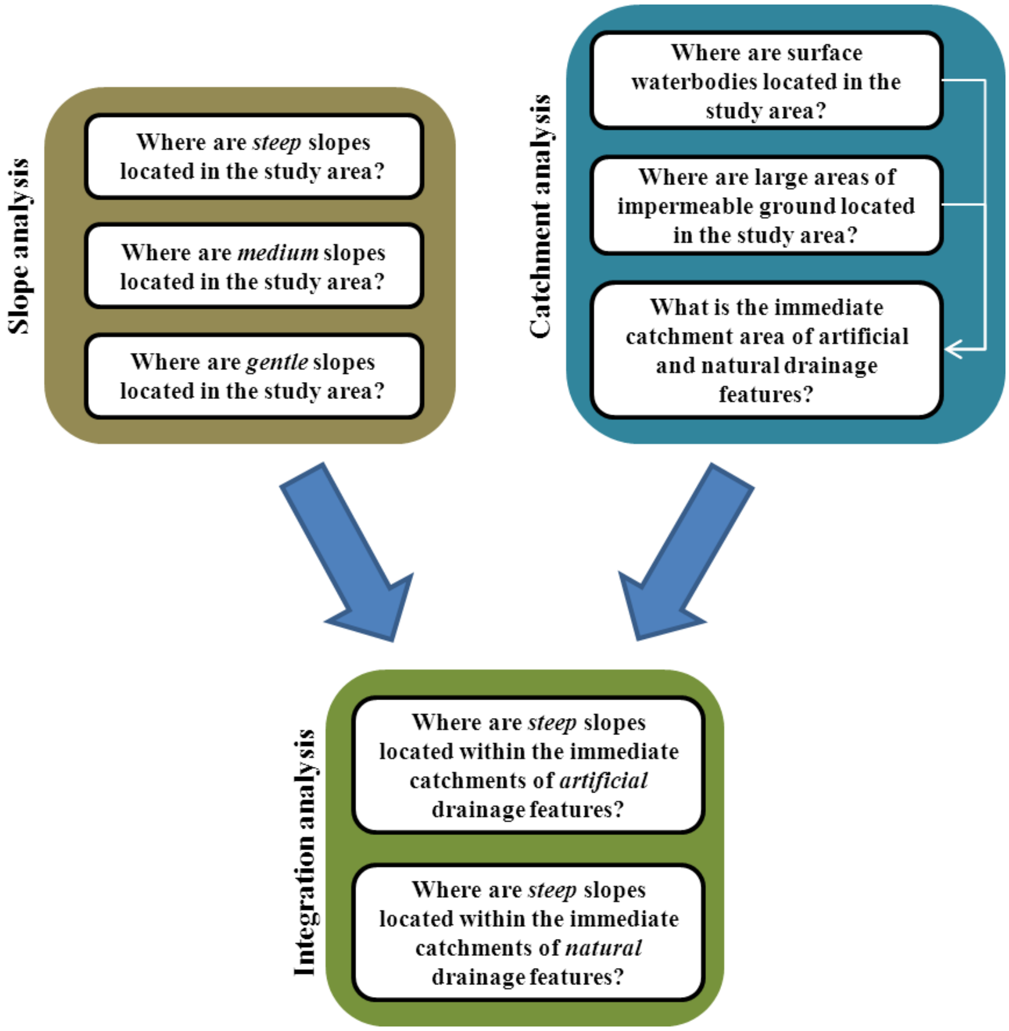


Figure 7.16 Overall structure of the hydrological cycle model

Note: Figure also available within standalone CD-ROM.

The utility of the hydrological cycle model lies in its use scoping sites that can provide runoff reduction ecosystem services, thereby enhancing overall natural flood management (NFM) capacity within urban catchments. Informed by standard hydrological principles concerning the interaction of slope and surface roughness in the functioning of overland flow based runoff generation mechanisms (see section 4.7), the focus of the hydrological cycle modelling is on the identification of sites within the wider catchment (i.e. away from the floodplain) that have the potential to provide runoff reduction services. This is in contrast to the flood control model (see section 7.2) which focuses on the identification of sites and measures within the floodplain itself. Working in concert therefore, the two models are intended to provide a catchment wide analytical approach to the identification of sites and potential measures for NFM. Integration of outputs from the two water management focussed models (i.e. the flood control and hydrological cycle models) with the habitat networks model (see section 7.4) is then undertaken to support the identification of an integrated land use/management strategy for the catchment as well as specific sites and potential interventions that have the potential to deliver multiple benefits (see section 8.2).

As indicated on Figure 7.16, the hydrological model comprises three main stages: 1) slope analysis; 2) analysis of natural and artificial drainage catchments; and 3) integration of slope and catchment analysis to identify potential intervention sites. Each of these stages comprises a number of individual steps. Unlike the flood control model, the hydrological cycle model is designed to be fully automated within the GIS. Key information on individual stages and steps in the hydrological cycle model is provided at sections 7.3.1 – 7.3.3 with additional detail and geoprocessing instructions provided at Appendix 9. Where relevant, this includes a critique of the new hydrological cycle model as it compares to relevant aspects of existing urban planning frameworks and the wider literature. In line with Research Objective No.5, an evaluation of the new tools and approaches developed through this research is provided at section 9.2.4.

Table 7.12 Hydrological cycle model – summary description of key stages

Stage	Objectives/purpose
1. Slope analysis	**The overall objective/purpose of Stage 1 is to characterise the study area in terms of slope and to delineate steep, medium and gently sloped areas of land in a vector dataset**. Slope and surface roughness are key factors influencing the function of overland flow based runoff generation mechanisms (see section 4.7). Accordingly, Stage 1 involves the analysis and mapping of slope to determine the degree to which this factor is significant for runoff generation within the study area – i.e. *where are steeply sloped areas of land that may be priorities for land use/management change in order to enhance runoff reduction ecosystem services?* Stage 1 categorises land in the study area on the basis of slope – i.e. land that is steeply, medium and gently sloped. The analysis uses a mixture of raster and vector

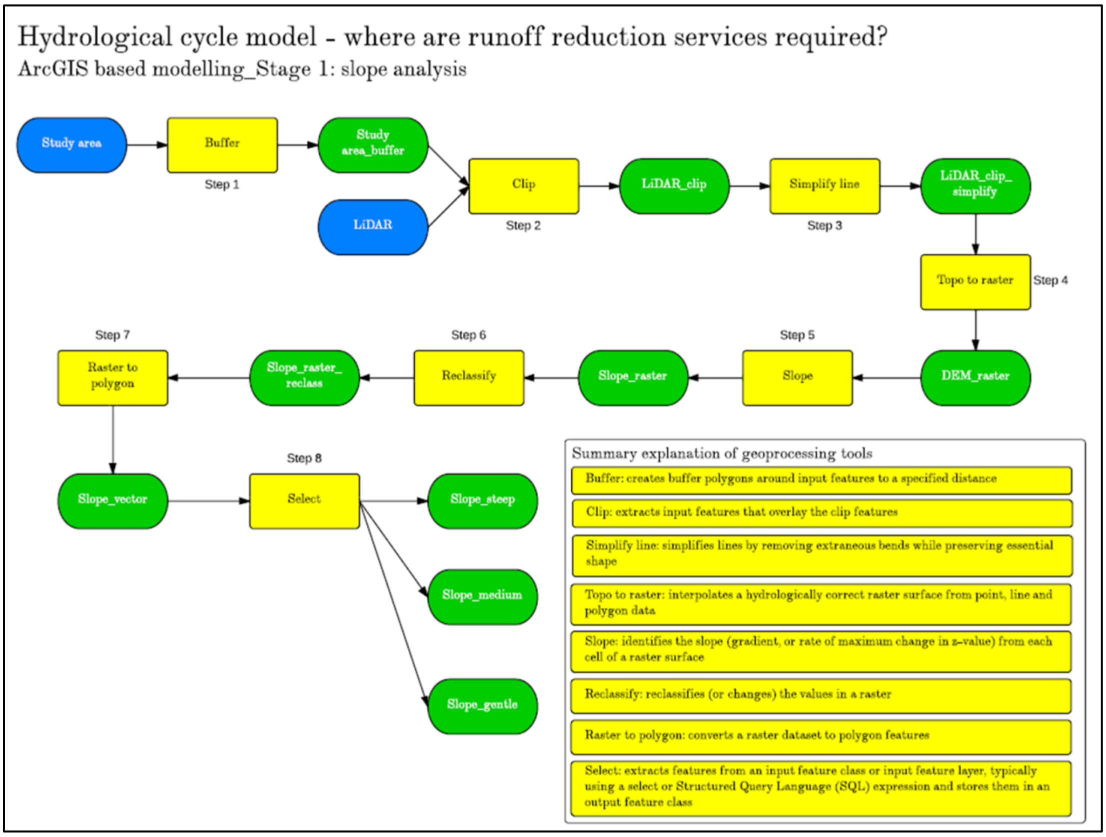
Stage	Objectives/purpose
	data though the final outputs from Stage 1 are in vector format – i.e. polygon feature classes of steep, medium and gently sloped land
2. Catchment analysis	**The overall objective/purpose of Stage 2 is to identify the immediate catchment areas of natural and artificial drainage features and to delineate these areas of land in a vector dataset**. The key purpose of the hydrological cycle model is to prioritise sites in urban catchments where appropriate land use/management can be used to alter surface roughness and/or where the provision of additional storm water storage should be prioritised (e.g. through the use of specific SuDS intervention such as rain gardens). The modelling approach is designed to work in tandem with generic/catchment-wide policy on water and flood risk management (e.g. policy on permeable paving, greenspace quotas within new development etc) by identifying specific sites where **topography** and **existing land use** is such that the potential for overland flow based runoff generation is high. In this regard, the Stage 2 analysis identifies the immediate catchment areas of natural and artificial drainage features, the rationale being that intervention at these locations to increase surface roughness and/or provide storm water storage can reduce runoff, thereby helping to reduce peak flows in natural and artificial drainage systems and the associated risk of fluvial and pluvial flooding. Natural drainage features are surface waterbodies. Large areas of impermeable ground are used as a proxy for artificial drainage features. Taken together, this approach to defining natural and artificial drainage features means that the scope of the analysis can cover whole catchments – the former captures river corridors and their immediate surrounds and the latter can capture all other parts of the catchment where land use is such that there are significant areas of impermeable ground. In essence however, the hydrological cycle model is intended to focus land use/management planning attention on those areas where runoff generation potential is particularly high – i.e. steeply sloped land in close proximity to natural and artificial drainage features. As discussed at section 7.3.2 however, model parameters can be adjusted and sensitivity analysis undertaken to explore the land use consequences of using a larger or smaller buffer in order to delineate the immediate catchment areas of natural/artificial drainage features
3. Integration analysis	**The overall objective/purpose of Stage 3 is to integrate outputs from Stages 1 and 2 by identifying where various classes of slope fall within the immediate catchment areas of natural and artificial drainage features. These areas of land are then delineated in a vector dataset and may become priorities for runoff reduction ecosystem services.** This is undertaken using the **intersect**[103] operation in ArcGIS to identify where the various classes of slope are coincidental with the immediate catchments of natural and artificial drainage features. Where appropriate (e.g. given various constraints on land use/management change), the focus of intervention would be on steeply sloped sites first as increasing roughness and/or providing storm water storage at these locations is likely to yield the greatest runoff reduction results in terms of the hydrological principles governing overland flow generation (Kuchment, 2014). The overall effect of the integration analysis is to identify various sites across the catchment where land use/management change could potentially be used to beneficially alter key physiographic characteristics of the catchment to reduce runoff coefficients thereby helping to reduce flood risk

---

[103] ArcGIS online help for intersect operations: http://help.arcgis.com/en/arcgisdesktop/10.0/help../index.html#//00080000000p000000 [accessed 09/02/14]

7.3.1 Hydrological cycle model stage 1 – slope analysis

As outlined at Table 7.12, the overall objective/purpose of Stage 1 of the hydrological cycle model is to characterise the study area by slope class. Slope is a key factor influencing the function of overland flow based runoff generation mechanisms and can therefore be used to steer land use/management intervention towards sites where runoff reduction ecosystem services are likely to be particularly important. The interaction of the various geoprocessing operations in Stage 1 of the hydrological cycle model are indicated on Figure 7.17.



Buffer: creates buffer polygons around input features to a specified distance

Clip: extracts input features that overlay the clip features

Simplify line: simplifies lines by removing extraneous bends while preserving essential shape

Topo to raster: interpolates a hydrologically correct raster surface from point, line and polygon data

Slope: identifies the slope (gradient, or rate of maximum change in z–value) from each cell of a raster surface

Reclassify: reclassifies (or changes) the values in a raster

Raster to polygon: converts a raster dataset to polygon features

Select: extracts features from an input feature class or input feature layer, typically using a select or Structured Query Language (SQL) expression and stores them in an output feature class

Figure 7.17 Hydrological cycle model – Stage 1 geoprocessing operations (Steps 1 – 8)

Note: The figure above shows the integrated sequence of geoprocessing operations carried out in ArcGIS in Stage 1 of the hydrological cycle model. Input datasets are: 1) study area polygon; and 2) LiDAR topographical contour polylines (see section 2.4.2). Steps 2-4 are not required if an existing DEM is available for the study area. Figure also available within standalone CD-ROM.

Step 1 (see Figure 6.17) buffers the input study area polygon. The importance of this step will vary depending on the nature of the study area under investigation. The buffer step is particularly important where study area delineation is not based on a natural feature e.g. it is based on an administrative unit such as a local development framework (LDF) area (see section 3.1.2).

In cases such as this, the functioning of key ecosystem processes/intermediate services (e.g. the hydrological cycle and ecological networks – see section 3.2.2) will overlap the boundaries of the study area. By buffering the study area therefore, some of this overlap can be captured in the subsequent analysis (see Figure 7.17). Conversely, where the study area is delineated on the basis of natural features like water catchments, the buffer step is less important as, in principle, the study area should be self-contained with respect to the functioning of key ecosystem process/intermediate service.

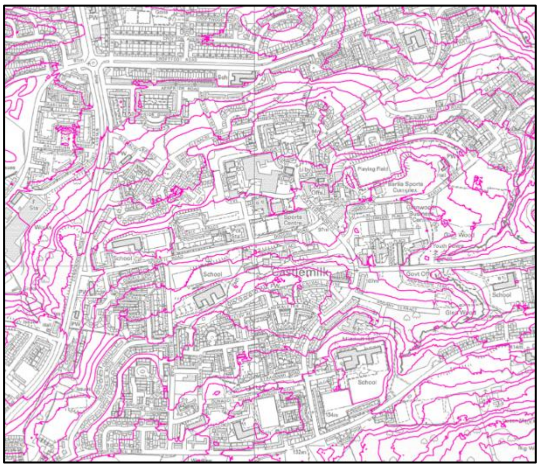
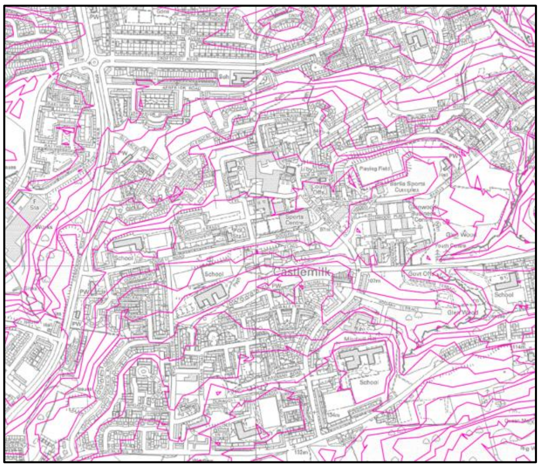
			
Model	Hydrological cycle model	Model	Hydrological cycle model
Step	2	Step	3
Step title	Clip the topographical contour dataset to the study area	Step title	Simplify the topographical contour dataset
Notes: The example output shows a LiDAR topographical contours dataset at 5m intervals (the pink lines) clipped to the study area. In this example, the study area is defined on the basis of an administrative boundary – the Castlemilk Regeneration Area in southeast Glasgow. For large study areas, it may be necessary to stitch several topographical contour datasets together.		**Notes:** The example output shows the LiDAR topographical contours dataset from Step 2 (see opposite) after a simplify line operation has been undertaken. Simplify line removes extraneous bends whilst maintaining the essential shape. The intention is to reduce the granularity of the dataset to ensure that subsequent steps of the slope analysis are manageable, even with limited computer processing power.	

Figure 7.18 Hydrological cycle model Steps 2 and 3 – example outputs

Note: Figure also available within standalone CD-ROM.

Step 2 (see Figure 7.17) simply involves clipping the digital topographical dataset to the buffered study area. Further information on the use of data in this regard is provided at section 2.4.2 and also at Appendix 9. In summary however, a balance needs to be struck between using topographical data of a desired granularity (and therefore accuracy) and the time and computer power required in order to process richer/more granular topographical data sets. For the case studies considered in this research (e.g. urban catchments and urban regeneration areas >20km^2), it was considered appropriate to use a LiDAR topographical contour dataset at 5m contour intervals (see Figure 7.18). Although this is arguably a relatively coarse dataset for use in water management planning/design, the intended use of integrated model outputs from this research (see sections 8.2 and 8.3) is focussed on the identification of *broad* priority locations for land use/management intervention to inform qualitative deliberation as part of the LDP-development process (see section 3.1) and *not* quantitative modelling processes such as Flood Risk Assessment (see section 4.3). Also, the tools, models and guidance developed in this research are intended for practical use by urban planners who are less likely to have access to the type of computer hardware required for processing large/rich datasets (e.g. a more detailed LiDAR topographical contour dataset, say at 0.5m intervals).

Although relatively coarse data was used in the case studies considered in this research it was still necessary to simplify the topographical dataset to ensure that subsequent geoprocessing tasks were manageable given the available computer hardware and processing power. In this regard, the third step in Stage 1 (see Figure 7.17) is a simplify line[104] operation to reduce the granularity of the LiDAR dataset (see Figure 7.18) thereby making it more manageable for subsequent steps in the slope analysis. Practitioners with access to greater computer processing power may wish to skip this step though as per the discussion above in relation to the use of data, the benefits of this given the decision-making context in question (i.e. LDP policy) are uncertain, especially at relatively broad spatial scales such as the catchments and regeneration areas considered in this research (i.e. areas of land >20km^2).

---

[104] ArcGIS online help for simplify line operations: http://resources.arcgis.com/en/help/main/10.1/index.html#//007000000010000000 [accessed 09/02/14]

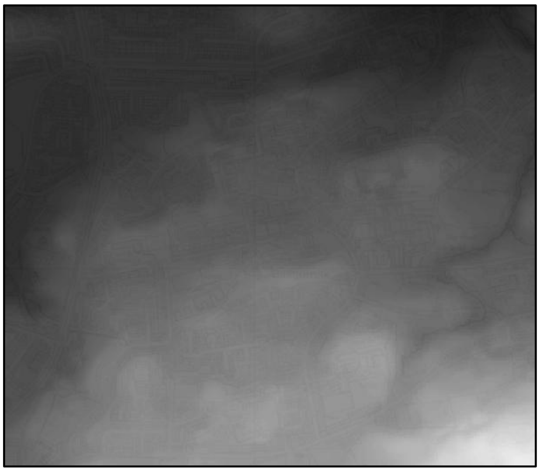
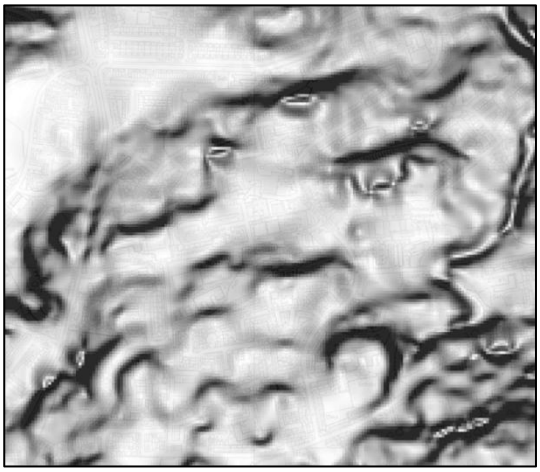
<table>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Model</td><td>Hydrological cycle model</td><td>Model</td><td>Hydrological cycle model</td></tr>
<tr><td>Step</td><td>4</td><td>Step</td><td>5</td></tr>
<tr><td>Step title</td><td>Construct Digital Elevation Model (DEM) raster</td><td>Step title</td><td>Construct slope raster</td></tr>
<tr><td colspan="2">Notes: The DEM raster is the starting point for all subsequent slope analysis steps and is constructed using the ArcGIS topo to raster[105] operation based on the simplified LiDAR topographical contours dataset from step 3. Within the DEM raster surface shown above, individual cells represent elevation – lighter cells represent higher elevations and darker cells lower elevations.</td><td colspan="2">Notes: The slope raster is constructed from the DEM raster. Slope is calculated in the GIS by analysing the rate of change in elevation between cells in the DEM raster surface (see opposite). Where the rate of change is great, slope is steep and <i>vice versa</i>. The figure above shows the slope raster for the Castlemilk case study area – darker cells indicate steeply sloped areas and lighter cells represent flat/gently sloped areas.</td></tr>
</table>

Figure 7.19 Hydrological cycle model Steps 4 and 5 – example outputs

Note: Figure also available within standalone CD-ROM.

Steps 4 and 5 (see Figure 7.17) construct a digital elevation model (DEM) and slope raster respectively based on the simplified topographical contour dataset from Step 3 (see Figure 7.19). The DEM raster is used to construct the slope raster which in turn is used to identify steeply sloped areas through a reclassify operation in Step 6 (see Figure 7.20). The purpose of the reclassify[106] operation is to categorise cells from the slope raster into discrete slope classes. The specific parameters used in the reclassify operation (see Appendix 9) are such that cells are reclassified to one of nine slope classes – from gentle to steeply sloped. In this manner, step six is a fundamental component in the characterisation of the study area by slope class.

---

[105] ArcGIS online help for topo to raster operations: http://resources.arcgis.com/en/help/main/10.1/index.html#//009z0000006s000000 [accessed 09/02/14]

[106] ArcGIS online help for reclassify operations: http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#//009z000000sr000000.htm [accessed 09/02/14]

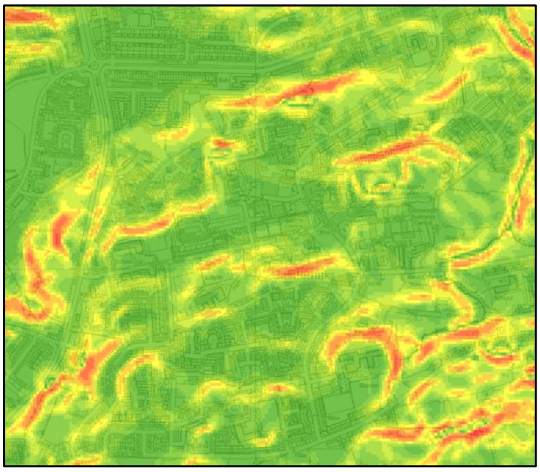
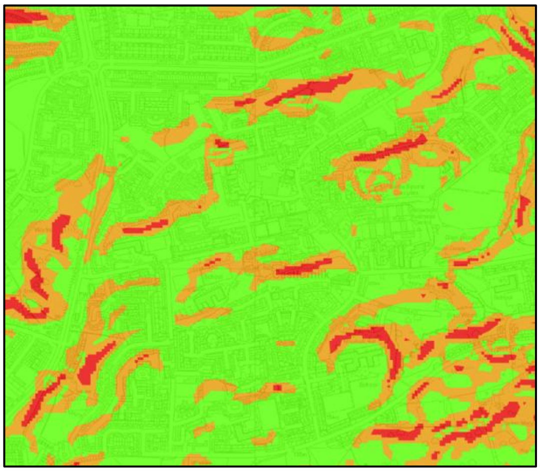
<table>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Model</td><td>Hydrological cycle model</td><td>Model</td><td>Hydrological cycle model</td></tr>
<tr><td>Step</td><td>6</td><td>Step</td><td>7</td></tr>
<tr><td>Step title</td><td>Reclassify slope raster to discrete slope classes</td><td>Step title</td><td>Convert the reclassified slope raster to vector format</td></tr>
<tr><td colspan="2">Notes: The figure above shows the reclassified slope raster for the Castlemilk case study area. Red cells indicate steep slopes, yellow medium slopes and green cells gentle slopes.</td><td colspan="2">Notes: Step 7 converts the reclassified slope raster into vector format. Groups of cells sharing the same slope class attribute become polygons in the vector dataset.</td></tr>
</table>

Figure 7.20 Hydrological cycle model Steps 6 and 7 – example outputs

Note: Figure also available within standalone CD-ROM.

As discussed at section 4.7, slope is a key factor influencing the function of overland flow based runoff generation mechanisms. In this regard, understanding and mapping the study area's slope characteristics provides useful data to support the identification of sites for land use/management intervention that can enhance runoff reduction ecosystem services. However, outputs from step six are in raster format and Stage 3 of the hydrological cycle model uses polygon-on-polygon analysis (intersect) to explore the spatial relationships between steeply sloped land and the catchments of natural and artificial drainage features (see Table 7.12 and section 7.3.3). As such, Step 7 converts the reclassified slope raster from Step 6 into vector format (polygons) to facilitate the intersect analysis at Stage 3. As indicated on Figure 7.20, groups of cells sharing the same slope attribute from the reclassified slope raster become discrete polygons in the vector dataset. These attributes are carried over into the vector dataset as a *slope* field, facilitating the final step of Stage 1 as outlined below.

<table>
<tr><td colspan="2"> </td><td colspan="2"> </td></tr>
<tr><td>Model</td><td>Hydrological cycle model</td><td>Model</td><td>Hydrological cycle model</td></tr>
<tr><td>Step</td><td>8</td><td>Step</td><td>8</td></tr>
<tr><td>Step title</td><td>Identify and extract steep, medium and gentle slope polygons from the vector dataset</td><td>Step title</td><td>Identify and extract steep, medium and gentle slope polygons from the vector dataset</td></tr>
<tr><td colspan="2">Note: The figure above shows polygons from the slope vector dataset indicating areas of steeply sloped land (i.e. slope classes 7, 8 and 9 from the raster dataset). Where these areas of steeply sloped land are located within the immediate catchment of a natural or artificial drainage feature they may represent an opportunity for land use/management intervention to enhance runoff reduction ecosystem services.</td><td colspan="2">Note: The figure above shows polygons from the slope vector dataset indicating areas of medium sloped land (i.e. slope classes 4, 5 and 6 from the raster dataset). Where these areas of medium sloped land are located within the immediate catchment of a natural or artificial drainage feature they may represent an opportunity for land use/management intervention to enhance runoff reduction ecosystem services.</td></tr>
</table>

Figure 7.21 Hydrological cycle model Step 8 – example outputs

Note: Figure also available within standalone CD-ROM.

Step 8 (see Figure 7.17) uses a Structured Query Language (SQL) based select[107] operation to extract specific slope polygons from the vector slope dataset. As described above and shown at Figure 7.20, the reclassified slope raster produced at step six classifies slope cells to one of nine slope classes – from gentle to steeply sloped. For the purposes of the integration analysis at Stage 3 however, only three slope classes are used – steep, medium and gentle slopes. As such, the select operation breaks the nine slope classes into three using SQL – steep and medium slopes for the Castlemilk (south-east Glasgow) example are shown on Figure 7.21. The three classes of slope polygon are the final output from Stage 1 of the

---

[107] ArcGIS online help for select operations: http://resources.arcgis.com/en/help/main/10.1/index.html#//000800000005000000 [accessed 09/02/14]

hydrological cycle model. In conjunction with outputs from Stage 2 that delineate the immediate catchments of natural and artificial drainage features, Stage 1 outputs are used in Stage 3 to identify priority locations for land use/management intervention that can enhance runoff reduction services.

7.3.2 Hydrological cycle model stage 2 – catchment analysis

The overall objective/purpose of Stage 2 of the hydrological cycle model is to identify the immediate catchment areas of natural and artificial drainage features located within the study area (see Table 7.12). Dependent on site specific slope factors (see section 7.3.1), these areas are construed as potential priority locations for runoff reduction ecosystem services. The interactions of the various geoprocessing operations in Stage 2 of the hydrological cycle model are indicated on Figure 7.22. In line with its objectives/purpose, Stage 2 is split into two components: a) analysis of *artificial* drainage feature catchments; and b) analysis of *natural* drainage feature catchments.

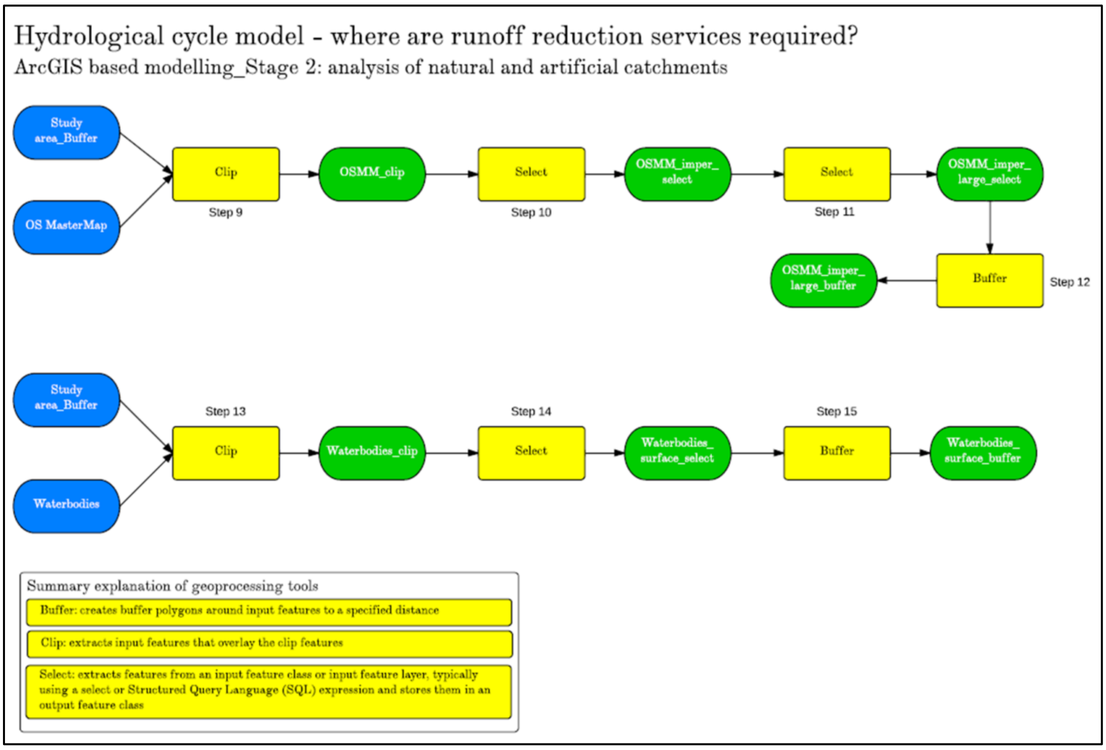
For the analysis of *artificial* drainage feature catchments, large areas of impermeable ground are used as a proxy for artificial drainage features. The rationale behind the use of this proxy is twofold. Firstly, large areas of impermeable ground – by definition – will be served by surface water drains connected to below ground drainage infrastructure[108] (including combined sewers in some cases e.g. Glasgow).

Secondly, large areas of impermeable ground, by their very nature, are more likely to be at risk of pluvial and sewer flooding as natural drainage processes are constrained by the impermeable nature of the ground (contributing to pluvial flooding) and associated below ground drainage infrastructure will have a finite capacity (contributing to pluvial and sewer flooding). Furthermore, there are close

---

[108] It may also be the case, for example, that the catchments of artificial drainage features are served by surface water management systems (e.g. source and site control SuDS interventions) designed to reduce pressure on below ground drainage infrastructure, including combined sewers. Depending on the treatment provided by SuDS, runoff will either be discharged to a waterbody (e.g. river, groundwater), surface water drain or combined sewer once the storm event is over and pressure on the drainage system has been reduced. In either case, the use of surface water management systems/SuDS techniques has the potential to reduce pressure on below ground drainage infrastructure (including combined sewers) and the need for enhanced runoff reduction ecosystem services (i.e. a source control SuDS technique – see section 4.7) within the immediate catchment area of artificial drainage features may be less critical. Susdrain background pages on sustainable drainage: http://www.susdrain.org/delivering-suds/using-suds/background/sustainable-drainage.html [accessed 10/02/14]

links between pluvial and sewer flooding that can act to compound flooding problems in urban catchments – the former occurs when rainwater cannot enter the artificial drainage system as it is already at capacity and the latter occurs under periods of heavy rainfall when flows exceed the design capacity of the drainage/sewer system (Scottish Government, 2011a). In essence, precipitation falling on or draining to areas of impermeable ground will either end up in the below ground drainage network, contribute to pluvial flooding or, depending on the severity of the rainfall event and the specific nature of the integrated drainage system, contribute to both (with the associated risk of sewer flooding).



Hydrological cycle model - where are runoff reduction services required?
ArcGIS based modelling_Stage 2: analysis of natural and artificial catchments

Summary explanation of geoprocessing tools

Buffer: creates buffer polygons around input features to a specified distance

Clip: extracts input features that overlay the clip features

Select: extracts features from an input feature class or input feature layer, typically using a select or Structured Query Language (SQL) expression and stores them in an output feature class

Figure 7.22 Hydrological cycle model – Stage 2 geoprocessing operations (Steps 9 – 15)

Note: The figure above shows the integrated sequence of geoprocessing operations carried out in ArcGIS in Stage 2 of the hydrological cycle model. Input datasets are: 1) study area polygon; 2) OS MasterMap topography polygons; and 3) waterbodies (see section 2.4.2). Figure also available within standalone CD-ROM.

As such, this thesis argues that focusing attention on the immediate catchment areas of large areas of impermeable ground is a useful approach for strategic land use/management planning – i.e. by changing land management and/or providing storm water storage at these locations, the intention is to enhance runoff reduction ecosystem services thereby manipulating runoff coefficients and reducing peak flows in artificial drainage systems. Also, in modified urban catchments there is a high degree of interaction between different sources of flooding and natural and artificial drainage systems (Scottish Government, 2013a). As such, intervention that reduces runoff and peak flows in artificial drainage systems can also help to reduce runoff and peak flows in natural drainage systems and *vice versa*.

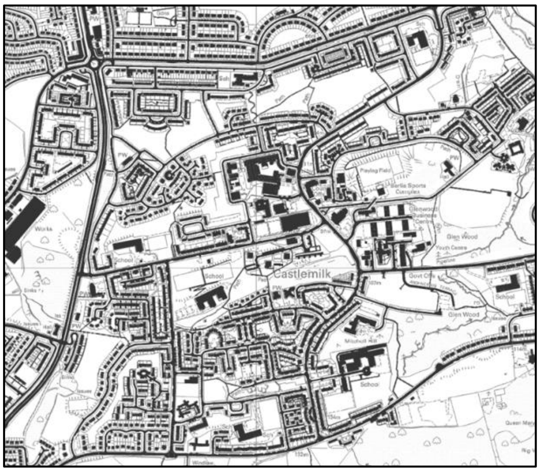
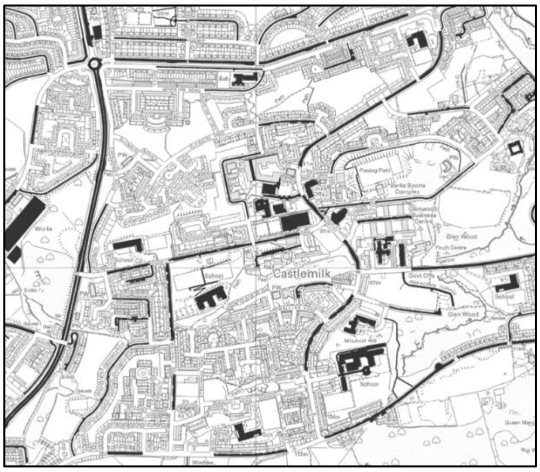
<table>
<tr><td colspan="2"> </td><td colspan="2"> </td></tr>
<tr><td>Model</td><td>Hydrological cycle model</td><td>Model</td><td>Hydrological cycle model</td></tr>
<tr><td>Step</td><td>10</td><td>Step</td><td>11</td></tr>
<tr><td>Step title</td><td>Identify and extract impermeable ground polygons only from OSMM topography layer</td><td>Step title</td><td>Identify and extract large impermeable ground polygons only from OSMM topography layer</td></tr>
<tr><td colspan="2">**Note:** Extracted from the OSMM topography layer, the figure above shows all OSMM polygons that are likely to comprise impermeable ground (black polygons). Polygons are identified and extracted on the basis of specific DESCGROUP attributes.</td><td colspan="2">**Note:** Extracted from impermeable ground OSMM polygons from Step 10, the figure above shows ‘large’ impermeable ground polygons only (black polygons). In the example above, ‘large’ polygons are construed as those >1,000m^2. The parameter used to define ‘large’ in the select operation is a key part of the model where sensitivity analysis can be undertaken to explore different outcomes overall.</td></tr>
</table>

Figure 7.23 Hydrological cycle model Steps 10 and 11 – example outputs

Note: Figure also available within standalone CD-ROM.

The proxy approach to identifying artificial drainage feature catchments is also beneficial in that it will identify a range of locations across the catchment away from river corridors. River corridors are dealt with specifically by the flood control model (see section 7.2) and in the hydrological cycle model's analysis of natural drainage feature catchments (see below). Large areas of impermeable ground are identified with reference to OS MasterMap (OSMM) topography polygons. This data provides a highly detailed view of Great Britain's landscape including individual buildings, areas of land and roads (OS, 2014). In urban areas, OS MasterMap is captured and designed for display at a scale of 1:1250 (OS, 2013).

Step 9 of the hydrological cycle model simply clips the OSMM data to the study area (see Figure 7.22). Step 10 then runs a select operation to extract OSMM polygons that are likely to comprise impermeable ground (see Figure 7.22). Features are selected on the basis of attributes from the descriptive group [DESCGROUP] field which is the primary classification attribute of a feature. Appendix 9 provides details of the attributes selected and a specific SQL code to run the select operation. A sample step ten output for the Castlemilk example is shown on Figure 7.23.

Step 11 of the hydrological cycle model runs a further select operation to extract only those impermeable ground OSMM polygons from step ten that are considered to be 'large' (see Figure 7.22). As with the clip operation at the start of Stage 2 (Step 9), the main purpose of imposing a size threshold is to reduce the number of features considered in the subsequent analysis (see Figure 7.22). Also, width is a factor in overland flow based runoff generation (see section 4.7) so imposing a size threshold on impermeable ground polygons can provide a partial proxy for this factor. In the Castlemilk example shown at Figure 7.23 (right-hand map) a threshold of 1,000m^2 is used in the select operation to discern those impermeable ground polygons that are considered 'large'. This is a key step where sensitivity analysis could be used to explore the implications for overall hydrological cycle model outputs by changing the size threshold parameter. For example, a smaller size threshold will capture a greater number of impermeable ground polygons which will have implications for overall hydrological cycle model outputs as outlined at section 7.3.3.

The overall purpose of Stage 2 of the hydrological cycle model is to identify the immediate catchment areas of natural and artificial drainage features (see Table 7.12). Step 12 identifies the immediate catchment areas of artificial drainage features identified at Step 11 (see Figure 7.22). This is undertaken in the GIS using a buffer[109] operation. The area of land falling within the buffer is construed as the immediate catchment area of the proxy artificial drainage feature. In principle therefore, these buffered areas may be candidates for land use/management intervention that can enhance runoff reduction ecosystem services and/or for the provision of specific storm water storage measures (see Figure 7.24).

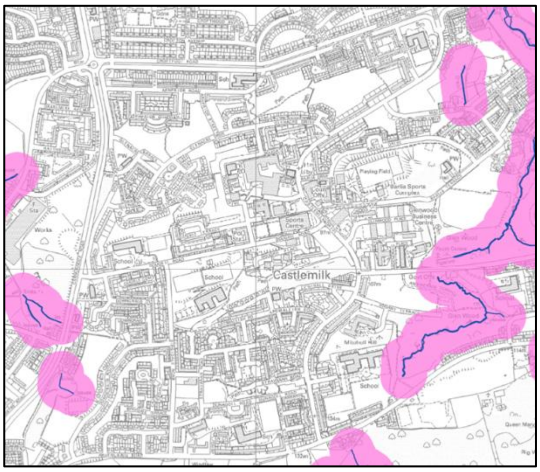
<table>
<tr><td colspan="2"> </td><td colspan="2"> </td></tr>
<tr><td>Model</td><td>Hydrological cycle model</td><td>Model</td><td>Hydrological cycle model</td></tr>
<tr><td>Step</td><td>12</td><td>Step</td><td>15</td></tr>
<tr><td>Step title</td><td>Buffer large areas of impermeable ground to identify the immediate catchment area of artificial drainage features</td><td>Step title</td><td>Buffer surface waterbodies to identify the immediate catchment area of natural drainage features</td></tr>
<tr><td colspan="2">Note: The figure above shows large areas of impermeable ground from Step 11 buffered to 30m (green polygons). For the purposes of the hydrological cycle model, these areas are construed as the immediate catchment areas of <i>artificial</i> drainage features and may be prime candidates for intervention that enhances runoff reduction ecosystem services. The distance parameter used in the buffer operation is a key part of the model where sensitivity analysis can be undertaken to explore different outcomes.</td><td colspan="2">Note: The figure above shows surface waterbodies from Step 14 (see Figure 7.22) buffered to 75m (purple polygons). For the purposes of the hydrological cycle model, these areas are construed as the immediate catchment areas of <i>natural</i> drainage features and may be prime candidates for intervention that enhances runoff reduction ecosystem services. The distance parameter used in the buffer operation is a key part of the model where sensitivity analysis can be undertaken to explore different outcomes.</td></tr>
</table>

Figure 7.24 Hydrological cycle model Steps 12 and 15 – example outputs

Note: Figure also available within standalone CD-ROM.

---

[109] ArcGIS online help for buffer operations: http://resources.arcgis.com/en/help/main/10.1/index.html#//000800000019000000 [accessed 10/02/14]

Step 12 is a key point where sensitivity analysis can be applied. For example the buffer operation shown on Figure 7.24 (left-hand map) uses a buffer distance parameter of 30m. This could feasibly be increased or reduced to reflect larger or smaller immediate catchment areas, as required, depending on the specific planning context or objectives at hand – e.g. for highly modified urban catchments where flooding is a significant problem, it may be desirable to use a larger buffer to identify larger areas of potential intervention.

Steps 13 – 15 for *natural* drainage features (surface waterbodies) adopt a similar process to that described above for artificial features (large areas of impermeable ground). The rationale is the same – appropriate land use/management intervention within the immediate catchment of surface waterbodies has the potential to enhance runoff reduction ecosystem services, thereby manipulating runoff coefficients and reducing peak flows in natural drainage systems.

The buffer operation for natural drainage features at step fifteen uses a larger buffer distance parameter than that used in the analysis of artificial features (see Appendix 9), the rationale being that the catchment areas of natural drainage features will be significantly larger than those of artificial features (e.g. the catchment area of the Tollcross Burn described at section 7.2 is circa 26km^2). In reality, there is a high degree of interaction between natural and artificial drainage systems in modified urban catchments (Scottish Government, 2013a) and any land use/management intervention that helps to reduce runoff and peak flow in either system has the potential to help reduce overall flood risk from a variety of sources (see sections 4.1, 4.2 and 4.7). In this regard, the locations identified through the analysis of large areas of impermeable ground and surface waterbodies is likely to capture a substantial portion of a natural drainage feature's *actual* catchment area. As such, the incremental delivery of runoff reduction ecosystem service enhancement measures across these locations has the potential to positively alter key physiographic characteristics of urban catchments by increasing greenspace and vegetation cover and through the provision of storm water storage infrastructure thereby increasing surface roughness and flood storage capacity. This is in addition to generic water and flood risk management measures (e.g. policy on permeable paving, greenspace quotas within new development etc) that can be delivered throughout the catchment to help increase the landscape's capacity to retain water thereby helping to reduce runoff (see Appendices 4 and 5).

7.3.3 Hydrological cycle model stage 3 – integration analysis

As outlined at Table 7.12 the overall objective/purpose of Stage 3 of the hydrological cycle model is to integrate outputs from Stages 1 and 2 by identifying the locations where various classes of slope fall within the immediate catchment areas of natural and artificial drainage features. These areas of land are then delineated in a vector dataset and may become priorities for the enhancement of runoff reduction ecosystem services. Stage 3 involves only one geoprocessing operation – the various slope polygon feature classes (i.e. steep, medium and gentle slopes) from Stage 1 are integrated with the catchment area polygons (i.e. the catchments of artificial and natural drainage features) from Stage 2 using an intersect[110] operation. This process is indicated on Figure 7.25.

As outlined at section 4.7, slope is a key factor influencing the function of overland flow based runoff generation mechanisms – the more steeply sloped the land, the greater the potential for runoff generation. As such, identifying where areas of steep and medium sloped land are located within the immediate catchment of artificial and natural drainage features can help to identify potential priority locations for the enhancement of runoff reduction ecosystem services. In essence, these are locations where land use/management intervention and/or storm water storage measures may be used to greatest effect to increase the roughness and flood storage capacity of water catchments, thereby helping to reduce runoff and peak flows in natural and artificial drainage systems.

Stage 3 analysis is undertaken using six intersect operations – the buffered large areas of impermeable ground polygons (i.e. the immediate catchment areas of artificial drainage features) and the buffered surface waterbody polygons (i.e. the immediate catchment areas of natural drainage features) are intersected with steep

---

[110] ArcGIS online help for intersect operations: http://help.arcgis.com/en/arcgisdesktop/10.0/help../index.html#//00080000000p000000 [accessed 10/02/14]

and medium slope[111] polygons from Stage 1. In intersect operations, all spatially overlapping portions of input features are retained in the output feature class. In the Stage 3 analysis therefore, only those portions of slope polygons falling within the immediate catchment areas of artificial or natural drainage features are retained in the output feature class.

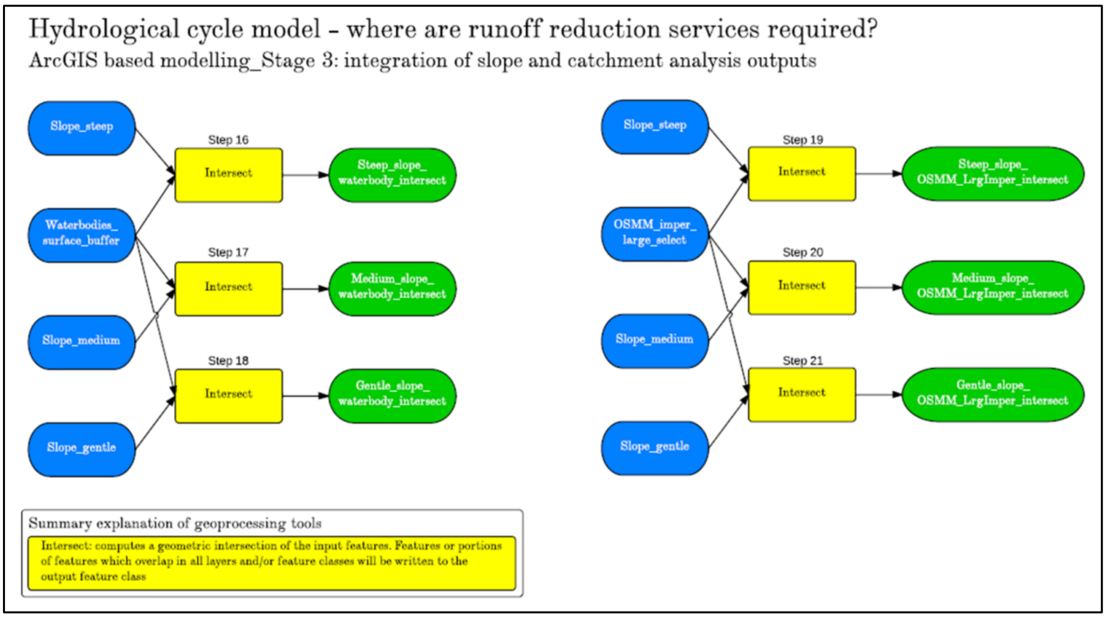


Figure 7.25 Hydrological cycle model – Stage 3 geoprocessing operations (Steps 16 – 21)

Note: The figure above shows the geoprocessing operations carried out in ArcGIS in Stage 3 of the hydrological cycle model. Input datasets come from Stages 1 and 2 of the hydrological cycle model and are as follows: 1) steep slope polygons; 2) medium slope polygons; 3) gentle slope polygons; 4) buffered large areas of impermeable ground i.e. the immediate catchment areas of artificial drainage features; and 5) buffered surface waterbodies i.e. the immediate catchment areas of natural drainage features. Figure also available within standalone CD-ROM.

In essence therefore, Stage 3 refines the analysis in Stages 1 and 2 by identifying discrete, highly specific areas of land where slope and land use are such that runoff generation potential is likely to be particularly high (at least for areas of steeply sloped and medium sloped land). The nature of intersect operations is such that Stage 3 outputs will always be smaller areas of land than the inputs from Stages 1 and 2. This is intentional, the purpose being to help urban planners prioritise land use/management intervention for the enhancement of runoff reduction ecosystem

---

[111] Practitioners may also wish to intersect gentle slope polygons though steep and medium slopes should be prioritised in the first instance

services by focussing on small, manageable areas of land in the first instance. This concept is indicated on Figures 7.26 and 7.27.

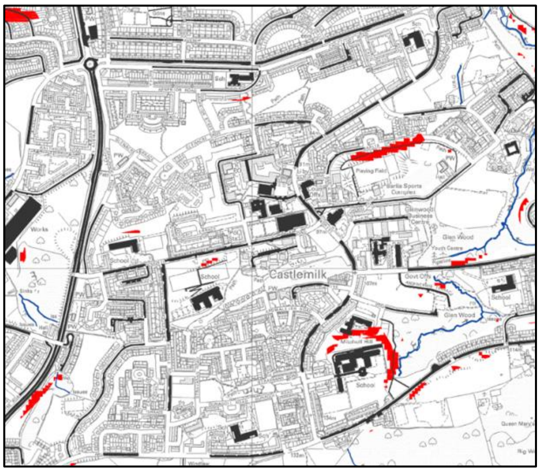
<table>
<tr><td colspan="2">
</td><td colspan="2">
</td></tr>
<tr><td>Model</td><td>Hydrological cycle model</td><td>Model</td><td>Hydrological cycle model</td></tr>
<tr><td>Step</td><td>8</td><td>Step</td><td>19</td></tr>
<tr><td>Step title</td><td>Identify and extract **steep**, medium and gentle slope polygons from the vector dataset</td><td>Step title</td><td>Identify where areas of **steeply** sloped land falls within the immediate catchment area of **artificial** drainage features</td></tr>
<tr><td colspan="2">**Note:** The figure above shows polygons from the slope vector dataset indicating areas of **steeply** sloped land (i.e. slope classes 7, 8 and 9 from the raster dataset).</td><td colspan="2">**Note:** The figure above shows the results of intersecting areas of **steeply** sloped land (Step 8 output polygons – see figure opposite) with the immediate catchment area of **artificial** drainage features (Step 12 output polygons – see Figure 7.2.4). The red polygons on the map above therefore show where areas of steeply sloped land falls within the catchment of artificial drainage features – *note how there are fewer red polygons on the right-hand map than the left-hand map as artificial drainage feature catchments/buffered large areas of impermeable ground (i.e. Step 12 outputs) occupy only a certain portion of the study area* (black polygons are large areas of impermeable ground from Step 11 – see Figure 7.23). These areas of land therefore may be prime candidates for land use/management intervention to enhance runoff reduction ecosystem services.</td></tr>
</table>

Figure 7.26 Hydrological cycle model Stage 1 (Step 8) and Stage 3 (step 19) – example outputs

Note: Figure also available within standalone CD-ROM.

There are however some key technical weaknesses with the modelling approach described above. In particular, the integration analysis (Steps 16 – 21) is undertaken simply by intersecting the slope polygons with the buffered waterbodies and large areas of impermeable ground polygons (i.e. the immediate catchments or natural and artificial drainage features – see section 7.3.2). Although this process will identify where slopes fall within the immediate catchment areas of drainage features (and therefore where land management for the enhancement of runoff reduction ecosystem services should be considered) it does not account for slope aspect.

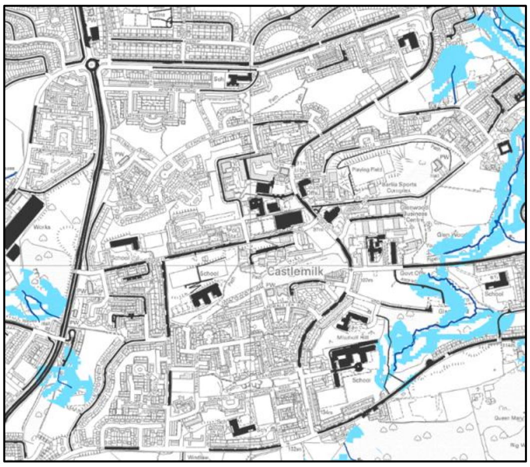
<table>
<tr><td colspan="2"> </td><td colspan="2"> </td></tr>
<tr><td>Model</td><td>Hydrological cycle model</td><td>Model</td><td>Hydrological cycle model</td></tr>
<tr><td>Step</td><td>8</td><td>Step</td><td>17</td></tr>
<tr><td>Step title</td><td>Identify and extract steep, medium and gentle slope polygons from the vector dataset</td><td>Step title</td><td>Identify where areas of medium sloped land falls within the immediate catchment area of natural drainage features</td></tr>
<tr><td colspan="2">Note: The figure above shows polygons from the slope vector dataset indicating areas of medium sloped land (i.e. slope classes 4, 5 and 6 from the raster dataset).</td><td colspan="2">Note: The figure above shows the results of intersecting areas of medium sloped land (Step 8 output polygons – see figure opposite) with the immediate catchment area of natural drainage features (Step 15 output polygons – see Figure 7.24). The blue polygons on the map above therefore show where areas of medium sloped land falls within the catchment of natural drainage features – <i>note how there are fewer blue polygons on the right-hand map than there are orange polygons on the left-hand map as natural drainage feature catchments/buffered river corridors (i.e. Step 15 outputs) occupy only a certain portion of the study area</i>. These areas of land may be prime candidates for intervention to enhance runoff reduction ecosystem services.</td></tr>
</table>

Figure 7.27 Hydrological cycle model Stage 1 (Step 8) and Stage 3 (step 17) – example outputs

Note: Figure also available within standalone CD-ROM.

The consideration of aspect is a key issue in this regard as aspect will determine flow direction and therefore whether or not runoff will flow towards or away from the drainage feature. This is less of an issue for natural drainage features as the parameters used in the modelling process (e.g. the buffer distance at Step 15 – see Figure 7.22) and the geomorphology of natural drainage features is such that the land identified in the intersects at Steps 16 – 18 (see Figure 7.25) will frequently be sloped towards the surface waterbody (see the blue polygons on Figure 7.27 for example). This is contrast to the approach used to model artificial drainage features which uses large areas of impermeable ground as a proxy (see Figure 7.2.3). Given this, the land identified in the intersects at Steps 19 – 21 may or may not be sloped towards the artificial drainage feature/large area of impermeable ground.

In many respects this is a moot point as the effects of land use/management intervention for the enhancement of runoff reduction ecosystem services will be felt at the catchment scale – i.e. the intention of intervention is to manipulate runoff coefficients at the catchment scale to help reduce peak flows in natural and artificial drainage systems, potentially reducing flood risk (see section 4.7). This issue is considered in section 8.2 where outputs from all three models (i.e. flood control, hydrological cycle and habitat networks) are considered together to identify integrated recommendations for land use/management intervention for the delivery of multiple benefits.

7.4 The habitat network model – where are ecological connectivity services required?

This section describes the structure, process and function of the habitat network model that has been developed through this research. The purpose of this model is to identify sites where appropriate land use/management intervention may be required in order to enhance ecological connectivity ecosystem services (see section 3.2) i.e. sites and interventions where improved management or the creation/recreation of habitat (see section 5.2.2) can help to improve the overall connectivity of the landscape for species, noting that this can be achieved through the enhancement of structural and/or functional connectivity (see section 5.2.1). The spatial analyses within the model have a particular focus on the identification of sites and interventions for the creation/recreation of habitat. In addition however, the consideration of PAN65 openspace data (see section 3.1.3 and Table 3.4) and habitat patch data (see sections 5.1.1 and 5.2.1) within the model integration stage described at Chapter 8 allows for the identification of habitat management and consolidation related land use/management actions as well.

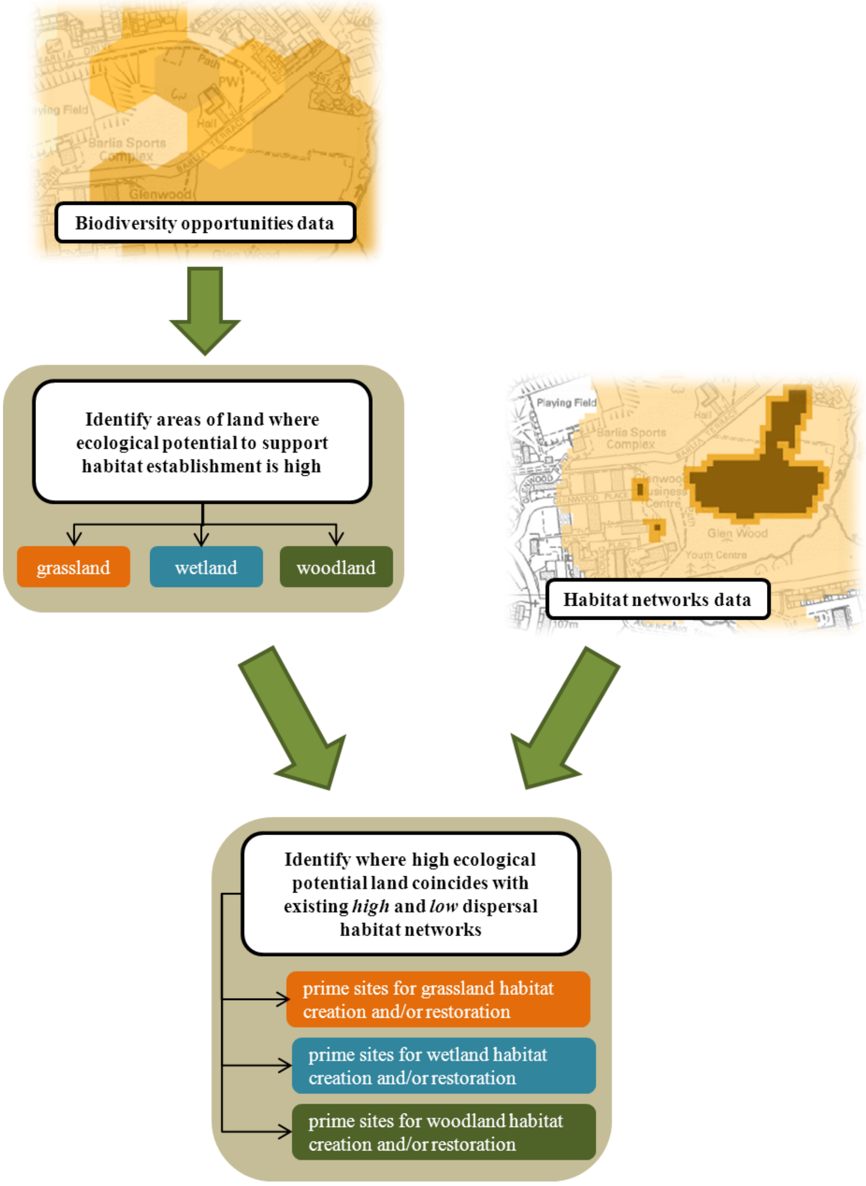


Figure 7.28 Overall structure of the habitat network model

Note: Figure also available within standalone CD-ROM.

As discussed at section 5.3, urban habitat and habitat networks have the potential to deliver a wide range of multiple benefits (see Table 5.2) including water management ecosystem services (flood storage and runoff reduction) as per the scope and objectives of the flood control model (see section 7.2) and hydrological cycle model (see section 7.3). In this regard, habitat network model outputs provide a key input to the model integration stage described at section 8.2 – i.e. identifying opportunities whereby the consolidation and improved management of existing habitat and/or the creation of new habitat can be targeted to deliver enhanced flood storage and runoff reduction ecosystem services at priority locations identified through the flood control model (see sections 7.2.6 and 7.2.8) and hydrological cycle model (see section 7.3.3).

Similarly to the hydrological cycle model (see section 7.3), the habitat network model can be run for a range of different geographies and scales in urban areas including those defined by natural features (e.g. water catchments) and administrative units (e.g. local development framework areas). As discussed at section 5.1.1 however, it is more appropriate to plan for ecological networks at the 'landscape scale' where this term is used to define an area of land covering several square kilometres. In this regard, it is suggested that the habitat network model is utilised at the catchment or city district scale to ensure that key pinch points and opportunities can be fully considered in the analysis. The development of the habitat network model has been informed by the material collated, analysed, synthesised and documented in Chapters 3 and 5 as part of Research Objective No.2 (see Box 1.2). The overall structure of the habitat network model is shown on Figure 7.28 and described at Table 7.13.

Table 7.13 Habitat network model – summary description of key stages

Stage	Objectives/purpose
1. Analysis of ecological potential	**The overall objective of Stage 1 is to identify areas of land within the study area where ecological potential to support habitat establishment is high.** This is undertaken on the basis of Forest Research's biodiversity opportunities data – a polygon dataset that categorises land on the basis of its ecological potential to support habitat establishment (see section 2.4.2). The highest scoring cells (in terms of their ability to support habitat establishment) are extracted from the overall dataset using a **select**[112] operation in ArcGIS. There is a biodiversity opportunities dataset available for each of the broad habitat types considered in the habitat networks model: 1) unimproved/neutral grassland; 2) wetland; and 3) woodland. The analysis summarised above is undertaken for each of these

---

[112] ArcGIS online help for select operations: http://resources.arcgis.com/en/help/main/10.1/index.html#//000800000005000000 [accessed 09/02/14]

Stage	Objectives/purpose
	datasets. Stage 1 also involves a simple data preparation step that clips all input data to the study area.
2. Identify prime sites for habitat establishment	**The overall objective of Stage 2 is to integrate the ecological potential data from Stage 1 with existing low and high dispersal habitat networks data to identify prime sites for habitat creation/recreation**. Land within existing low and high dispersal habitat networks is already functionally connected with one or more habitat patches (see section 5.2.1 and Figures 5.2 and 5.3). Stage 1 described above identifies land where ecological potential to support habitat establishment is high. Stage 2 then integrates this data with habitat networks data to identify prime sites for habitat creation/recreation – i.e. locations where land with high ecological potential to support habitat establishment is located **within** an existing habitat network (this analysis is facilitated using the **intersect**[113] operation in ArcGIS). As this land is already functionally connected with one or more habitat patches (at least in terms of the model – see 5.2.2 for further information about the uncertainties and weaknesses of habitat network data), habitat establishment at these locations can act to consolidate existing habitat networks as well as potentially creating new networks e.g. if improvements in functional connectivity (i.e. as a result of the creation of new patches) are such that additional patches are encompassed within the habitat network (see Figure 5.5 for an illustration of this principle).

7.4.1 Habitat network model Stage 1 – analysis of ecological potential

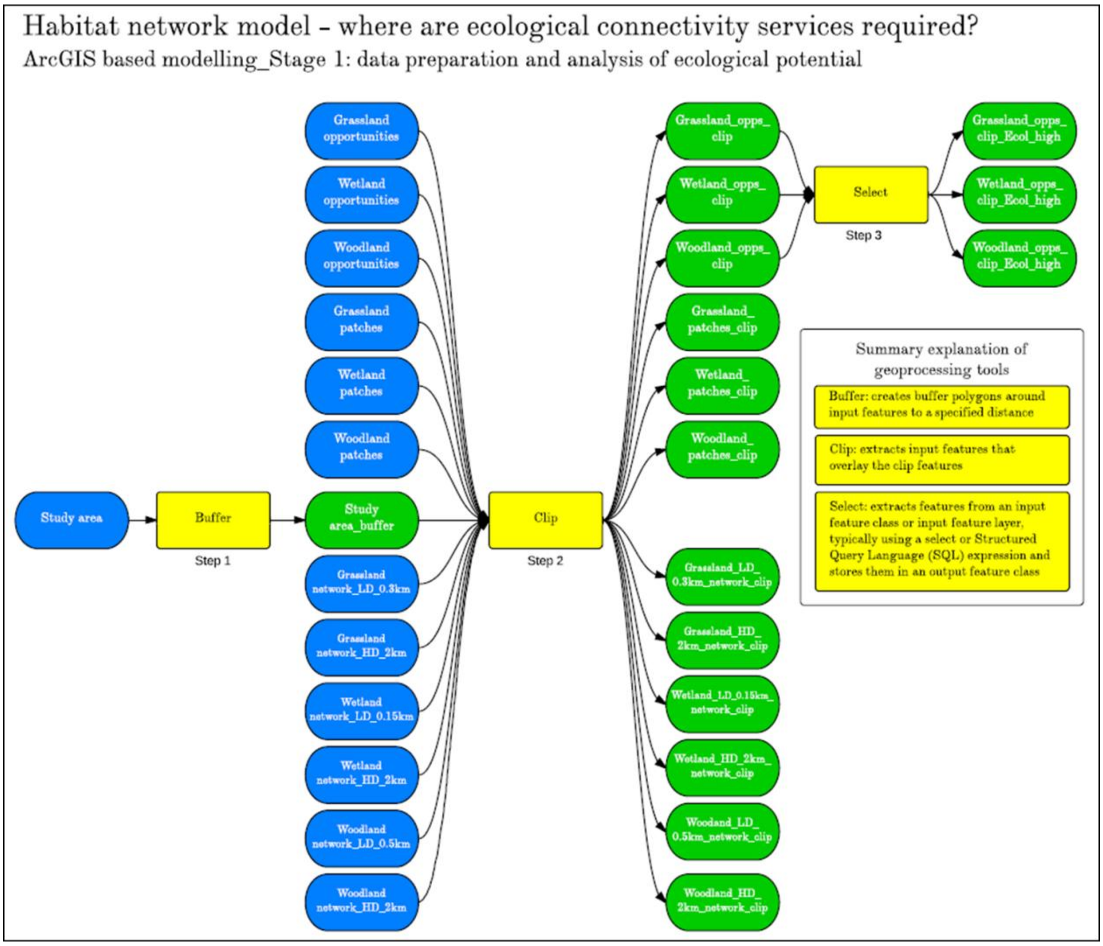
As outlined at Table 7.13, the overall objective/purpose of Stage 1 of the habitat network model is to identify areas of land within the study area where ecological potential to support habitat establishment is high. The interaction of the various geoprocessing operations in Stage 1 of the habitat network model are indicated on Figure 7.29. More detailed geoprocessing instructions are provided at Appendix 10. Step 1 (see Figure 7.29) buffers the input study area polygon. As with the hydrological cycle model the importance of this step will vary depending on the nature of the study area under investigation (see section 7.3.1).

Step 2 (see Figure 7.29) is, in essence, a data preparation step. The habitat network model is based on 12 input datasets covering biodiversity opportunities (i.e. ecological potential), habitat patch, low dispersal habitat networks and high dispersal habitat networks for each of the three broad habitats considered in the modelling (i.e. grassland, wetland and woodland). Further information on the data is provided at section 2.4.2 and 5.2.2. As such, there may be a need to reduce the amount of data considered in subsequent steps of the habitat network model (e.g. to speed up

---

[113] ArcGIS online help for intersect operations: http://help.arcgis.com/en/arcgisdesktop/10.0/help../index.html#//00080000000p000000 [accessed 10/02/14]

processing time in the GIS). Accordingly, Step 2 simply clips the 12 input datasets to the buffered study area polygon (see Figure 7.30).



Buffer: creates buffer polygons around input features to a specified distance

Clip: extracts input features that overlay the clip features

Select: extracts features from an input feature class or input feature layer, typically using a select or Structured Query Language (SQL) expression and stores them in an output feature class

Figure 7.29 Habitat network model – Stage 1 geoprocessing operations

Note: The figure above shows the geoprocessing operations carried out in ArcGIS in Stage 1 of the habitat network model. Input datasets are: 1) study area polygon; 2) biodiversity opportunity area polygons; 3) habitat patch polygons; 4) low dispersal habitat network polygons; and 5) high dispersal habitat network polygons (see section 2.4.2). As indicated on the Figure, input datasets for each of the three broad habitats considered in the habitat network model are used (i.e. there are 12 separate habitat related input datasets in total). Appendix 10 provides further information on Stage 1 including geoprocessing instructions and suggested filenames for input and output feature classes as per the Figure above. Figure also available within standalone CD-ROM.

Step 3 of the habitat network model (see Figure 7.29) uses a Structured Query Language (SQL) based select[114] operation to extract specific biodiversity opportunity

---

[114] ArcGIS online help for select operations: http://resources.arcgis.com/en/help/main/10.1/index.html#//000800000005000000 [accessed 09/02/14]

polygons from the clipped biodiversity opportunities dataset (see the grassland habitat example shown on the right-hand map at Figure 7.30).

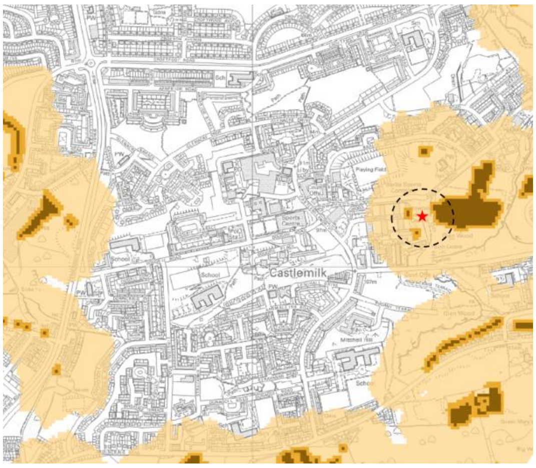
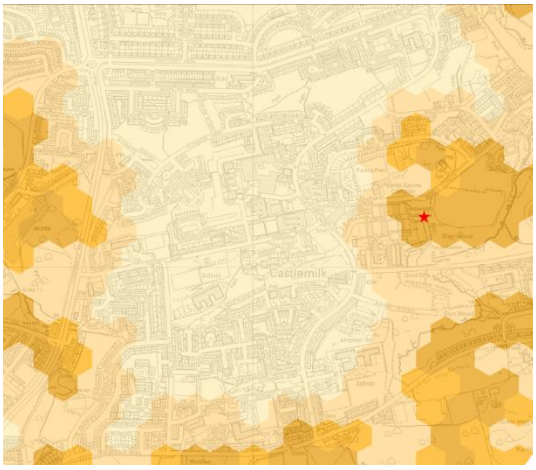
<table>
<tr><td colspan="2">
</td><td colspan="2">
</td></tr>
<tr><td>Model</td><td>Habitat network model</td><td>Model</td><td>Habitat network model</td></tr>
<tr><td>Step</td><td>2</td><td>Step</td><td>2</td></tr>
<tr><td>Step title</td><td>Clip habitat patches and habitat network data to the buffered study area polygon</td><td>Step title</td><td>Clip opportunities (ecological potential to support habitat establishment) data to the buffered study area polygon</td></tr>
<tr><td colspan="2">**Note:** The Figure above shows unimproved/ neutral grassland patches (brown polygons), low/0.3km dispersal habitat network (dark orange polygons) and high/2km dispersal habitat network (pale orange polygons) data clipped to the study area. Note how the spatial delineation of the habitat networks is not uniform, reflecting variation in the permeability/resistance of the surrounding matrix as a result of variation in land use (see section 5.2.2 for further information).</td><td colspan="2">**Note:** The Figure above shows the grassland opportunities data clipped to the study area. Darker orange polygons indicate land with a higher ecological potential to support habitat establishment. One key parameter considered in Forest Research's biodiversity opportunities data (see section 2.4.2) is the potential for habitat creation/recreation to contribute to increased ecological connectivity. The influence of this parameter is readily apparent in the example shown above as areas of higher ecological potential for grassland establishment (dark orange polygons) are clustered around areas of existing habitat (see left-hand Figure). In effect, these are prime areas where habitat management and creation could help to consolidate existing networks and improve functional connectivity.</td></tr>
<tr><td colspan="4">The location indicated by the red star on both Figures is a case in point – habitat creation at this location could enhance the functional connectivity of the low dispersal network (dark orange polygons on the left-hand Figure) thereby increasing the area of contiguous network and providing functional connections between the three discrete habitat patches (brown polygons) shown within the black dashed circle. This concept is explained further at section 7.4.2.</td></tr>
</table>

Figure 7.30 Habitat network model Stage 1 (Step 2) – example outputs

Note: Figure also available within standalone CD-ROM.

The intention of the SQL operation is to focus the integration analysis at Stage 2 on land that has high ecological potential to support habitat establishment **only**. In conjunction with the clipped low and high dispersal habitat networks data from Stage 1 (see Figure 7.30), outputs from the biodiversity opportunities data select operation are used as the inputs to Stage 2 to identify prime sites for habitat establishment (see section 7.4.2). An example output from the select operation is shown at Figure 7.31.

Summary details of example output	
Model	Habitat network model
Step	3
Step title	Identify land where ecological potential to support habitat establishment is high
Note: The Figure to the left shows land in the study area where ecological potential to support grassland habitat establishment is high (brown polygons). This has been extracted from the overall grassland opportunities dataset shown at Figure 7.30 (right-hand map) using an SQL based select operation in the GIS.	

Figure 7.31 Habitat network model Stage 1 (step 3) – example output

Note: Figure also available within standalone CD-ROM.

7.4.2 Habitat network model Stage 2 – identify prime sites

The overall objective/purpose of Stage 2 of the habitat network model is to integrate the ecological potential data from Stage 1 with existing low and high dispersal habitat networks data to identify prime sites for habitat creation/recreation (see Table 7.13). The interaction of the various geoprocessing operations in Stage 2 of the habitat network model are indicated on Figure 7.32. More detailed geoprocessing instructions are provided at Appendix 10.

Stage 2 of the habitat network model has one step only – polygons representing areas of land with high ecological potential to support habitat establishment are subject to an intersect[115] operation with polygons representing existing low and high dispersal habitat networks. As indicated on Figure 7.32, these operations are repeated for each broad habitat considered in the habitat network model (grassland, wetland and woodland) – i.e. there are six intersect operations in total. An example Stage 2 output for grassland habitat is shown at Figure 7.33.

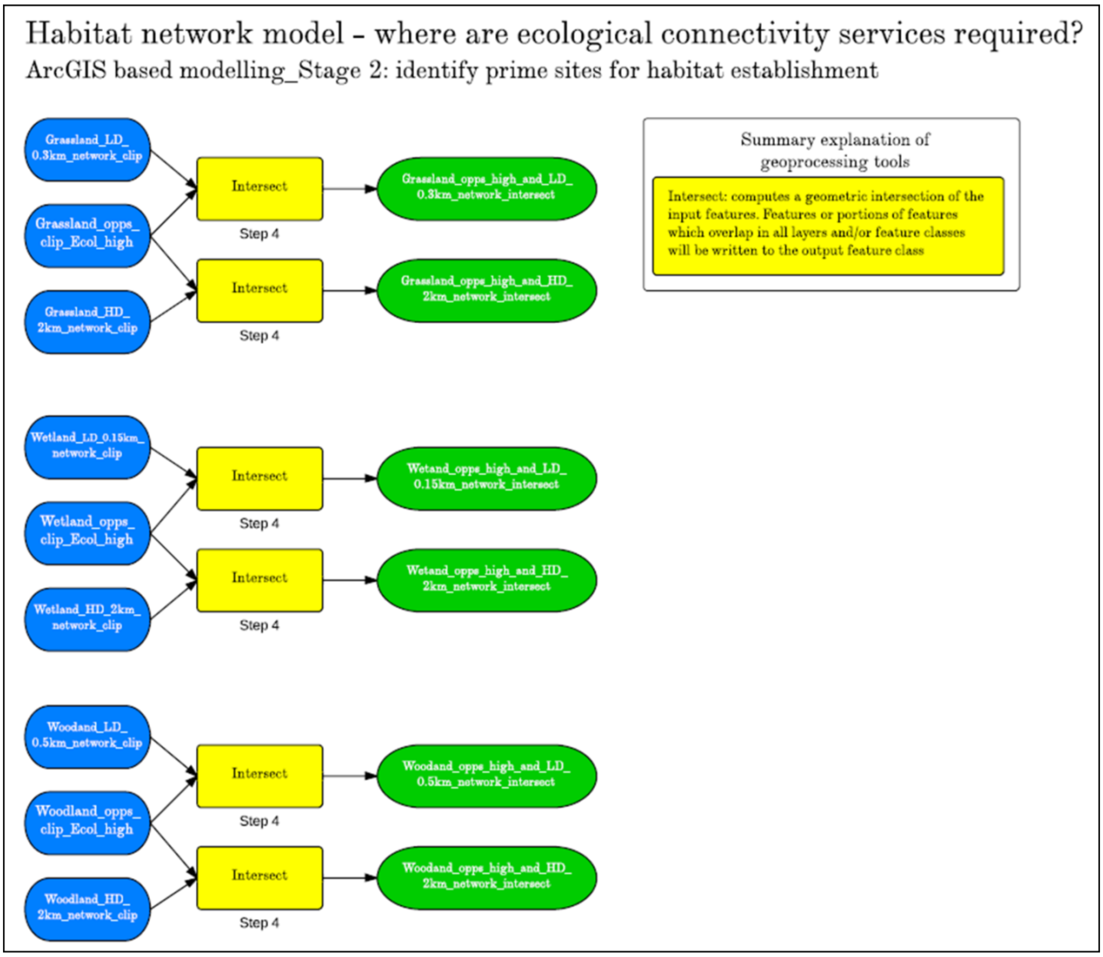


Figure 7.32 Habitat network model – Stage 2 geoprocessing operations

Note: The figure above shows the geoprocessing operations carried out in ArcGIS in Stage 2 of the habitat network model. Input datasets are key outputs from Stage 1 of the habitat network model (see Figure 7.29). These are: 1) land with high ecological to support habitat establishment clipped to the study area; 2) low dispersal habitat network polygons clipped to the study area; and 3) high dispersal habitat network polygons clipped to the study area. As indicated on the Figure, input datasets for each of the three broad habitats considered in the habitat network model are used (i.e. there are nine habitat input datasets in total – three for each broad habitat considered in the model). Appendix 10 provides

---

[115] ArcGIS online help for intersect operations: http://help.arcgis.com/en/arcgisdesktop/10.0/help../index.html#//00080000000p000000 [accessed 10/02/14]

further information on Stage 2 including geoprocessing instructions and suggested filenames for input and output feature classes as per the Figure above. Figure also available within standalone CD-ROM.

In effect, the intersect operation identifies where areas of land with high ecological potential to support habitat establishment coincide with existing habitat networks. Where this situation occurs, the areas of land identified may be prime candidates for habitat creation/recreation as the land is: 1) likely to be ecologically suitable for habitat establishment (e.g. in terms of existing land use, soils etc); and 2) located within an existing habitat network. In this regard, any habitat establishment works should help to consolidate the existing network and may also help to increase the area of contiguous network (and therefore functional connectivity between discrete habitat patches that may have previously been isolated).

<table>
<tr><td colspan="2"> </td><td colspan="2"> </td></tr>
<tr><td>Model</td><td>Habitat network model</td><td>Model</td><td>Habitat network model</td></tr>
<tr><td>Step</td><td>2</td><td>Step</td><td>4</td></tr>
<tr><td>Step title</td><td>Clip habitat patches and habitat network data to the buffered study area polygon</td><td>Step title</td><td>Intersect high ecological potential polygons with existing habitat network polygons</td></tr>
<tr><td colspan="2">Note: The step 2 output from Figure 7.30 has been included here for comparison. The Figure above shows unimproved/neutral grassland patches (brown polygons), low/0.3km dispersal habitat network (dark orange polygons) and high/2km dispersal habitat network (pale orange polygons) data clipped to the study area.</td><td colspan="2">Note: The Figure above shows the output (pale pink polygons) of intersecting land with high ecological potential to support grassland habitat establishment and existing high dispersal grassland habitat networks. The brown polygons show existing grassland habitat patches.</td></tr>
</table>

The intersect operation shows how the area of high ecological potential land is smaller than the area of land encompassed by existing high dispersal habitat networks (see left-hand Figure) – i.e. although the nature of the matrix within the high dispersal network may be such that it can facilitate species movements, some of the land within this area has lower ecological potential for habitat establishment. This is illustrated by the area of land within the black dashed rectangle – on the left-hand Figure this land falls within the high dispersal network however on the right-hand Figure this area of land is not featured. In effect, the nature of the existing landcover at this site is such that the land has more limited potential to support grassland habitat establishment. Interestingly, the area indicated by the red star shown on the left-hand Figure (see Figure 7.30 also) remains as a key opportunity area on the right-hand Figure whereby habitat related land use/management action could be delivered to improve functional connectivity (including within low dispersal networks).

Figure 7.33 Habitat network model Stage 1 (Step 2) and Stage 2 (step 4) – example outputs

Note: Figure also available within standalone CD-ROM.

This concept is discussed and depicted on Figures 7.30 and 7.33. Practitioners may wish to focus initial habitat creation/recreation works on sites identified within low dispersal networks as improved functional connectivity within low dispersal networks is likely to cater for a wider array of species (i.e. including those with low dispersal abilities), thereby contributing to wider conservation objectives (see section 5.2.2). As discussed at Chapter 8 however, land use/management actions informed by the models and tools developed in this research should be designed to deliver a wide range of multiple benefits – i.e. at least in terms of the three key ecosystem services considered in this research (flood storage, runoff reduction and ecological connectivity). In this regard, practitioners may wish to use outputs from the high dispersal intersect operation (i.e. to effectively broaden the search area for potential habitat related land use/management action) given that ecological connectivity (and associated support for conservation and biodiversity objectives) is just one of several land use/management benefits considered in the integration analysis described at section 8.2.

As suggested in the literature (see section 5.2.2), high and low dispersal networks are used in Stage 2 as a means of dealing with some of the inherent uncertainty and ‘fuzziness’ associated with the use of outputs from least-cost type habitat network models. In effect, this approach facilitates the consideration of high and low species dispersal abilities and can help to account for some of the uncertainty when using generic focal species (GFS) to model functional habitat network connectivity (see section 5.2.2).

This concludes the introduction to and explanation of the three new spatial models developed through this research. Chapter 8 now explains how the spatial models can be combined, in conjunction with the new guiding principles and technical guidance, to inform the development of integrated urban land use/management strategies.

8. Integrating spatial models: how do we know where multiple urban ecosystem services are required?

As described in Chapter 1, the overarching aim of this research is "to understand, develop, trial and evaluate new approaches to urban planning that can operationalise aspects of the ecosystems approach". To meet this overarching aim, a substantial evidence assessment has been undertaken as documented in Chapters 3, 4, 5 and 6. Research Objective No.4 (see Box 1.2) has focused on the development of new approaches to urban planning. Drawing on the evidence assessment findings, Chapter 7 introduced three new spatial models for urban planning that can help practitioners identify where land use/management change may be required to enhance the three ecosystem services considered in this research (see section 3.2.5). The approach taken in the development of the new spatial models is described at sections 2.2, 2.3.3 and 2.4.2. The evidence assessment has also informed the development of a new set of guiding principles for ecosystems approach based urban land use planning as well as technical guidance for interpreting and acting on outputs from the new spatial models (see sections 2.2.10 and 2.4.1 and Appendices 3, 4, 5 and 6).

The key purpose of this Chapter therefore is to describe how the three new spatial models, the new ecosystems approach guiding principles and the technical guidance can be combined to inform the development of integrated urban land use/management strategies, as part of the process of developing urban Local Development Plans (see section 3.1). Section 8.1 introduces the ecosystems approach guiding principles and technical guidance. By way of a worked example, section 8.2 then describes how the various new tools, models and guidance developed in this research can be combined to inform the development of integrated land use/management strategies. Finally, section 8.3 explains how integration analysis outputs from section 8.2 could be used to inform practical land use/management decision-making as part of the process of developing an urban Local Development Plan (LDP), as per the requirements of the Planning etc (Scotland) Act 2006. Readers should note that all Figures within this Chapter are also provided in a standalone document that is available on the CD-ROM enclosed with this thesis.

8.1 Introduction to the new ecosystems approach guiding principles and technical guidance

The evidence assessment undertaken as part of this research (see Chapters 3, 4, 5 and 6) has informed the development of a new suite of ecosystems approach guiding principles and technical guidance for interpreting and acting on outputs from the new spatial models (see Chapter 7) in the development of integrated urban land use/management strategies. This section introduces the new principles and technical guidance. Section 8.1.1 describes the analysis approach that informed the development of the principles and technical guidance. Section 8.1.2 explains the structure of the new principles and technical guidance.

8.1.1 Analysis approach

The new ecosystems approach guidance principles can be found in Appendix 3. The new principles have used the CBD ecosystems approach principles (see section 3.2.4 and Table 3.8) as an overarching framework (see section 8.1.2). The new technical guidance for interpreting and acting on outputs from the flood control model (see section 7.2), hydrological cycle model (see section 7.3) and habitat network model (see section 7.4) can be found at Appendices 4, 5 and 6 respectively. The general approach to the analysis of qualitative data in this research is described at section 2.4.1. The following specific steps were undertaken in the development of the new ecosystems approach guiding principles and technical guidance:

- **Step 1:** Analysis of all data collected as part of the evidence assessment process (see sections 2.2 and 2.3 and Chapters 3, 4, 5 and 6) to identify possible ecosystems approach guiding principles and technical information (example approaches and technical principles) to inform the development of technical guidance. A record of references for each possible principle and technical information note identified was maintained.

- **Step 2:** The CBD ecosystems approach principles (see Table 3.8) were used to categorise possible ecosystems approach guiding principles identified at Step 1. Analysis of technical information from Step 1 identified possible concepts and categories. Technical information was then grouped by category.

- **Step 3:** All possible guiding principles and technical information from Step 1 were analysed to identify areas of overlap, differences and similarities. A consolidated list of principles and technical information was then developed. Consolidated principles and technical information were then allocated to categories identified at Step 2. Categories were then refined as required.

8.1.2 Structure of the new guiding principles and technical guidance

The new guiding principles for ecosystems approach based urban land use planning have used the CBD ecosystems approach principles as an overarching framework. As shown at Table 3.8, the suite of CBD principles is detailed and comprehensive, especially when compared with other example frameworks such as the Scottish Government's (2011c) information note on applying an ecosystems approach to land use, which includes only three principles. For the purposes of developing useful practical guidance therefore, the CBD principles are considered to provide a more useful framework given the greater level of detail they afford. This issue is depicted on Figure 8.1 which shows the overall structure of the new ecosystems approach guiding principles and technical guidance. Table 8.1 provides an example of the new ecosystems approach guiding principles which can be seen in full at Appendix 3.

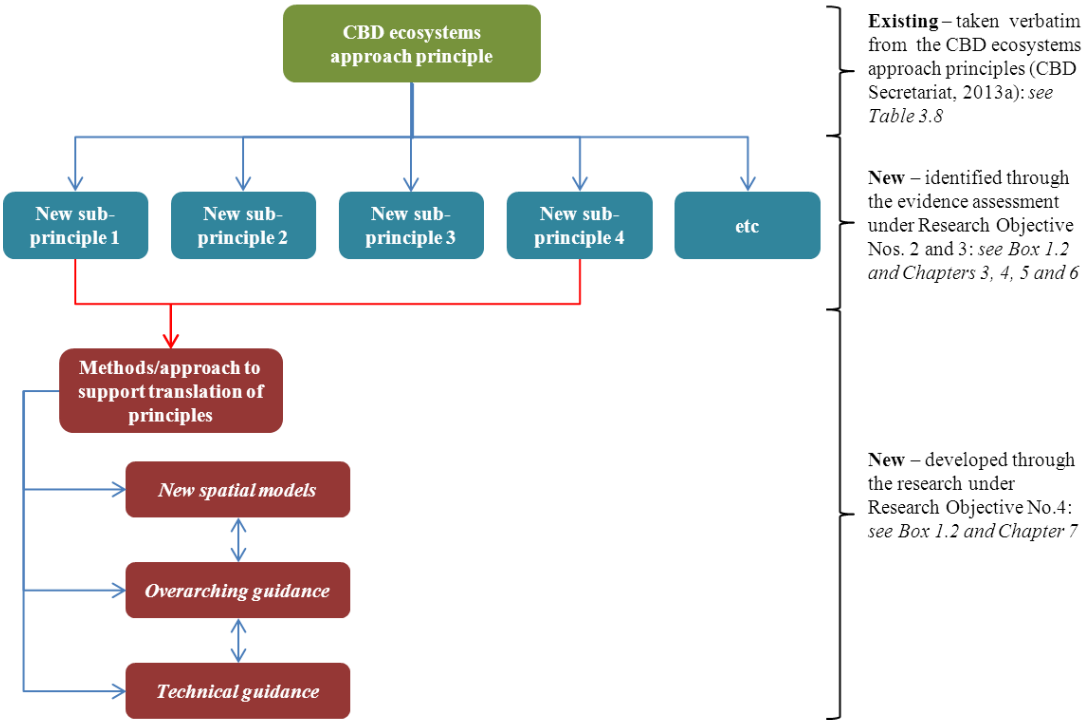


Figure 8.1 Overall structure of the new guiding principles and technical guidance for ecosystems approach based urban land use planning

Note: The Figure depicts the overall structure of the new guiding principles and technical guidance developed through this research (including the new spatial models introduced at Chapter 7). The Figure shows the structure for one CBD ecosystems approach principle as an example though there are 12 CBD principles in total (see Table 3.8). Ecosystems approach guiding principles have been developed for each CBD principle (see Appendix 3). As indicated by the red lines on the Figure, spatial models and technical guidance have been developed to support certain principles only. Figure also available within standalone CD-ROM.

The CBD Secretariat (2013a) and Phillips et al (2014) highlight how principles can provide overarching guidance to support the delivery of action on the ground. In this regard, the new suite of ecosystems approach guiding principles developed through this research are intended to provide overarching guidance for urban planning stakeholders in the development of integrated, ecosystems approach based urban land use/management strategies. It may be the case however that strategic, generic principles can benefit from the application of specific methods and approaches to help translate the strategic intent of the principles into action on the ground (Scottish Government, 2011d; Phillips et al, 2014). This is the key purpose of the new spatial models and associated technical guidance developed through this research. As indicated on Figure 8.1 however, new spatial models and technical guidance have only been developed for some of the CBD principles/new ecosystems approach guiding principles, reflecting the scope of this thesis in terms of the specific urban ecosystem services considered (see section 3.2.5). As discussed at section 9.3 therefore, a key area for future research is the development of additional models and technical guidance for the principles that have not been addressed by this thesis.

Table 8.1 Extract from the new set of guiding principles for ecosystems approach based urban land use planning

CBD ecosystems approach principle	**Sub-principles for ecosystems approach based urban land use planning**		**Reference(s)**
	Ref.	**Details of sub-principle**	
EsA_1: Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems	**ESA_1.1**	Spatial delineation of urban ecosystems for management purposes (e.g. on the basis of similar climatic conditions, geophysical conditions, surface cover, resource management systems) should consider how delineation can incorporate multiple ecosystems. Where relevant, this can help to ensure that the functioning of ecosystem processes/intermediate services (e.g. ecological interactions, nutrient cycling etc) are considered both within and between ecosystems. **This sub-principle is also relevant to EsA_2**	Section 3.2.1
	EsA_1.4	Regional scale land use/management plans are likely to incorporate multiple whole ecosystems/landscapes/catchments. Planning at this scale therefore can ensure that the effects of land use/management change on adjacent ecosystems are considered. This could be undertaken as part of a tiered planning system - e.g. regional scale plans establishing a broad framework for more detailed sub-regional and local level plans	Section 6.4.1 Phillips et al (2014)
EsA_4: The ecosystem approach should be undertaken at the appropriate spatial and temporal scales	**EsA_4.1**	It may be useful to disaggregate the urban natural environment into 'green' and 'natural environment' type land parcels. For planning and management purposes, these can then be construed as the spatial 'building blocks' of urban ecosystems. In Scotland, Planning Advice Note (PAN) 65 provides a useful typology of openspace for this purpose	Sections 3.1.3 and 3.2.1 Figure 3.3 Table 3.4 AECOM (2011) Scottish Government (2008)
	EsA_4.2	Ensure that the approach adopted in the spatial delineation and disaggregation of the urban natural environment sufficiently reflects the heterogeneity of the urban landscape	Section 6.1.2 Phillips et al (2014)

8.2 Combined use of the new spatial models and technical guidance to inform the development of integrated urban land use/management strategies

The new spatial models developed through this research and described at Chapter 7 identify locations where land use/management change may be required to enhance the three urban ecosystem services considered in this research (see section 3.2.5). In effect, these are potential priority areas for the enhancement of *individual* ecosystem services. The true benefit of the new spatial models and technical guidance however lies in their combined use – i.e. identifying *multifunctional* priority areas (MPAs) for the enhancement of multiple ecosystem services through the planning and design of integrated land use/management strategies. Multifunctional land use in this regard chimes well with the general principles of urban land use planning (see sections 1.3, 3.1.1 and 3.1.3), Scotland's land use strategy (see section 3.1.4) and the principles of the ecosystems approach (see sections 1.2, 3.2.2 and 3.2.4). This section describes the steps that urban land use/management practitioners can take to integrate the technical guidance and outputs from individual spatial models to identify MPAs and inform the development of integrated land use/management strategies. Section 8.2.1 explains the general concepts involved and section 8.2.2 provides a worked example.

8.2.1 Identifying priority areas for multifunctional land use

Individual outputs from the new spatial models developed in this research identify priority areas for the enhancement of discrete ecosystem services. In this regard, individual outputs could feasibly be fed into urban land use/management planning processes (e.g. the LDP process) to inform the development of land use policy for specific ecosystem services. This is illustrated by the three schematic maps at the top of Figure 8.2 (Maps 1 – 3). For example, the priority areas identified for enhancing runoff reduction services indicated on Map 1 could feasibly inform urban land use policy in their own right – e.g. *ensure that land use/management change within the identified priority areas is designed to support the enhancement of* ***runoff reduction*** *ecosystem services*.

The key functionality of the new tools, models and guidance however lies in their integrated use. A classical function of GIS in this regard is the ability to 'overlay' multiple spatial datasets to explore spatial relationships between different features (Ormsby et al, 2009). As such, outputs from individual spatial models (Maps 1 – 3 on Figure 8.2) can be overlayed in the GIS to identify potential congruencies between discrete ecosystem service priority areas (i.e. Map 4 on Figure 8.2). In essence, locations where output polygons from individual spatial model outputs coincide can be construed as multifunctional priority areas (MPAs) – i.e. where land use/management change may be required to deliver multiple ecosystem services.

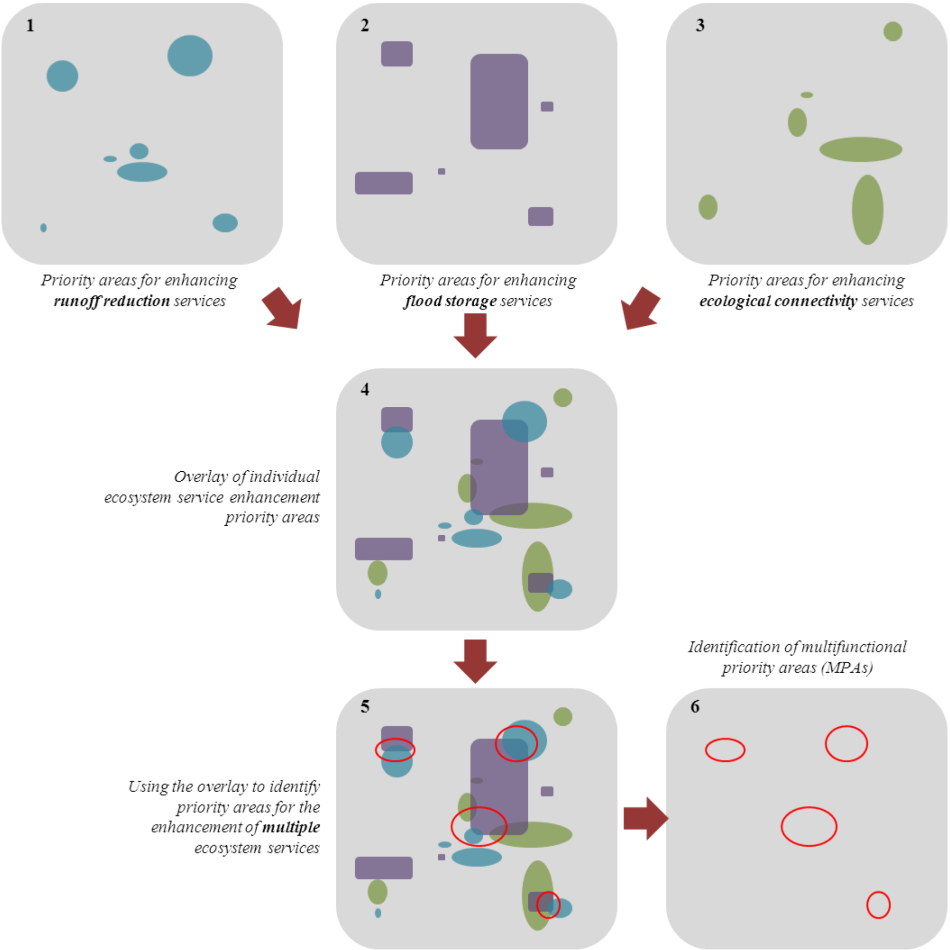


Figure 8.2 Integrating individual spatial model outputs to identify priority areas for multifunctional land use – schematic representation of GIS overlay process

Note: Figure also available within standalone CD-ROM.

In this research, MPAs have been identified simply by reviewing Map 4 type overlays (see Figure 8.2) by eye to identify distinct overlaps and congruencies. In this regard, Map 5 on Figure 8.2 shows a range of possible MPAs based on an overlay of Maps 1, 2 and 3. Clearly there is an element of value judgment here and practitioners wishing to identify MPAs in this manner should consider using a stakeholder-led deliberative approach. An alternative approach could have been to use multiple intersect operations in the GIS to identify discrete areas of land where multiple ecosystem services are required. The analysis can be enhanced by including other spatial datasets e.g. pluvial flood extent and PAN65 openspace (see Table 3.4).

8.2.2 Combined use of new spatial models/technical guidance: worked example

Figure 8.3 shows an overlay of outputs from the hydrological cycle model (see section 7.3) and habitat network model (see section 7.4). In line with the discussion at section 8.2.1, there are clearly several locations on Figure 8.3 that could be scoped-in as MPAs – i.e. locations where demand for multiple ecosystem services coincides. For the purposes of illustration, two MPAs have been identified. The anticipated direction of runoff has been determined with reference to outputs from the slope analysis undertaken as part of the hydrological cycle model (see section 7.3.1 and Appendix 9).

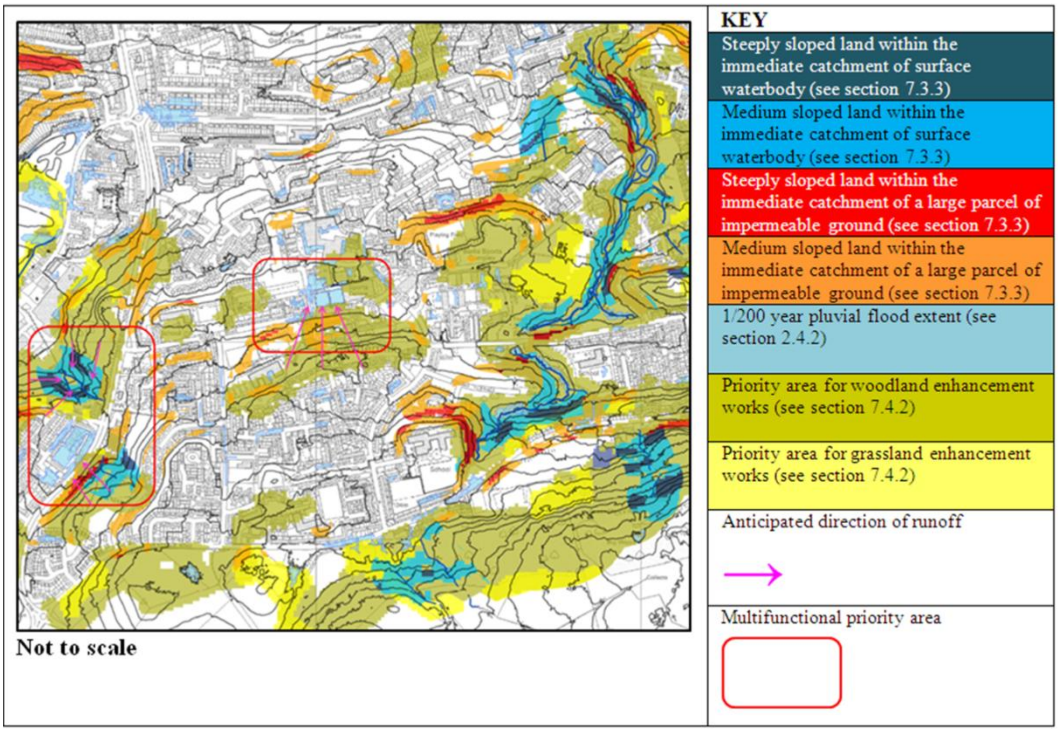


Figure 8.3 Example overlay of hydrological cycle model and habitat network model outputs showing two potential multifunctional priority areas (MPAs)

Note: Figure also available within standalone CD-ROM.

Once MPAs have been identified and scoped-in, practitioners should appraise the identified areas against the relevant technical guidance for interpreting and acting on model outputs. In the case illustrated on Figure 8.3, the hydrological cycle and habitat network model technical guidance appendices are relevant (Appendices 5 and 6 respectively). Each individual guidance note should be considered for potential relevance to the site and practitioners should keep a record of relevant guidance notes. In this regard, a degree of familiarity of the site is useful in order to assess the relevance of each guidance note e.g. speaking to local stakeholders, reviewing aerial photography, overlaying openspace audit data to characterise the area in terms of its existing 'green' and 'natural environment' type land uses and green infrastructure (see section 3.1.3).

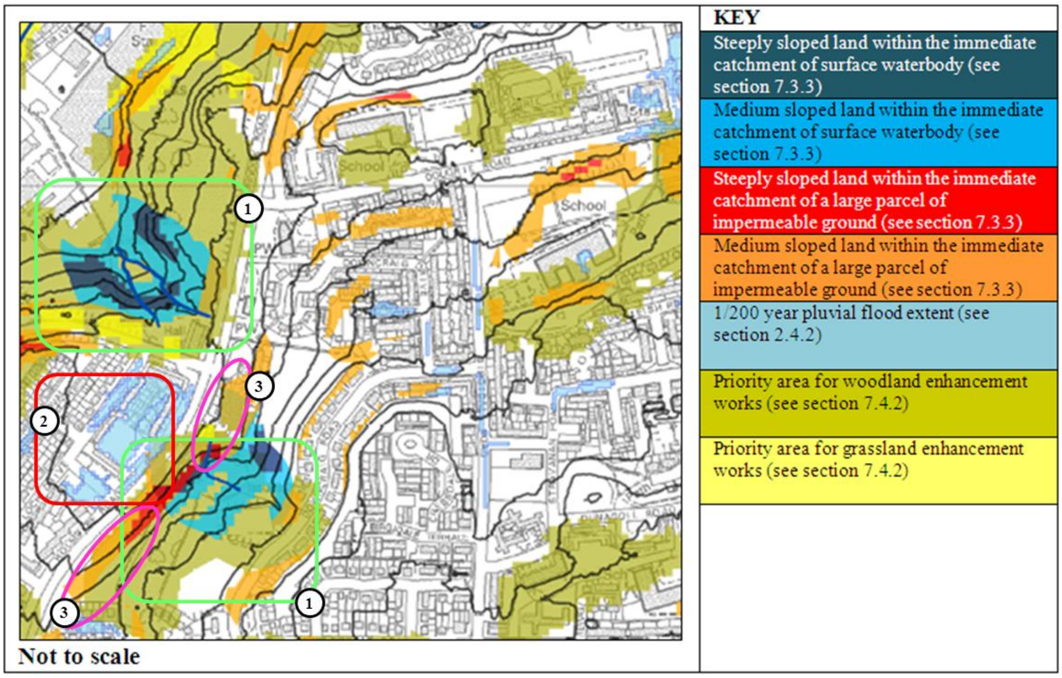


Figure 8.4 Developing broad-brush land use/management intervention proposals for scoped-in multifunctional priority areas (MPAs)

Note: Figure also available within standalone CD-ROM.

It may also be useful to break the site up into broad-brush compartments where specific land use/management interventions may be applied, in line with relevant technical guidance. As such, Figure 8.4 shows how recommendations for broad-brush land use/management interventions (the numbered areas) can be developed for an MPA on the basis of individual spatial model outputs and the technical guidance – i.e. understanding where discrete ecosystems services may be required and the type of land use/management intervention that can enhance that ecosystem service. Practitioners should then draw on the relevant technical guidance and overarching principles to develop outline land use/management objectives for the MPA. These objectives, in conjunction with a record of all relevant technical guidance notes and a schematic such as that shown at Figure 8.4, may provide sufficient detail to carry the identified MPAs through for consideration in the LDP process. This is discussed further in section 8.3. An example schedule of objectives and relevant technical guidance for the MPA identified at Figure 8.4 is provided at Table 8.2. Designed effectively, the suite of measures outlined at Table 8.2 could help to restore natural drainage processes (see Table 4.6) and enhance storm water storage such that peak flows within this catchment are delayed and/or reduced (see section 4.7.1). This could potentially help to reduce the extent of pluvial flood hazard indicated at compartment 2 on Figure 8.4 i.e. by helping to reduce runoff. This is in addition to the ecological connectivity, biodiversity and wider ecosystem service benefits that might be realised through the enhancement of habitat networks at intervention area 1 in particular (see Figure 8.4 and section 5.3).

Table 8.2 Example schedule of objectives and relevant technical guidance for a scoped-in multifunctional priority area (MPA)

Intervention area	**Objective(s)**	**Relevant technical guidance (reference and short name)**
1	Restructure existing woodland cover to include a greater proportion of native conifers and move to continuous cover forestry (CCF) management	*Hydrological cycle model technical guidance (Appendix 5):* • Hydro_B: Enhance interception and attenuation capacity of existing greenspace • Hydro_C: Enhance evapotranspiration capacity of existing greenspace • Hydro_D: Enhance infiltration capacity of existing greenspace • Hydro_E: Enhance natural drainage function of existing natural/semi-natural greenspace (woodland) • Hydro_L: Silvicultural regime and woodland management *Habitat network model technical guidance (Appendix 6):* • Habitat_B: Improve management of existing habitat • Habitat_C: Reduce land use intensity within existing

Intervention area	Objective(s)	Relevant technical guidance (reference and short name)
		functional habitat networks - Habitat_D: Reduce land use intensity adjacent to existing functional habitat networks
2	Promote retrofit of source control SuDS measures across the housing stock and consider options for retrofit of site control SuDS measure(s)	*Hydrological cycle model technical guidance (Appendix 5):* - Hydro_H: Enhance drainage function of private gardens and grounds e.g. *use policy measures(grants, incentives and regulation) to promote retrofit of rain gardens and green roofs across the housing stock* - Hydro_K: Enhance drainage function of public realm e.g. *incorporate permeable surfaces, consider options for a site control SuDS intervention (e.g. detention basin) at Holmbyre Terrace* *Habitat network model technical guidance (Appendix 5):* - Habitat_D: Reduce land use intensity adjacent to existing functional habitat networks
3	Enhance the drainage and storm water attenuation capacity of the B766/Carmunnock Road corridor at this location	*Hydrological cycle model technical guidance (Appendix 5):* - Hydro_H: Enhance drainage function of private gardens and grounds e.g. *use policy measures(grants, incentives and regulation) to promote retrofit of rain gardens and green roofs across the housing stock* - Hydro_K: Enhance drainage function of public realm e.g. *incorporate permeable surfaces and integrated water management street trees within the road corridor* *Habitat network model technical guidance (Appendix 5):* - Habitat_D: Reduce land use intensity adjacent to existing functional habitat networks

Note: The information in this Table relates to the example multifunctional priority area shown on Figure 8.4.

8.3 Integrating model outputs with the Local Development Plan (LDP) process

Section 3.1 analyses the extant land use planning system in Scotland[116] to identify process issues and opportunities whereby consideration of urban ecosystem services (and the urban natural environment more generally) could be integrated. This issue was also picked up in the expert interviews (see sections 2.3.4 and 3.1.1 and Appendix 2). Chapter 7 and sections 8.1 and 8.2 explain how the new spatial models and technical guidance developed through this research can be used to identify

---

[116] Recognising that the Scottish planning system influences land use planning processes in the pilot urban centre considered in this research – Glasgow (see section 2.1.4)

priority areas for single and multiple ecosystem services – i.e. multifunctional priority areas *or* MPAs. The key purpose of this section therefore is to evaluate how the outputs of the new models and technical guidance can inform practical decision-making as part of the process of preparing Local Development Plans (LDP), as per the requirements of the Planning etc (Scotland) Act 2006 (see section 3.1). Based on the discussion in Chapter 7 and sections 8.1 and 8.2 and an understanding of the LDP development process (see section 3.1.2 and Figure 3.2), Figure 8.5 shows a potential process by which outputs of the new spatial models, technical guidance and integration analysis (i.e. the MPA process – see section 8.2) developed through this research could be integrated with the statutory LDP development process.

The proposed integration process depicted on Figure 8.5 is premised on multifunctional priority area (MPA) recommendations (see section 8.2) informing spatial considerations at the LDP Main Issues Report (MIR) stage. In this regard, the MIR was identified in the expert interview process as the most useful stage to integrate consideration of urban ecosystem services into LDP-development (see sections 2.3.4 and 3.1.2 and Appendix 2). In particular, there is scope for MPA recommendations to feed into various statutory MIR provisions (see Table 3.3), especially the identification of site specific land use/management change proposals that can enhance urban ecosystem services. This, in essence, is what MPA recommendations are designed to facilitate (see Figure 8.4 and Table 8.2).

As indicated on Figures 8.3 and 8.4, the nature of the integration analysis is such that identified MPAs are often at the ‘neighbourhood’ scale. Defining amorphous concepts such as neighbourhood scale and neighbourhood spatial units is inherently difficult though Lebel et al (2007) discuss three interconnected spatial levels defining the concept of neighbourhood: 1) the home area; 2) the locality; and 3) the urban district. In this thesis, neighbourhood scale is taken to be the home area and its surrounding locality e.g. single or multiple streets in residential and mixed use areas with associated green infrastructure such as parks, areas of semi-natural habitat and footpaths. This definition chimes well with the MPAs identified on Figure 8.3.

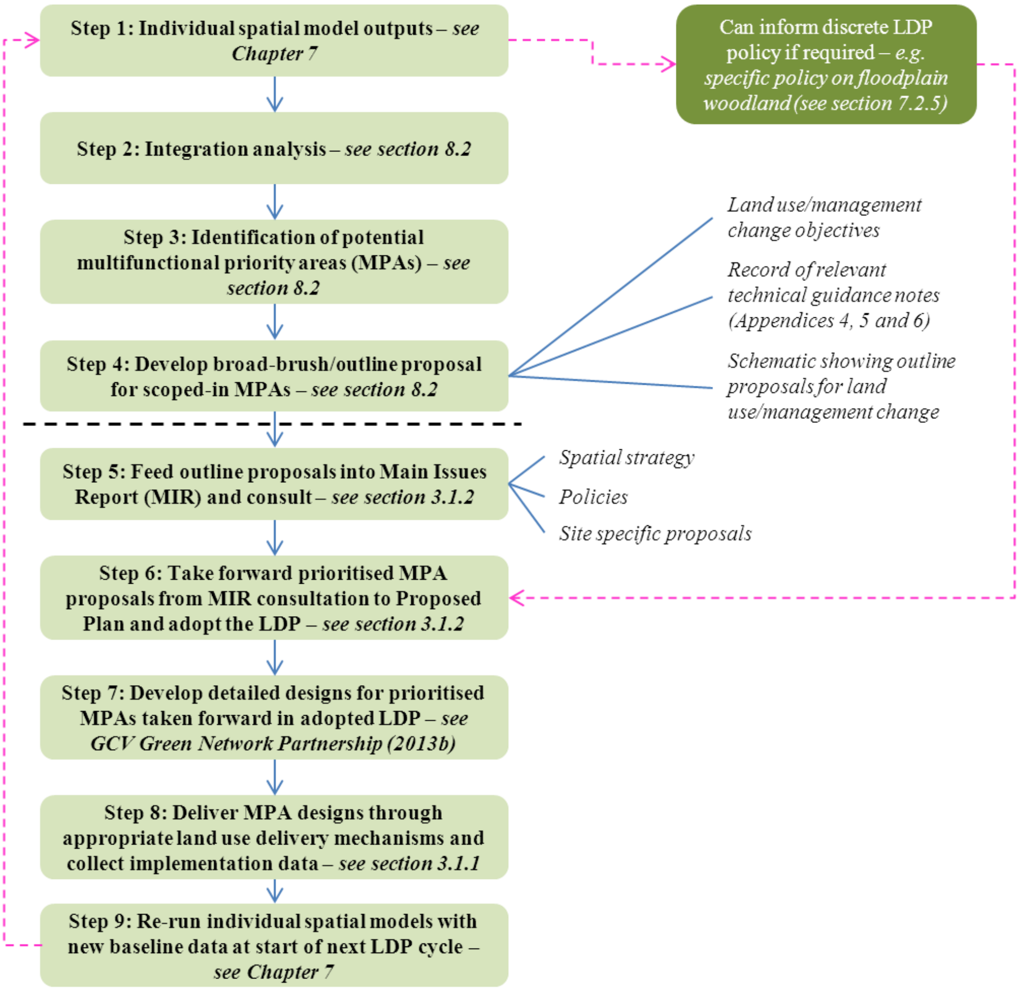


Figure 8.5 Proposed process for integrating the new tools, models and guidance with the statutory Local Development Plan (LDP) process

Note: The dashed line between Steps 4 and 5 indicates the scope of this thesis which has developed a methodology up to and including Step 4. Subsequent Steps have not been tested and have been included here based on an understanding of the statutory LDP process (see section 3.1). Figure also available within standalone CD-ROM.

The issue of scale was discussed in the expert interviews (see section 2.3.4 and Appendix 2). Question 3.3 asked – **at what scale do you think it is most useful to think about, plan for and manage the urban natural environment?** All interviewees highlighted how planning at multiple scales is essential and two interviewees focussed specifically on planning at the neighbourhood scale. In particular, I-3 equated neighbourhood scale to masterplan scale suggesting that this is a useful scale as *"…it offers a chunk of city that can be considered and planned and where plans and designs can reasonably influence Development Management"*. I-3 went on to discuss how *"the big problem with [urban planning and design] is that* *there is a gap in the system at the masterplan [neighbourhood] scale – there isn't the planning infrastructure in place at present to drive this"*. In terms of land use/management and green infrastructure planning for ecosystem services, the approach outlined on Figure 8.5 is intended to address this. In essence, MPAs are designed to work at the neighbourhood scale – bridging the gap between city-wide policy in the LDP and practical delivery on the ground, through Development Management and other relevant land use delivery mechanisms (see Table 8.3). Formalising the MPAs through detailed designs that are adopted in the LDP (e.g. as supplementary guidance – see section 3.1.2) could further support and facilitate delivery on the ground. In this regard, the GCV Green Network Partnership's Integrated Green Infrastructure (IGI) Design Study methodology (GCV Green Network Partnership, 2013b) could provide a useful approach. The IGI methodology can also provide a means of exploring site specific constraints in greater detail e.g. specific natural heritage and landscape designations, underground infrastructure etc.

Table 8.3 Expert interview Question 4.7 results – other than LDP policy, what other key mechanisms are there for delivering natural environment and ecosystem service enhancements through urban land use planning/management?

Mechanism	**Number of experts that identified the mechanism**
PAN65 openspace strategies (see section 3.1.3)	2
Local Biodiversity Action Plans (LBAPs)	2
Ensuring the integration of different sectors (e.g. transport and drainage)	1
Flood Risk Management (FRM) Strategies and Plans as per the Flood Risk Management (Scotland) Act 2009 (see sections 4.1 and 4.2)	2
Development Management	1
The placemaking agenda	1
Market demand for an enhanced urban landscape	1

As per Step 8 on Figure 8.5, data should be collected continuously as MPA designs are delivered, through various land use delivery mechanisms (e.g. location and area of semi-natural habitats brought back into appropriate management, location and area of newly created habitat, location and capacity of new surface water management infrastructure). As per Step 9, the spatial models should then be re-run with new baseline data at the end of the LDP cycle to identify new priority areas and MPAS for the subsequent planning cycle.

9. Conclusions and recommendations

Urbanisation – the demographic transition from rural to urban – can create both challenges and opportunities for urban areas. This thesis has focussed on a specific urbanisation problem concerning the way in which urban land is used and managed for the provision of key land based services *or* ecosystem services. The problem required investigation because there is limited practical understanding of how urban land use/management can impact urban ecosystem services. Furthermore, there is a need for better tools, techniques and modelling/scenario evaluation frameworks to help urban planners consider the impacts of their decisions on urban ecosystems and ecosystem services. As such, the overarching aim of this thesis has been "to understand, develop, trial and evaluate new approaches to urban planning that can operationalise key aspects of the ecosystems approach".

In line with this aim, the research process undertaken was split into three main stages: 1) review, assessment and synthesis of technical evidence to inform the development of principles and technical guidance for ecosystems approach based urban land use planning; 2) development and trialling of new tools, models and guidance for considering ecosystem services in urban planning; and 3) evaluation of new tools, models and guidance. This Chapter describes the conclusions and recommendations from this research. Section 9.1 provides a critique of the methodology adopted in this research. Section 9.2 then presents a summary of key findings of the research in terms of the objectives and questions posed at the start of the research process (see Box 1.2). Sections 9.3 and 9.4 then outline recommendations for future research and practice respectively.

9.1 Methodology evaluation

Reflecting on the research process undertaken there are some key areas where the methodology could have been improved and future research in this area should consider these issues (see section 9.3 also). Specific aspects of the methodology in this regard are: 1) the evidence assessment (primarily the Rapid Evidence Assessment/REA and action research aspects); and 2) the trialling of the new spatial models. In terms of the evidence assessment, the nature of the REA approach (see section 2.3.2) was such that it had a very tight scope based on a defined search strategy. As such, the potential for ‘snowballing’ (where the review goes beyond the scope of defined search parameters) was arguably more limited than would have been the case in a more traditional literature review. Whilst there are clear benefits of action research, especially in terms of identifying practical/problem focussed research outcomes (see section 2.3.3), there is a risk of researcher bias, given the researcher’s dual role as a participant as well. In this regard, it would have been useful to test the draft spatial models using more objective methods as well such as semi-structured interviews or a stakeholder workshop. The trialling of spatial models in this research did not include any sensitivity analysis to explore how outputs might change using different parameters (e.g. buffer distances within key GIS based operations). Sensitivity analysis would have been a useful addition to test the efficacy and practicality of model outputs with different parameter settings.

9.2 Summary of key findings

In line with the overarching aim of this thesis (see above), this research has identified how new approaches to urban land use planning, based on the principles of the ecosystems approach, can be developed drawing on existing theories and datasets, especially from the natural sciences. In this regard, the new urban planning approach developed through this research is the key contribution to knowledge made by this thesis as explained at section 9.2.1.

9.2.1 Land use planning in urban areas – towards an ecosystems approach

This thesis sought to develop new approaches to urban planning that can operationalise key aspects of the ecosystems approach. Sections 9.2.2 – 9.2.4 summarise key findings from the evidence assessment that provided the technical basis for the development of the new approaches, in line with Research Objectives Nos. 1 – 3 (see Box 1.2). This section summarises and evaluates key findings against Research Objectives Nos. 4 and 5. These findings appear first as they are the most important in terms of the thesis' contribution to knowledge.

In essence, this thesis has demonstrated how existing technical principles from discrete disciplines (e.g. planning, landscape ecology and hydraulics – see Figure 2.1 and Appendix 1) can be combined with existing spatial datasets through integrated spatial analyses to produce tools, models and guidance for ecosystems approach based urban land use planning (see Chapters 7 and 8). In this regard, the new approach developed through this research is the thesis' key contribution to knowledge. The new approach is made up of the following discrete elements:

1. Three new **spatial models** that identify where land use/management change may be required to deliver certain urban ecosystem services – flood storage, runoff reduction and ecological connectivity (see Chapter 7 and Appendices 8, 9 and 10)
2. A new suite of **guiding principles** for ecosystems approach based urban land use planning (see Appendix 3)
3. New **technical guidance** for interpreting and acting on outputs from the three new spatial models in the development of integrated urban land use/management strategies (see Chapter 8 and Appendices 4, 5 and 6)
4. An approach for **integrating** the new spatial models and technical guidance to inform ecosystems approach based urban land use planning, as part of the process of developing urban Local Development Plans in line with the Planning etc (Scotland) Act 2006 (see Chapter 8)

The literature map in Appendix 1 shows how literature, theories and technical principles from various discrete natural and social science disciplines can be combined to support the development of ecosystems approach based urban land use planning. In particular, Appendix 1 highlights key literature that is directly concerned with the ecosystems approach **and** land use planning, noting that other literature categories within Appendix 1 are more concerned with discrete disciplines/theories such as hydrology and hydraulics, floodplain woodland natural flood management (NFM) and ecosystems approach theory. As such, this thesis directly contributes to the literature on the ecosystems approach and land use planning (e.g. Chan et al, 2006; Sheate et al, 2012; Baker et al, 2013; Gaston et al, 2013). The thesis makes a particular contribution in relation to planning in an urban context with respect to the key ecosystem services considered (see section 9.2.2).

Radar Diagram Code	Ecosystem approach principle	Theme
EsA 1	Consider effects on adjacent ecosystems	*Management of natural systems*
EsA 2	Conserve ecosystem structure and function	
EsA 3	Ecosystem management must respect environmental limits	
EsA 4	Adopt the ecosystems approach at appropriate spatial and temporal scale	
EsA 5	Set long term objectives for ecosystem management	
EsA 6	Ecosystem management must recognise that change is inevitable	
EsA 7	Understand and manage the ecosystem in an economic context	*Ecosystem services*
EsA 8	Ensure an appropriate balance between conservation and use of biodiversity	
EsA 9	Objectives for ecosystem management are a matter of societal choice	*Involving people*
EsA 10	Ecosystem management should be decentralised to the lowest appropriate level	
EsA 11	Consider all forms of relevant information including scientific/local knowledge, practice and innovation	
EsA 12	Involve all relevant sectors of society and scientific disciplines	

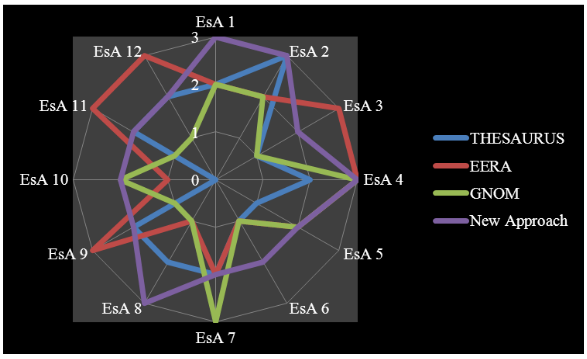


Figure 9.1 Performance of the new approach proposed in this thesis against the Convention on Biological Diversity (CBD) ecosystems approach principles – qualitative comparison with example urban land use planning frameworks evaluated in Chapter 6

Note: The Figure integrates findings from the evaluation of the three example land use planning frameworks (see Chapter 6) with the evaluation of the new approach developed through this research (see Appendix 11). The radar diagrams show the degree to which each approach has considered and translated the CBD principles. Overlaying individual radar diagrams facilitates a cross-analysis – i.e. identifying strengths and weaknesses of the approaches relative to each other.

In addition, the findings of this research (in terms of the approach adopted in the development of new tools and models for urban planning) highlight the interdisciplinary utility of technical principles from discrete natural and social science disciplines supporting integrated urban land use planning, in line with the ecosystems approach. For example, technical principles from planning theory literature on defining urban land use and green infrastructure (e.g. Landscape Institute, undated; Scottish Government, 2008; Scottish Government, 2011b) can be used in conjunction with key principles from the literature on hydraulics (e.g. Tabacchi et al, 2000; RRC, 2002; SEPA, 2010) to improve urban land use/management planning from the perspective of key regulating ecosystem services, especially flood storage and runoff reduction services (see sections 7.2 and 7.3).

The title of this thesis is **land use planning in urban areas – towards an ecosystems approach**. In conjunction with the aim of this thesis (i.e. the focus on operationalising **key aspects** of the ecosystems approach), this recognises that whilst there is clearly a need for better tools, techniques and modelling/scenario evaluation frameworks to help urban planners consider ecosystem services, the scope of the challenge is large and will not be addressed by this thesis alone.

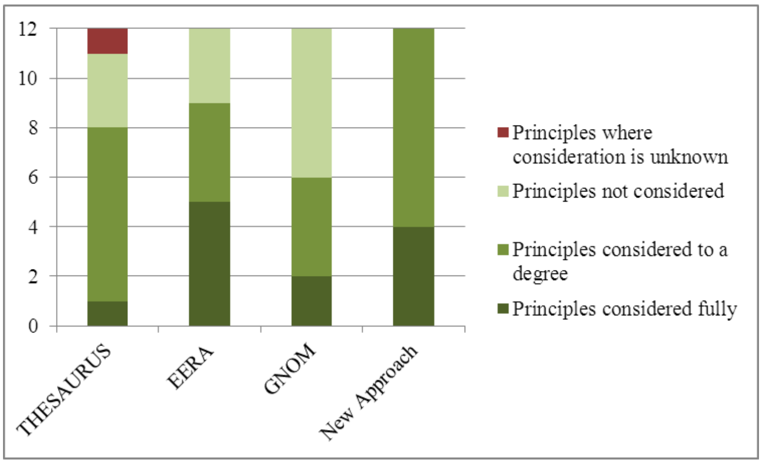


Figure 9.2 Performance of the new approach proposed in this thesis against the Convention on Biological Diversity (CBD) ecosystems approach principles – quantitative comparison with example urban land use planning frameworks evaluated in Chapter 6

As such, the new approaches developed through this research have been evaluated against the CBD ecosystems approach principles, as per the example land use planning frameworks in Chapter 6, to identify the degree to which the new tools, models and guidance may be able to operationalise the ecosystems approach. This has identified key strengths of the new approaches informing recommendations for future practice (section 9.4) and key weaknesses/gaps informing recommendations for future research (section 9.3). A comparison of the evaluation of the new approaches against existing land use planning frameworks considered under Research Objective No.2 (see Chapter 6) is shown at Figures 9.1 and 9.2. Appendix 11 provides a detailed evaluation of the new approaches.

As is evident from Figures 9.1 and 9.2, the new approaches developed through this research have been found to be more consistent in their consideration of CBD ecosystems approach principles than the three example approaches evaluated at Chapter 6. For example, although the EERA case (see section 6.2) considered more principles fully, it did not consider six principles at all. In contrast, the new approach proposed in this thesis considered all principles at least to a degree, with four principles considered fully. In this regard, the new approach offers a relatively comprehensive means of operationalising the ecosystems approach in urban land use planning though there are certain areas that can be improved upon as discussed at section 9.3. In particular, the development of new spatial models undertaken in this research only considered three ecosystem services, therefore further research is needed to develop and test the approach for additional ecosystem services.

In addition to the evaluation of all aspects of the new approach against the CBD principles, the initial spatial models were evaluated in practical terms through the action research stage of the research process (see sections 2.2.6 and 2.3.3). As highlighted on Figure 2.3, the action research contributed to a range of outcomes for the researcher and the Glasgow City Council (GCC) participants. In terms of researcher outcomes, this stage demonstrated the efficacy of the initial spatial models, both in terms of the support the models received from the participants and, crucially, in terms of the practical successes of the models informing land use/management decision-making as part of the Glasgow 2014 Multifunctional Greenspace Project[117] (MGP). This is evidenced in Appendix 12 which is a GCC report setting out how the spatial models: 1) informed specific land management proposals at one of the MGP sites; 2) helped to secure funding from a range of

---

[117] The initial spatial models were used to identify sites and potential interventions as part of the Glasgow 2014 Multifunctional Greenspace Project (the MGP) – one of nineteen 'greener theme' legacy projects being developed as part of the Glasgow 2014 Commonwealth Games. Further information on the MGP and the use of the spatial models in this regard is provided at Appendix 12. http://www.glasgow.gov.uk/index.aspx?articleid=11143 [accessed 20/04/14]

different sources for on the ground project delivery; and 3) helped to garner support for the MGP project from various partners.

9.2.2 Important ecosystem services for northern European urban centres

Research Objective No.1 sought to identify urban ecosystem services that are particularly important to urban centres in northern Europe (see Box 1.2). The intention was to focus subsequent research steps on key urbanisation challenges that can be addressed using ecosystem services. From a review of key EU and Scottish Government policy and reports, resilience to climate change impacts was found to be a pervasive issue for urban centres in Scotland and elsewhere in northern Europe. Climate change impacts in this regard can be addressed through land use/management approaches that enhance certain ecosystem services, especially climate and hazard regulation services such as flood storage and runoff reduction. This was a key part of the rationale for the consideration of water management related ecosystem services in substantive aspects of this research (evidence assessment and development of new spatial models).

This issue was also tested through the expert interview process which found that, to varying degrees, all ecosystems services assessed within the UKNEA may be provided by the natural environment in northern European urban centres. The expert interviews identified how flood control (including flood storage and runoff reduction) and several cultural services (aesthetic/inspiration, recreation/tourism, food production, spiritual/religious and healthy lifestyles) may be particularly important in this regard. This finding aligns quite closely with the UKNEA (Davies et al, 2011; UKNEA, 2011) which identified cultural services as high importance and hazard regulation services (including flood control) as medium-high importance for urban areas. Crucially, the UKNEA assessed hazard regulation services as displaying ‘some deterioration’ (ibid), adding further weight to the explicit consideration of flood storage and runoff reduction services in this thesis.

9.2.3 The impact of urban land use/management on urban ecosystem services

Research Objective No.2 sought to understand how urban land use/management can impact the functioning of urban ecosystems and the provision of certain urban ecosystem services (see Box 1.2). The response to this objective covered a broad range of issues – from identifying opportunities whereby ecosystem services could be integrated with urban land use planning in Scotland to understanding how urban land use/management can impact the hydrology of urban catchments. In essence, this aspect of the research highlighted how the ecosystems approach can provide a framework for integrating consideration of existing theories (especially from the natural sciences) with urban land use planning for the enhancement of urban ecosystem services. Key findings under this objective include:

- The Main Issues Report (MIR) stage of the statutory Local Development Plan (LDP) process was identified as the most useful and appropriate stage to incorporate consideration of ecosystems with LDP-development
- The urban natural environment can be characterised in various ways for the purposes of ecosystems approach based land use planning, depending on scale and context
- For more strategic planning (e.g. city districts and urban catchments) it can be helpful to characterise the urban natural environment in terms of discrete green land parcels (e.g. the openspace typology defined by PAN65)
- For more granular or site scale planning, it can be helpful to think in terms of discrete green infrastructure interventions within green and grey land parcels (e.g. street trees, SuDS infrastructure and footpaths)
- Ecosystems produce final ecosystem services that can be managed to produce goods. In this regard, urban ecosystems can be managed to produce the type of goods required given the specific context e.g. changing the management of all amenity greenspace in a catchment to alter its hydraulic properties, reduce runoff and help to restore catchment hydrology
- The principles of the ecosystems approach are relevant to a range of practical policy decision-making processes. There are several examples of the ecosystems approach being applied in EU, UK and Scottish policy
- As a general principle, green and natural environment type urban land uses with denser, taller and more structurally diverse vegetation will be

hydraulically ‘rougher’ and have more porous, open structured soils, supporting the function of natural drainage processes

- Key land based techniques for enhancing flood storage and runoff reduction ecosystem services in urban areas include river restoration, floodplain woodland, wider catchment land management measures (e.g. increasing tree cover, greater use of conifer species) and the use of sustainable drainage system (SuDS) measures to reduce runoff at source and provide storm water attenuation
- Urban landscapes comprise structural elements of habitat patch, corridor and barrier arranged within a dominant urban land use (the matrix). All these elements need to be managed to ensure well-connected urban landscapes
- Reducing land use intensity between habitat patches to maintain functional connectivity is likely to be as important for urban biodiversity as the management of habitat patches themselves

9.2.4 Lessons from existing ecosystems approach based urban planning frameworks

Research Objective No.3 used the Convention on Biological Diversity (CBD) ecosystems approach principles (CBD Secretariat, 2013a) to evaluate three existing urban planning approaches in terms of their potential to operationalise the ecosystems approach (see Box 1.2). Overall, the research found that consideration of the CBD principles was mixed at best with the principles considered fully in only 22% of instances assessed[118]. Principles were considered to a degree in 42% of instances and not at all in 33%. The three example approaches[119] used a range of methods to support the consideration of CBD principle type[120] issues in their land use/management activities including spatial analysis, ecosystem service assessments,

---

[118] There are 12 CBD ecosystems approach principles and three case studies equating to 36 possible instances where the CBD principles could have been considered

[119] The three approaches evaluated were: 1) Thames Gateway Ecosystem Services Assessment Using Green Grids and Decision Support Tools for Sustainability *or* THESAURUS (section 6.1); 2) Environmental Capacity in the East of England; Applying an Environmental Limits to the Haven Gateway *or* EERA (section 6.2); and 3) the Glasgow and Clyde Valley Green Network Partnership Green Network Opportunities Mapping approach *or* GNOM (section 8.3)

[120] Recognising that consideration of the CBD principles was always implicit and teased out with the evaluation criteria as opposed to explicit

engagement and awareness-raising and environmental assessment. The evaluation also sought to identify the main strengths and weaknesses of the example approaches, the rationale being that this understanding could inform the new approaches developed through this research. The ensuing analysis of existing innovations and gaps/weaknesses played a key role informing the new approaches as described in Chapter 6. The main strengths and weaknesses of the existing approaches were as follows:

Strengths

- Relatively comprehensive consideration of ecosystem processes/intermediate services
- Effective consideration of spatial and temporal scale
- Disaggregation of the natural environment using management units that are familiar to planners and decision-makers
- Use of stakeholder input to validate technical modelling processes
- Visual presentation of spatial land use/management issues to communicate key messages to planners and decision-makers
- Using a multi-staged mixed methods approach to refine a proxy based approach for ecosystem service assessment and mapping

Weaknesses

- Poor consideration of environmental limits
- Poor/mixed consideration of biodiversity
- Potential for misinterpretation of environmental limits maps
- Limited consideration of regulating services

9.3 Recommendations for future research

This thesis has begun to address some of the key gaps concerning the need for better tools, techniques and modelling/scenario evaluation frameworks to support ecosystems approach based urban land use planning. In particular, the structure of the new approaches developed is such that there is significant scope for future research to develop spatial models and technical guidance for further ecosystem services that were not considered in this thesis.

9.3.1 The need for a proof of concept study

Although the new approaches were trialled in the development of a Glasgow City Council (GCC) greenspace development project (see Appendix 12), there remains an important need to fully test the ability of the new approaches to inform and improve the Local Development Plan (LDP) process, as set out at section 8.3. Ideally, this should be delivered as a full scale proof of concept study including an evaluation of the approach's impact on LDP policy decision-making and subsequent impact in terms of land use delivery on the ground, through a variety of different mechanisms such as Development Management (DM), Flood Risk Management (FRM) Plans and local level/community projects. It may also be useful to test the applicability of the new approaches informing other planning frameworks such as Supplementary Guidance and masterplans.

9.3.2 The need for better data

Some of the spatial datasets used and technical principles adopted in the new spatial models developed in this research are themselves based on models as opposed to empirical data. Given the pragmatic worldview behind this research (see section 2.1.1), this was considered to be reasonable given the focus of the new approaches helping to address 'real-world' sustainability issues (Stock and Burton, 2011). That said, there is a need for better data in order to validate key parameters used in the new spatial models. Specific areas for future research are:

- **The need for empirical data concerning the efficacy of key natural flood management (NFM) measures:** especially the case for NFM measures considered in this research – floodplain and riparian zone woodland planting/restoration and wider catchment land management measures. Studies should ideally address rural, urban and mixed rural-urban catchments.
- **Validation of functional connectivity habitat network models:** there is a need for further studies (e.g. mark-release-recapture) to gain a better understanding of how species interact with a range of different urban landscapes.

- **More detailed consideration of spatial datasets and technical principles concerning other NFM measures that were not considered in this thesis:** 1) floodplain wetland; 2) a broader range of river restoration techniques; and 3) opportunities for integrating analyses of surface water conveyance with strategic urban land use/management planning.

9.3.3 Enhancing the scope of the new approaches

There is significant potential for future research to enhance the scope and applicability of the new approaches developed through this research. Data issues in this regard have been dealt with separately at section 9.3.2. Key recommendations are as follows:

- **Develop a practical guidance note on the ecosystems approach guiding principles:** this research developed a new suite of guiding principles for ecosystems approach based urban land use planning (see Appendix 3). The principles are based on the evidence assessment (see Chapters 3 – 6) and are intended to develop and further characterise the CBD ecosystems approach principles, from the perspective of urban land use planning. That said, they represent a substantial increase in detail over the CBD principles and their utility for urban planning stakeholders could be improved through the development of a supporting guidance note to aid interpretation and understanding.
- **Develop additional spatial models and technical guidance:** this research developed spatial models and technical guidance for three ecosystem services. There is a need for additional models and guidance to support the full translation of ecosystems approach principles in practical urban land use/management planning. Further development in this regard could be prioritised on the basis of data from the expert interviews (see section 3.2.5).
- **Refine flood control model Multi Criteria Analysis (MCA) step:** Step 6 of the flood control model uses MCA to prioritise site level intervention on the basis of three criteria for sustainable flood risk management (FRM). The

MCA could be refined through the use of additional criteria, especially biodiversity, landscape and social/community issues.

- **Linking new spatial models with relevant quantitative models:** in their current guise, the new spatial models are primarily intended to guide and help prioritise the development of land use/management policy in LDPs. Linking the new spatial models with relevant quantitative models (e.g. hydrological and hydraulic models) would enable the potential benefits of land use/management change to be quantified (e.g. potential reduction in peak flows and flood extent).
- **Develop explicit methods to account for environmental limits in urban land use/management planning:** the evaluation of existing and new approaches highlighted how environmental limits have generally been considered less well. Environmental limits are considered implicitly within aspects of the new approach developed through this research though there is a need for more explicit, robust approaches.
- **Develop explicit mechanisms for the involvement of stakeholders and affected communities:** the evaluation of the new approaches against the CBD principles highlighted how the involving people principles is covered less well. There is a need to develop specific mechanisms for engaging people in spatial model outputs and the identification of multifunctional priority areas (MPAs) as part of the LDP MIR stage. This should include stakeholder input to technical modelling processes and the identification of environmental limits based on social preferences.

9.4 Recommendations for future practice

This research has focussed on urban land use planning through LDPs, as per the Planning etc (Scotland) Act 2006. As such, although some recommendations for future practice are focussed on a Scottish audience, most recommendations are of more general relevance to an international/northern European audience. Recommendations are differentiated on this basis noting however that all general recommendations are also relevant in Scotland. The northern European focus reflects the specific ecosystem services considered in the research, which are likely to be particularly significant for addressing urbanisation problems in northern European urban centres (see section 9.2.2).

9.4.1 Recommendations for urban land use planning stakeholders of general applicability internationally/in northern Europe

- **Interdisciplinarity:** urban land use planning should be undertaken collectively, drawing on a range of expertise. The ecosystems approach can provide a common framework within which different disciplines can align for common objectives – ecosystem health and human wellbeing.
- **Adoption of the new ecosystems approach principles:** practitioners should use the new ecosystems approach principles to support the translation of the CBD principles within urban land use/management planning.
- **Consideration of the new technical guidance:** practitioners should use the new technical guidance for specific technical support on key issues, especially land use/management planning for flood storage, runoff reduction and ecological connectivity ecosystem services.
- **Prioritising ecosystem services:** depending on specific local context, practitioners in northern European urban centres should consider prioritising land use/management and green infrastructure intervention towards the enhancement of climate resilience and cultural ecosystem services.
- **Evaluating existing practice:** practitioners should evaluate their existing urban land use/management practice from the perspective of the main strengths and weaknesses identified through this research.
- **Training and awareness-raising:** local authority corporate/human resource policy leads should consider the need for training and awareness-raising into the ecosystems approach, within land use planning and other policy issues that may impact the natural environment.

9.4.2 Recommendations for urban land use planning stakeholders in Scotland

- **Use of the new spatial models:** practitioners should use the new spatial models to identify priority locations where land use/management change may be required to deliver discrete ecosystem services and multifunctional priority areas (MPAs) for multiple ecosystem services.

- **Integrating spatial model outputs and technical guidance with LDP development:** practitioners should integrate MPA recommendations with LDP development, especially at the MIR stage, to identify land use/management priorities for the enhancement of key ecosystem services.
- **Land use delivery mechanisms:** practitioners should seek to integrate MPA recommendations with a range of land use delivery mechanisms, especially through Development Management (DM) and other relevant mechanisms such as Flood Risk Management (FRM) Plans and River Basin Management Plans (RBMP) and the placemaking agenda.
- **Training:** local authority corporate/human resource policy leads should consider the benefits of training staff in the use of key technologies, especially geographic information systems (GIS) and spatial analysis/modelling.

This thesis has demonstrated how the ecosystems approach can provide a framework for integrating technical principles from existing disciplines to develop land use/management based solutions to key urban sustainability problems. The various tools, models and guidance developed through this research provide a framework for progressing the urban sustainability agenda in this regard, including practical tools that have the potential to inform urban land use/management decision-making on the ground. There is significant scope to improve the sustainability of urban systems through ecosystem services based approaches that simultaneously enhance urban biodiversity and reduce the need for traditionally engineered infrastructure.

References

AECOM (2011). *Scotland's Greenspace Map Final Report* [online]. Available at: http://www.greenspacescotland.org.uk/SharedFiles/Download.aspx?pageid=131&mid=127&fileid=166 [accessed 27/02/14].

American Planning Association (2013). *What is Planning?* [online]. Chicago: APA. [accessed 08/05/14]. Available at: https://www.planning.org/aboutplanning/whatisplanning.htm.

Baker, J. (2010). *Incorporating ecosystem services into SEA: how and why*. MSc Thesis, Imperial College London Centre for Environmental Policy.

Baker, J., Sheate, W.R., Phillips, P.M., and Eales, R.P. (2013). Ecosystem services in environmental assessment – help or hindrance? *Environmental Impact Assessment Review*, 40, pp.3-13.

Beedell, J., Morris, J., and Hess, T.M. (2012). *Mobilising the Contribution of Rural Land Management to Flood Risk Management in Scotland*. Report to Scottish Government: Ref CR/2010/14. Peterborough: Smiths Gore.

Belton, S., and Stewart, T.S. (2002). *Multiple Criteria Decision Analysis: An Integrated Approach*. Massachusetts: Kluwer Academic Publishers.

Bellamy, C., and Winn, J. (2013). *EcoServ-GIS Version 1 (England only): A Wildlife Trust Toolkit for Mapping Multiple Ecosystem Services* [online]. Available at: http://www.durhamwt.co.uk/wp-content/uploads/2012/06/EcoServ-GIS-Executive-Summary-Only-WildNET-Jan-2013-9-pages.pdf [accessed 15/04/14].

Bockelmann, B.N., Fenrich, E.K., Lin, B., and Falconer, R.A. (2004). Development of an ecohydraulics model for stream and river restoration. *Ecological Engineering*, 22, pp.227-235.

Briers, R. (2011). *Habitat Networks – Reviewing the Evidence Base: Final Report*. Report to Scottish Natural Heritage: Ref 29752. Edinburgh: Edinburgh Napier University.

Broadmeadow, S., and Nisbet, T. (2010). *Opportunity mapping for woodland to reduce flooding in the Yorkshire and the Humber region*. Forest Research Monograph, 1, Forest Research, Surrey.

Brown, C., Walpole, M., Simpson, L., and Tierney, M. (2011). *Introduction to the UK National Ecosystem Assessment*. Cambridge: UNEP-WCMC.

Bryman, A. (2012). *Social Research Methods*. 4th ed. Oxford: Oxford University Press.

Calder, I. R. and Aylward, B. (2006) Forests and Floods: Moving to an evidence-based approach to watershed and integrated flood management. *Water International*, 31(1), pp.87-99.

Carpenter, S.R., DeFries, R., Dietz, T., Mooney, H.A., Polasky, S., and Reid, W.V. (2006). Millennium Ecosystem Assessment: Research Needs. *Science*, 3(14), pp.257-258.

Convention on Biological Diversity Secretariat (2000). *Fifth meeting of the Conference of the Parties of the Convention on Biological Diversity Decision V/6 – Ecosystems Approach* [online]. Montreal: CBD Secretariat. [accessed 04/01/14]. Available at: http://www.cbd.int/decision/cop/default.shtml?id=7148.

Convention on Biological Diversity Secretariat (2006). *Global Biodiversity Outlook 2*. Montreal.

Convention on Biological Diversity Secretariat (2013a). *Ecosystems approach principles* [online]. Montreal: CBD Secretariat. [accessed 04/01/14]. Available at: https://www.cbd.int/ecosystem/principles.shtml.

Convention on Biological Diversity Secretariat (2013b). *Operational guidance for application of the ecosystems approach* [online]. Montreal: CBD Secretariat. [accessed 04/01/14]. Available at: https://www.cbd.int/ecosystem/operational.shtml.

Collingwood Environmental Planning and Geodata Institute (2008a). *Thames Gateway Ecosystem Services Assessment Using Green Grids and Decision Support Tools for Sustainability: Supporting the Development of a Strategy for the Kent Thameside Green Grid Using Ecosystem Services – Strategic Study Report*. Report to Defra: Ref NR0109. London: Collingwood Environmental Planning.

Collingwood Environmental Planning and Geodata Institute (2008b). *Thames Gateway Ecosystem Services Assessment Using Green Grids and Decision Support Tools for Sustainability: Supporting the Development of a Strategy for the Ebbsfleet Green Grid Using Ecosystem Services – Local Study Report*. Report to Defra: Ref NR0109. London: Collingwood Environmental Planning.

Chartered Institution of Water and Environmental Management (2007). *Policy Position Statement on the Deculverting of Watercourses* [online]. London: CIWEM. [accessed 08/05/14]. Available at: http://www.ciwem.org/policy-and-international/policy-position-statements/de-culverting-of-watercourses.aspx.

Countryside Council for Wales (2011). *Sustaining Ecosystem Services for Human Wellbeing: Mapping Ecosystem Services* [online]. Available at: file:///H:/My%20Documents/Downloads/Sustaining%20Ecosystem%20Services%20for%20Human%20Well%C3%AF%C2%BF%C2%BDBeing%20Mapping%20Ecosystem%20Services.pdf [accessed 15/04/14].

Corbett, A., Hyslop, M., and Smith, M. (2009). Landscape scale approach to conservation management: Glasgow and Clyde Valley case study. *Ecological Networks: Science and Practice: Proceedings of the 16th Annual IALE (UK) Conference*. Edinburgh University, Edinburgh 1-3 September 2009. Garstang: IALE (UK), pp.161-168.

Cresswell, J.W. (2009). *Research Design Qualitative, Quantitative and Mixed Methods Approaches*. 3rd ed. London: Sage Publications Ltd.

Chan, K.M.A., Shaw, M.R., Cameron, D.R., Underwood, E.C., and Daily, G.C. (2006). Conservation Planning for Ecosystem Services. *PLOS Biology*, 4(11), pp.2138-2152.

Davies, L., Kwiatkowski, L., Gaston, K.J., Beck, H., Brett, H., Batty, M., Scholes, L., Wade, R., Sheate, W.R., Sadler, J., Perino, G., Andrews, B., Kontoleon, A., Bateman, I., Harris, J.A., Burgess, P., Cooper, N., Evans, S., Lyme, S., McKay, H.I., Metcalfe, R., Rogers, K., Simpson, L., and Winn, J. (2011). *UK National Ecosystem Assessment Urban Chapter*. Cambridge: UNEP-WCMC.

Department for Communities and Local Government (2012). *National Planning Policy Framework*. London: DCLG.

Department for Communities and Local Government (2013). *Giving communities more power in planning local development* [online]. London: DCLG [accessed 25/10/13]. Available at: https://www.gov.uk/government/policies/giving-communities-more-power-in-planning-local-development/supporting-pages/local-plans.

Defra (2007). *Securing a healthy natural environment: an action plan for embedding an ecosystems approach*. London: Defra.

Defra (2008). *Case Study to Develop Tools and Methodologies to Deliver an Ecosystems Approach – Thames Gateway Green Grids*. Defra Project Code NR0109.

Defra (2005). *One future – different paths: the UK's shared framework for sustainable development*. London: Defra.

Defra (2009). *Natural environment policy archive: Ecosystems approach case studies* [online]. London: Defra. [accessed 27/01/14]. Available at: http://archive.defra.gov.uk/environment/policy/natural-environ/research/case-studies.htm.

Defra (2011). *The Natural Choice: securing the value of nature White Paper 2011*. London: The Stationary Office.

De Smedt, P. (2010). The Use of Impact Assessment Tools to Support Sustainable Policy Objectives in Europe [online]. *Ecology and Society*, 15(4). Available at: http://www.ecologyandsociety.org/vol15/iss4/art30/ [accessed 27/04/14].

Dick, B. (2012). *Grounded theory: a thumbnail sketch* [online]. Available at: http://www.aral.com.au/resources/grounded.html#a_gt_code [accessed 22/04/14].

Dick (2013). *Action research FAQ* [online]. Available at: http://www.aral.com.au/resources/arfaq.html [accessed 22/04/14].

EA (1999). *Environment Agency Policy Regarding Culverts: Explanation of Policy*. Bristol: The Environment Agency.

EC (2000). *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy [2000] OJ L327/1.*

EC (2007). *Directive 2007/60/EC of the European Parliament and of the Council of the 23 October 2007 on the Assessment and Management of Flood Risks [2007] OJ L288/27.*

EC (2010). *DG Environment News Alert Service: Cities occupy 0.5% of the world's total land* [online]. Bristol: SCU The University of the West of England. [accessed 08/05/14]. Available at: http://ec.europa.eu/environment/integration/research/newsalert/pdf/179na4.pdf.

EC (2011a). *Our life insurance, our natural capital: an EU biodiversity strategy to 2020, COM (2011) 244, final.*

EC (2011b). *Roadmap to a Resource Efficient Europe, COM (2011) 571, final.*

EC (2013a). *Green Infrastructure (GI) – Enhancing Europe's Natural Capital, COM (2013) 249, final.*

EC (2013b). *Decision No 1386/2013/EU of the European Parliament and of the Council of 20 November 2013 on a General Union Environment Action Programme to 2020 'Living well within the limits of our planet' [2013] OJ L354/171.*

EC (2013c). Geographic maps of Europe, the EU and the candidate countries [online]. Available at: http://ec.europa.eu/avservices/photo/photoByMediaGroup.cfm?sitelang=en&mgid=38 [accessed 22/04/14].

EEA (2006). *Urban sprawl in Europe: The ignored challenge*. EEA Report No.10/2006. Luxembourg: Office for Official Publications of the European Communities.

EEA (2010a). *The European Environment State and Outlook 2010: Urban Environment*. Luxembourg: Office for Official Publications of the European Communities.

EEA (2010b). *The European Environment State and Outlook 2010: Land Use*. Luxembourg: Office for Official Publications of the European Communities.

EEA (2010c). *EU 2010 Biodiversity Baseline*. EEA Technical Report No 12/2010. Luxembourg: Office for Official Publications of the European Communities.

EERA (2008). *Environmental Capacity in the East of England: Applying an Environmental Limits Approach to the Haven Gateway Final Report*. London: Land Use Consultants.

Emmanuel, R., and Kruger, E. (2012). Urban heat island and its impact on climate change resilience in a shrinking city: The case of Glasgow, UK. *Building and Environment*, 53, pp.137-149.

Emery, J.C., Gurnell, A.M., Clifford, N.J., Petts, G.E., Morrissey, I.P., and Soar, P.S. (2003). Classifying the Hydraulic Performance of Riffle-Pool Bedforms for Habitat Assessment and River Rehabilitation Design. *River Research and Applications*, 19, pp.533-549.

Eigenbrod, F., Armsworth, P.R., Anderson, B.J., Heinemeyer, A., Gillings, S., Roy, D.B., Thomas, C.D., and Gaston, K.J. (2010). Impact of proxy-based methods on mapping the distribution of ecosystem services. *Journal of Applied Ecology*, 47, pp.377-385.

ESRI (undated). *What is GIS? Overview* [online]. Redlands: ESRI. [accessed 22/04/14]. Available at: http://www.esri.com/what-is-gis/overview.

ESRI (2012). *ArcGIS Help 10.1 – What is ModelBuilder?* [online]. Redlands: ESRI. [accessed 22/04/14]. Available at: http://resources.arcgis.com/en/help/main/10.1/index.html#//002w00000001000000.

Ernst, J., Dewals, B.J., Detrembleur, S., Arcahmbeau, P., Erpicum, S., and Pirotton, M. (2010). Micro-scale flood risk analysis based on detailed 2D hydraulic modelling and high resolution geographic data. *Nat Hazards*, 55, pp.181-209.

Fathi-Maghadam, M., and Kouwen, N (1997). Non-rigid, non-submerged vegetative roughness on floodplains. *Journal of Hydrological Engineering*, 123(1), pp.51-57.

Fee, E., Gerber, K., Rust, J., Haggenmueller, K., Korn, H., and Ibisch, P. (2009). Stuck in the Clouds: Bringing the CBD's Ecosystem Approach for conservation management down to Earth in Canada and Germany. *Journal for Nature Conservation*, 17, pp.212-227.

Forest Research (2014a). *The 'basics' of landscape ecology* [online]. Farnham: Forest Research. [accessed 06/01/14]. Available at: http://www.forestry.gov.uk/fr/infd-5txhba

Forest Research (2014b). *Tools and methods in landscape ecology* [online]. Farnham: Forest Research. [accessed 30/03/14]. Available at: http://www.forestry.gov.uk/website/forestresearch.nsf/ByUnique/INFD-69PLA5

Forman, R.T.T. (1995). *Land Mozaics: The Ecology of Landscapes And Regions*. Cambridge: Cambridge University Press.

Gaston, K.J., Avila-Jimenez, M.L., and Edmondson, J.L. (2013). The UK National Ecosystem Assessment: Managing urban ecosystems for goods and services. *Journal of applied ecology*, 10, pp.1-11.

GCV Green Network Partnership (2011). *West Dunbartonshire Green Network Opportunities Mapping Draft Interim Report V1*. Glasgow: AMC.

GCV Green Network Partnership (2013a). *About us* [online]. Glasgow: GCV Green Network Partnership. [accessed 08/05/14]. Available at: http://www.gcvgreennetwork.gov.uk/about-us/introduction

GCV Green Network Partnership (2013b). Integrating Green Infrastructure [online]. Glasgow: GCV Green Network Partnership. [accessed 06/02/14]. Available at: http://www.gcvgreennetwork.gov.uk/igi/introduction

GCVSDPA (2011). *Glasgow and the Clyde Valley Strategic Development Plan Proposed Plan: Background Report 08 Green Network Spatial Priorities* [online]. Glasgow: GCVSDPA. [accessed 06/02/14]. Available at: http://www.gcvsdpa.gov.uk/images/stories/documents/BR08%20Green%20Network%20Spatial%20Priorities.pdf

Geneletti, D. (2013a). Ecosystem services in environmental impact assessment and strategic environmental assessment. *Environmental Impact Assessment Review*, 40, pp.1-2.

Geneletti, D. (2013b). Assessing the impact of alternative land-use zoning policies on future ecosystem services. *Environmental Impact Assessment Review*, 40, pp.25-35.

Glasgow City Council (undated). *White Cart Water Flood Prevention Scheme* [online]. Glasgow: GCC. [accessed 08/04/14]. Available at: http://www.whitecartwaterproject.org/.

Gore, T., Ozdemiroglu, E., Eadson, W., Gianferrara, E., and Phang, Z. (2013). *Green infrastructure's contribution to economic growth: a review*. Report to Defra and Natural England: Ref. WCO820. London: Eftec.

Government Social Research (undated). REA Toolkit [online]. London: Government Social Research. [accessed 05/05/14]. Available at:

http://www.civilservice.gov.uk/networks/gsr/resources-and-guidance/rapid-evidence-assessment/what-is

Graham, A., Day, J., Bray, B., and Mackenzie, S. (2012). *Sustainable drainage systems – maximising the potential for people and wildlife: a guide for local authorities and developers*. Sandy: RSPB.

Greenspace Scotland (2010). *Urban greenspace mapping and characterisation handbook* [online]. Stirling: Greenspace Scotland. [accessed 27/02/14]. Available at: http://www.greenspacescotland.org.uk/SharedFiles/Download.aspx?pageid=133&mid=129&fileid=124.

Gret-Regamey, A., Celio, E., Klein, T.M., and Wissen-Hayek, U. (2013). Understanding ecosystem services trade-offs with interactive procedural modelling for sustainable urban planning. *Landscape and Urban Planning*, 109, pp.107-116.

Gutzwiller, K., and Forman, R.T.T. (2002). *Applying Landscape Ecology in Biological Conservation*. New York: Springer-Verlag New York Inc.

Haines-Young, R., and Potschin, M. (2008): *England's Terrestrial Ecosystem Services and the Rationale for an Ecosystem Approach: Overview Report*. Defra Project Code NR0107.

Hart, C. (1991). *Practical Forestry for the Agent and Surveyor*. Stroud: Sutton Publishing Ltd.

Hasse, J.E., and Lathrop, R.G. (2003). Land Resource Impact Indicators of Urban Sprawl. *Applied Geography*, 23, pp.159-175.

Helming, K., Diehl, K., Geneletti, D., and Wiggering, H. (2013). Mainstreaming ecosystem services in European policy impact assessment. *Environmental Impact Assessment Review*, 40, pp.82-87.

The Highland Council (2013). *Ward Statistics: 01 North, West and Central Sutherland* [online]. Inverness: The Highland Council. [accessed 08/05/14]. Available at: http://www.highland.gov.uk/yourcouncil/highlandfactsandfigures/ward01-z-wardstats.htm.

Hölzinger, O., Tringham, N., Grayson, N., and Coles, R. (2013). *Multiple Challenge Map for Birmingham: Ecosystem Services Supply and Demand Maps* [online]. Birmingham: CEEP. [accessed 08/05/14]. Available at: file:///H:/My%20Documents/Downloads/672506GLSP-Appendix_2-Multiple_Challenge_Map_for_Birmingham_2013[1].pdf

Hughes, J., and Brooks., S. (2009). *Living landscapes: towards ecosystem-based conservation in Scotland*. Edinburgh: Scottish Wildlife Trust

Humphrey, J., Ray, D., Watts, K., Brown, C., Poulsom, L., Griffiths, M. and Broome, A. (2004). *Balancing upland and woodland strategic priorities*. Scottish Natural Heritage Commissioned Report No. 037 (ROAME No. F02AA101).

IALE (undated). *Landscape ecology: what is it?* [online]. Utah: IALE. [accessed 06/01/14]. Available at: http://www.landscape-ecology.org/index.php?id=13.

James, P., Millward, A., Morrison, K., Bishop, O.J., and Dennis, M. (2013). Changing urban areas using landscape scale ecological processes and thinking. *Proceedings of the IALE 2013 European Congress – Changing European Landscapes: Landscape ecology, local to global* [online]. University of Manchester: Manchester 9-12 September 2013. [accessed 08/05/14]. Available at: http://www.iale2013.eu/.

Jankowski, P. (2008). Towards participatory geographic information systems for community-based environmental decision making. *Journal of Environmental Management*, 90, p.1966–1971.

Jones-Walters, L. (2009). Preface to Ecological Networks: Science and Practice. *Ecological Networks: Science and Practice: Proceedings of the 16th Annual IALE (UK) Conference*. Edinburgh University, Edinburgh 1-3 September 2009. Garstang: IALE (UK), pp.vi-vii.

Kenyon, W. (2007). Evaluating flood risk management options in Scotland: A participant-led multi-criteria approach. *Ecological Economics*, 64, pp.70-81.

KTGG (2006). *The Green Grid: Conserving and enhancing our natural heritage* [online]. Kent: Kent Wildlife Trust. [accessed 08/05/14]. Available at: http://gtgkm.org.uk/documents/kt-gg-framework-1304434814.pdf.

Kuchment, L.S. (2014). The hydrological cycle and human impact on it *in* Kuchment, L.S. (*ed.*) *Water Sciences, Engineering and Technology Resources Encyclopaedia of Life Support Systems (EOLSS)*. Developed under the Auspices of the UNESCO. Paris: Eolss Publishers.

Kent Thameside (2010). *Kent Thameside website* [online]. Kent: Kent Wildlife Trust. [accessed 02/11/11]. Available at: http://www.kent-thameside.co.uk/

Kumar Jat, M., Garg, P.K., and Khare, D. (2008). Monitoring and Modelling of Urban Sprawl Using Remote Sensing and GIS Techniques. *International Journal of Applied Earth Observation and Geoinformation*, 10, pp.26-43.

Labiosa, W.B., Forney, W.M., Esnard, A.M., Mitsova-Boneva, D., Bernknopf , R., Hearn, P., Hogan, D., Pearlstine, L., Strong e, D., Gladwin, H., and Swain, E. (2013). An integrated multi-criteria scenario evaluation web tool for participatory land-use planning in urbanized areas: The Ecosystem Portfolio Model. *Environmental Modelling & Software*, 41, pp.210-222.

Lebel, A., Pampalon, R., and Villeneuve, P.Y. (2007). A multi-perspective approach for defining neighbourhood units in the context of a study on health inequalities in the Quebec City region. *International Journal of Health Geographics* [online]. 6(27) [accessed 05/05/14]. Available at: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1936419/.

Leichenko, R. (2010). Climate change and urban resilience. *Current Opinion in Environmental Sustainability*, 3, pp.164-168.

London Councils (2013). *London Key Facts*. London: London Councils. [accessed 25/10/13]. Available at: http://www.londoncouncils.gov.uk/londonfacts/default.htm?category=2.

MA (2003). Ecosystems and human wellbeing – a framework for assessment [online]. Available at: http://www.unep.org/maweb/documents/document.765.aspx.pdf [accessed 11/01/14].

MA (2005). *Ecosystems and Human Wellbeing: Synthesis*. Washington DC: Island Press.
Macdonald, D.W., and Rushton, S. (2003). Modelling space use and dispersal of mammals in real landscapes: a tool for conservation. *Journal of Biogeography*, 30, pp.607-620.

Mace, M.G., Bateman, I., Albon, S., Balmford, A., Brown, C., Church, A., Haines-Young, R., Pretty, J.N., Turner, K., Vira, B., and Winn, J. (2011). *UK National Ecosystems Assessment Conceptual Framework and Methodology*. *In: The UK National Ecosystem Assessment Technical Report*. UK National Ecosystem Assessment, UNEP-WCMC, Cambridge.

Mansell, M.G. (2003). *Rural and Urban Hydrology*. UK: ICE Publishing.

Matthies, S., Ruter, S., and Prasse, R. (2013). Urban green spaces – the effects of patch size and distance to the urban edge on vascular plant and bird species diversity. *Proceedings of the IALE 2013 European Congress – Changing European Landscapes: Landscape ecology, local to global* [online]. University of Manchester: Manchester 9-12 September 2013. [accessed 08/05/14]. Available at: http://www.iale2013.eu/.

McCall, M. (2003). Seeking good governance in participatory-GIS: a review of processes and governance dimensions in applying GIS to participatory spatial planning. *Habitat International*, 27, pp.549-573.

Mills, G. (2007). Cities as agents of global change. *International Journal of Climatology*, 27, pp.1849-1857.

Mostafavi, M. (2010). Why Ecological Urbanism? Why Now? *in* Mostafavi, M. and Doherty, G. *Ecological Urbanism*. Zurich: Lars Muller Publishers, pp.12-13.

Naot, D., Nezu, I., and Nakagawa, H. (1996). Hydrodynamic behaviour of partly vegetated opened channels. *Journal of Hydrological Engineering*, 122(1), pp.625-633.

Nisbet, T.R., and Thomas, H. (2006). The role of woodland in flood control: a landscape perspective. *Water and the Landscape – the Landscape Ecology of Freshwater Ecosystems: Proceedings of the 14th Annual IALE (UK) Conference*. Oxford Brookes University, Oxford 5-8 September 2006. Oxford: IALE (UK), pp.118-125.

Nisbet, T.R., and Thomas, H. (2008). *Restoring Floodplain Woodland for Flood Alleviation: Final Report*. London: Defra. Report to Defra: Ref. Project SLD2316.

Nisbet, T.R., Marrington, S., Thomas, H., Broadmeadow, S., and Valatin, G. (2011a). *Slowing the flow in Pickering Final Report*. London: Defra. Report to Defra: Ref. Project RMP5455.

Nisbet, T.R., Silgram, M., Shah, N., Morrow, K., and Broadmeadow, S. (2011b). *Woodland for Water: Woodland measures for meeting Water Framework Directive objectives – Summary of final report*. Bristol: Environment Agency.

Nisbet, T., Silgram, M., Shah, N., Morrow, K., and Broadmeadow, S. (2011c). Woodland for Water: Woodland measures for meeting Water Framework Directive objectives. *Forest Research Monograph,* 4, Forest Research, Surrey, 156pp.

Nolan, P.A., and Guthrie, N. (1998). River rehabilitation in an urban environment: examples from the Mersey Basin, North West England. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 8, pp.685-700.

Odoni, A.N., and Lane, S.N. (2010). *Assessment of the Impact of Upstream Land Management Measures on Flood Flows in Pickering Beck Using Overflow*. Durham: Durham University.

Olsson, J., Amaguchi, H., Alsterhag, E., Daverhog, M., Adrian, P., and Kawamura, A. (2012). Adaptation to climate change impacts on urban storm water: a case study in Arvika, Sweden. *Climatic Change*, 116, pp.231-247.

Ormsby, T., Napoleon, E., Burke, R., Groessl, C., and Bowden, L. (2009). *Getting to know ArcGIS Desktop*. Redlands: ESRI Press.

Perth and Kinross Council (2012). *Proposed Plan: Local Development Plan* [online]. Perth: Perth and Kinross Council. [accessed 03/01/14]. Available at: http://www.pkc.gov.uk/CHttpHandler.ashx?id=3655&p=0.

Partidario, M.R., and Gomes, R.C. (2013). Ecosystem services inclusive strategic environmental assessment. *Environmental Impact Assessment Review*, 40, pp.36-46.

Pascual-Hortal, L. and Saura, S. (2006). Comparison and development of new graph based landscape connectivity indices: towards the priorization of habitat patches and corridors for conservation. *Landscape Ecology*, 21, pp.959-967.

Phillips, P.M., and Sheate, W.R. (2010). A new SEA pathway: reflecting on Strategic Environmental Assessment in Scotland. *The Environmentalist*, 104, pp.19-22.

Phillips, P.M. (2013). Planning for green infrastructure in urban areas – towards an ecosystems approach. *Proceedings of the IALE 2013 European Congress – Changing European Landscapes: Landscape ecology, local to global* [online]. University of Manchester: Manchester 9-12 September 2013. [accessed 08/05/14]. Available at: http://www.iale2013.eu/.

Phillips, P.M., Eales, R.P., Baker, J., João, E.J., and Lord, R. (2014). *Land Use Strategy (LUS) Delivery Evaluation Project Final Report*. Report to Scottish Government. London: Collingwood Environmental Planning.

Planning etc (Scotland) Act 2006. London: The Stationary Office.

Parliamentary Office of Science and Technology (2011). *Natural Flood Management* [online]. London: Parliamentary Office of Science and Technology. [accessed 08/05/14]. Available at: http://www.parliament.uk/business/publications/research/briefing-papers/POST-PN-396/natural-flood-management.

Price (2005). *Loch Katrine: Land use change impacts to yield*. Contract report from Jacobs Babtie to Scottish Water.

Public Health Resource Unit England (2006). *Ten questions to help you make sense of qualitative research* [online]. Oxford: NHS. Available at:

http://www.civilservice.gov.uk/wp-content/uploads/2011/09/Qualitative-Appraisal-Tool_tcm6-7385.pdf.

Quine, C., Cahalan, C., Hester, A., Humphrey J., Kirby, K., Moffat, A., and Valatin, G. (2011). *Chapter 8: Woodlands*. *In: The UK National Ecosystem Assessment Technical Report.* UK National Ecosystem Assessment, UNEP-WCMC, Cambridge.

Robinson, M., Moore, R.E., Nisbet, T.R. & Blackie, J.R. (1998). *From moorland to forest: the Coalburn catchment experiment*. Institute of Hydrology Report No.133. Institute of Hydrology, Wallingford, UK, 64 pp.

RRC (2002). *Manual of River Restoration Techniques* [online]. Cranfield: RRC at Cranfield University. [accessed 15/09/13]. Available at: http://www.therrc.co.uk/rrc_manual.php.

SCCIP (2009). *Scottish Climate Change Information: UKCP09 Compendium Maps of UKCP09 projected change in mean temperature and mean precipitation* [online]. Edinburgh: Adaptation Scotland. [accessed 05/01/14]. Available at: http://www.adaptationscotland.org.uk/Upload/Documents/SCCIP_UKCP09compendium_maps_v1.pdf.

Schneider, A., Friedl, M.A., and Potere, D. (2009). A New Map of Global Urban Extent from MODIS Satellite Data. *Environmental Research Letters*, 4, pp.1-11.

Scott, A.V., and James, P. (undated). *What is landscape ecology and how does it apply to urban regeneration?* Manchester: The University of Salford.

Scottish Executive (2004). *Planning Advice Note (PAN) 69: Planning and Building Standards Advice on Flooding* [online]. Edinburgh: Scottish Executive. [accessed 08/05/13]. Available at: http://www.scotland.gov.uk/Resource/Doc/17002/0026290.pdf.

Scottish Government (2008): *Planning Advice Note (PAN) 65: Planning and Openspace* [online]. Edinburgh: Scottish Government. [accessed 10/09/2012]. Available at: http://www.scotland.gov.uk/Resource/Doc/225179/0060935.pdf.

Scottish Government (2009a). *A Guide to the Planning System in Scotland* [online]. Edinburgh: Scottish Government. [accessed 01/02/2014]. Available at: http://www.scotland.gov.uk/Resource/Doc/1070/0119912.pdf.

Scottish Government (2009b). *Planning Circular 1 on Development Planning* [online]. Edinburgh: Scottish Government. [accessed 01/02/2014]. Available at: http://www.scotland.gov.uk/Resource/Doc/261030/0077887.pdf.

Scottish Government (2010a). *Planning Advice Note (PANJ) 1/2010 on Strategic Environmental Assessment of Development Plans* [online]. Edinburgh: Scottish Government. [accessed 05/01/2014]. Available at: http://www.scotland.gov.uk/Resource/Doc/306466/0096206.pdf.

Scottish Government (2010b). *Scottish Planning Policy* [online]. Edinburgh: Scottish Government. [accessed 10/12/2013]. Available at: http://www.scotland.gov.uk/Resource/Doc/300760/0093908.pdf.

Scottish Government (2011a). *Flood Risk Management (Scotland) Act 2009: Delivering Sustainable Flood Risk Management* [online]. Edinburgh: Scottish Government. [accessed 10/12/2013]. Available at: http://www.scotland.gov.uk/Resource/Doc/351427/0117868.pdf.

Scottish Government (2011b). *Green Infrastructure: Design and Placemaking* [online]. Edinburgh: Scottish Government. [accessed 08/05/14]. Available at: http://www.scotland.gov.uk/Resource/Doc/362219/0122541.pdf.

Scottish Government (2011c). *Applying an ecosystems approach to land use: Information Note* [online]. Edinburgh: Scottish Government. [accessed 10/11/12]. Available at: http://www.scotland.gov.uk/Resource/Doc/345453/0114927.pdf.

Scottish Government (2011d). *Getting the best from our land – A land use strategy for Scotland* [online]. Edinburgh: Scottish Government. [accessed 10/11/12]. Available at: http://www.scotland.gov.uk/Resource/Doc/345946/0115155.pdf.

Scottish Government (2013a). *Flood Risk Management (Scotland) Act 2009: Surface Water Management Planning Guidance* [online]. Edinburgh: Scottish Government. [accessed 10/08/2013]. Available at: http://www.scotland.gov.uk/Resource/0041/00413778.pdf.

Scottish Government (2013b). *Climate Ready Scotland: Scottish Climate Change Adaptation Programme - Draft Scottish Climate Change Adaptation Programme Required by Section 53 of Climate Change (Scotland) Act 2009* [online]. Edinburgh: Scottish Government. [accessed 05/05/14]. Available at: http://www.scotland.gov.uk/Resource/0042/00426516.pdf.

Scottish Government (2013c). *The Planning System in Scotland* [online]. Edinburgh: Scottish Government. [accessed 11/12/13]. Available at: http://www.scotland.gov.uk/Topics/Built-Environment/planning.

Scottish Government (2013d). *Development Planning* [online]. Edinburgh: Scottish Government. [accessed 11/12/13]. Available at: http://www.scotland.gov.uk/Topics/Built-Environment/planning/National-Planning-Policy/themes/dev-plan.

Scottish Government (2013e). *Development Management* [online]. Edinburgh: Scottish Government. [accessed 11/12/13]. Available at: http://www.scotland.gov.uk/Topics/Built-Environment/planning/National-Planning-Policy/themes/dev-man.

Scottish Government (2013f). *Planning Advice Note PAN 1/2013: Environmental Impact Assessment* [online]. Edinburgh: Scottish Government. [accessed 03/12/13]. Available at: http://www.scotland.gov.uk/Resource/0043/00432581.pdf.

Scottish Government (2013g). *2020 Challenge for Scotland's Biodiversity - A Strategy for the conservation and enhancement of biodiversity in Scotland* [online]. Edinburgh: Scottish Government. [accessed 05/09/13]. Available at: http://www.scotland.gov.uk/Resource/0042/00425276.pdf.

Scottish Government (2013h). *Introduction to Planning* [online]. Edinburgh: Scottish Government. [accessed 02/01/14]. Available at: http://www.scotland.gov.uk/Topics/Built-Environment/planning/National-Planning-Policy.

Scottish Government (2013j). *Draft Scottish Planning Policy for Consultation* [online]. Edinburgh: Scottish Government. [accessed 05/09/13]. Available at: http://www.scotland.gov.uk/Resource/0042/00421076.pdf.

Scottish Government (2013l). *Land Use Strategy* [online]. Edinburgh: Scottish Government. [accessed 05/05/14]. Available at: http://www.scotland.gov.uk/Topics/Environment/Countryside/Landusestrategy.

SEPA (2006). *SEPA Position Statement to support the implementation of the Water Environment (Controlled Activities) (Scotland) Regulations 2005: Culverting of Watercourses*. Stirling: SEPA.

SEPA (2010). *Technical Flood Risk Guidance for Stakeholders* [online]. Stirling: SEPA. [accessed 05/05/14]. Available at: http://www.sepa.org.uk/planning/flood_risk/developers.aspx.

SEPA (2012). *Strategic Flood Risk Assessment – SEPA technical guidance to support Development Planning* [online]. Stirling: SEPA. [accessed 05/05/14]. Available at: http://www.sepa.org.uk/planning/flood_risk/planning_authorities.aspx.

SEPA (2014). *Flood Map* [online]. Stirling: SEPA. [accessed 15/02/14]. Available at: http://map.sepa.org.uk/floodmap/map.htm.

Shanghai Municipal Population and Family Planning Commission (2012). *Current Demographic Situation of Shanghai (2012)* [online]. Shanghai: SHPFPC. [accessed 05/05/14]. Available at: http://www.shrkjsw.gov.cn/spfpen/dr/data/2013110/00000660406604346981 36.html?openpath=spfpen/data.

Sheate, W.R., Eales, R.P., Daly, E., Baker, J., Murdoch, A., Hill, C., Ojike, U. and Karpouzoglou, T. (2012). Spatial representation and specification of ecosystem services: a methodology using land use/land cover data and stakeholder engagement. *Journal of Environmental Assessment Policy and Management*, 14(1), pp.1-36.

Sheate, W.R., and Phillips, P.M. (2014). *Proposals for Scotland Rural Development Programme 2014-2020: Strategic Environmental Assessment Environmental Report* [online]. Edinburgh: Scottish Government. [accessed 05/05/14]. Available at: http://www.scotland.gov.uk/Topics/farmingrural/SRDP/SRDP20142012/SRDP2014 2020ExAnteEvaluationSEA.

Smith, M., Moseley, D., Chetcuti, J., and de Loanni, M. (2008). *Glasgow and Clyde Valley Integrated Habitat Networks*. Roslin: Forest Research.

SNH (2011). *An essential guide to habitat networks* [online]. Inverness: SNH. [accessed 08/05/14]. Available at: http://www.snh.gov.uk/docs/C331645.pdf.

SNH (2012). *An Ecosystems Approach in Action – Working With Nature for Multiple Benefits: Event Report* [online]. Inverness: SNH. [accessed 08/05/14] Available at: http://www.snh.gov.uk/docs/A796537.pdf.

SNH (2014a). *Landscape glossary of terms* [online]. Inverness: SNH. [accessed 06/01/14]. Available at: http://www.snh.gov.uk/protecting-scotlands-nature/looking-after-landscapes/landscape-resource-library/glossary-of-terms/.

SNH (2014b). *Interactive habitat network user tool* [online]. Inverness: SNH. [accessed 01/04/14]. http://www.snh.gov.uk/land-and-sea/managing-the-land/spatial-ecology/habitat-networks-and-csgn/interactive-habitat-network-tool/.

SNIFFER (2008). *Urban networks for people and biodiversity – form and function*. Edinburgh: SNIFFER.

SNIFFER (2010). *The use of Environmental Limits in Regulating Environmental Systems – How Could the Concept be Applied by Environment Agencies?* Edinburgh: SNIFFER.

Stock, P., and Burton, R.J.F. (2011). Defining terms for Integrated (Multi-Inter-Trans-Disciplinary) Sustainability Research. *Sustainability*, 3, pp.1090-1113.

Susdrain (2012). *The community for sustainable drainage* [online]. London: Susdrain. [accessed 08/05/14]. Available at: http://www.susdrain.org/.

Suter, W., Bollmann, K. and Holderegger, R. (2009) Landscape permeability: from individual dispersal to population persistence. *in* Kienast, F., Wildi, O. & Ghosh, S. (eds.) *A Changing World. Challenges for Landscape Research*, 157–174.

Swan, A. (2010). How increased urbanisation has induced flooding problems in the UK: A lesson for African cities? *Physics and Chemistry of the Earth*, 35, pp.643-647.

TEEB (2011). TEEB Manual for Cities: Ecosystem Services in Urban Management [online]. Geneva: TEEB. [accessed 08/05/14]. Available at: http://www.teebweb.org/publication/teeb-manual-for-cities-ecosystem-services-in-urban-management/.

Tabacchi, E., Lambs, L., Guilloy, H., Planty-Tabacchi, A., Muller, E., and Decamps, H. (2000). Impacts of riparian vegetation on hydrological processes. *Hydrological Processes*, 14, pp.2959-2976.

Town and Country Planning (Scotland) Act 1997. London: The Stationary Office.

Town and Country Planning (Use Classes) (Scotland) Order 1997. No. 3061 (S.195). London: The Stationary Office.

Trochim, W.M.K. (2006). Research Methods Knowledge Base [online]. Available at http://www.socialresearchmethods.net/kb/index.php [accessed 22/04/14].

Twigger-Ross, C., Kashefi, E., Weldon, S., Brooks, K., Deeming, H., Forrest, S., Fielding, J., Gomersall, A., Harries, T., McCarthy, S., Orr, P., Parker, D., and Tapsell, S (2014) *Flood Resilience Community Pathfinder Evaluation: Rapid Evidence Assessment*. London: Defra.

UN (1992). United Nations Convention on Biological Diversity.

UKNEA (2011) *The UK National Ecosystem Assessment: Technical Report*. UNEP-WCMC, Cambridge.

UKNEA (2012). Ecosystem assessment concepts: ecosystems [online]. Cambridge: UNEP-WCMC. [accessed 04/01/14]. Available at: http://uknea.unep-wcmc.org/EcosystemAssessmentConcepts/tabid/98/Default.aspx.

UKTAG (2003). *UK Technical Advisory Group on the Water Framework Directive. Guidance on Morphological Alterations And the Pressures and Impacts Analyses* [online]. Available at: http://www.wfduk.org/sites/default/files/Media/Characterisation%20of%20the%20w ater%20environment/Morphological%20alterations%20and%20the%20pressures%20and%20impact%20analyses_Draft_251103.pdf [accessed 05/05/14].

United States Census Bureau (2008). *Community Facts* [online]. Washington DC: United States Census Bureau. [accessed 08/05/14]. Available at: http://factfinder2.census.gov/faces/nav/jsf/pages/index.xhtml.

UNFCCC (2013). *Background on the UNFCCC: The international response to climate change* [online]. Geneva: UNFCCC. [accessed 12/09/13]. Available at: http://unfccc.int/essential_background/items/6031.php.

Urban, D. and Keitt, T.H. (2001). Landscape connectivity: a graph theoretic perspective. *Ecology*, 82, pp.1205-1218.

Wamsler, C., Brink, E., and Rivera, C. (2013). Planning for climate change in urban areas: from theory to practice. *Journal of Cleaner Production*, 50, PP.68-81.

Watts, K., Humphrey, J.W., Griffiths, M., Quine, C., and Ray, D. (2005). *Evaluating Biodiversity in Fragmented Landscapes: Principles*. Edinburgh: Forestry Commission.

WDC (2013). *West Dunbartonshire Local Development Plan Proposed Plan* [online]. Dumbarton: WDC. [accessed 05/05/14]. Available at: http://www.west-dunbarton.gov.uk/media/2589474/west_dunbartonshire_proposed_local_development_plan.pdf.

Wild, T.C., Bernet, J.F., Westling, E.L., and Lerner, D.N. (2010). Deculverting: reviewing the evidence on the ‘daylighting’ and restoration of culverted rivers. *Water and Environment Journal*, 25, pp.412-421.

Woodland Trust (2011). *Trees or Turf?* Grantham: The Woodland Trust.

WHO (2013). *Urban population growth* [online]. Geneva: WHO. [accessed 06/09/13]. Available at: http://www.who.int/gho/urban_health/situation_trends/urban_population_growth_text/en/.