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TOWN AND COUNTRY PLANNING ACT 1990

PUSH ENERGY LTD

PROPOSED SOLAR FARM AND GLASSHOUSES

DECOY FARM, SPALDING ROAD, CROWLAND, PETERBOROUGH. PE6 0LX

FLOOD RISK ASSESSMENT

October 2013

Reference: 1310 FRA

FLOOD RISK ASSESSMENT

PROPOSED SOLAR FARM AND GLASSHOUSES

DECOY FARM, SPALDING ROAD, CROWLAND, PETERBOROUGH. PE6 0LX

Contents: -

1. Introduction.
2. Site details and proposed development.
3. Fluvial and Tidal flooding risks.
4. Surface water drainage of the proposal site.
5. Conclusions

Appendices: -

A. Location Plan.
B. Site and Proposal Plans.
C. Environment Agency Indicative Flood Risk
D. Environment Agency Flood Zone Report.
E. Hydrogeological Data.
F. Swale calculation sheets.
G. Balancing Lagoon calculation sheets.

1.0 INTRODUCTION

1.1 This flood risk assessment has been prepared in accordance with the recommendations contained in **National Planning Policy Framework and the associated Technical Guidance** and in accordance with the South Holland District Council's Policy requiring Flood Risk Assessments to accompany planning submissions.

2.0 SITE DETAILS AND PROPOSED DEVELOPMENT

2.1 The site is located at Decoy Farm, Spalding Road, Crowland, Peterborough. PE6 0LX. The site centroid is at National Grid Reference TF 25852 12520. Refer to **Appendix A** for general location and **Appendix B** for site and Proposal Plans. The proposal site is zoned by the Environment Agency (EA) to be within the 1:100 year return period potential flood risk area. Refer to **Appendix C** for the EA Indicative Flood Risk Map.

2.2 The proposal site is zoned to be within an area where automated flood warnings are available. Refer to **Appendix C** for EA flood warning area map.

2.5 The site lies wholly within the North Level District Internal Drainage Board's administrative area. The Board's bylaws will apply. The Board requires that all new development does not discharge surface waters above the equivalent rate of 1.40 litres per second per hectare (lts/s/Ha).

2.6 The proposed development is to provide a Solar Farm and Glasshouses of nominally 81142m^2 impermeable surfaces which will require formal drainage. The surfaces requiring formal drainage systems are presented by the roof drainage serving the 7No transformer and inverter houses of 9.0m^2 each and the drained surfaces associated with glasshouses of 81090m^2.

2.7 The proposed development will discharge surface waters from the transformer and inverter house elements (63.0m^2) to adjacent swales. Refer to **Appendix B** for site and Proposal Plans.

2.8 The proposed development will discharge surface waters from the glasshouse elements (81090m^2) to adjacent IDB drains via flow attenuation and associated balancing storage. Refer to **Appendix B** for site and Proposal Plans.

2.9 The proposal for the solar panels and glasshouses, by discharging surface waters either to infiltration systems or via flow attenuation to 'greenfield' runoff rates, will not modify the land drainage status by any measurable amounts.

3.0 FLUVIAL AND TIDAL FLOODING RISKS

3.1 The proposed development site is shown by the Environment Agency Indicative Flood Maps to be within the 1:100 year return period extent of tidal and fluvial flooding concern. The proposed development site is shown by the Environment Agency Indicative Flood Maps to be within the 1:100 year return period extent of fluvial flooding concern. The Environment Agency Indicative Flood Maps show the site to be within an area not benefiting from flood defences although extensive flood defences are in place. Refer to **Appendix C** for Environment Agency Indicative Flood Risk Map.

3.3 The Environment Agency in their 'Fenland Flood Zone Improvements Final Report' declare in the Executive Summary that "The flood outlines, derived for annual exceedance probabilities of 1% and 0.1%, cover the majority of the study area and are generally more extensive than the existing fluvial Flood Zones". The draft report advises that the relevant 1:100 year return period flood level is predicted at 1.91m ODN, presumably near to a flood defence breach. However, in the Final issue of the report the potential flood levels are described differently by referring to the 'equilibrium level from tidal sources' this being the level after which flood defences have failed extensively and have not been repaired. The equilibrium level was found to be fully established after 2 years at 1.42m ODN. Thereafter, the Final report uses critical rainfalls to establish the critical fluvial flood levels and presents these as plus 130mm for the 1:100 year return period and plus 210mm for the 1:1000 year return period. Accordingly, the worst flood level currently predicted will be 1.63m ODN. Refer to **Appendix D** for Environment Agency Fenland Flood Zones Final Report.

3.6 To provide a 300mm freeboard against the Environment Agency predicted flood level of 1.63m ODN all solar panels, electrical services and glasshouse floor levels will be at a minimum of 1.93m Ordnance Datum Newlyn (ODN).

3.0 SURFACE WATER DRAINAGE OF THE PROPOSAL SITE.

3.1 It is intended to provide formal drainage for transformer and inverter (60.0m^2) roof areas by directing roof waters, via piped systems to swales. It is intended that the dispersed solar panels will not be formally drained and that waters from each individual panel will fall to the rough grassed surface. The panels will be sited in rows. The site is virtually flat and with this lack of gradient it is improbable that the runoff from each solar panel could coalesce on the rough grassland surface to become a meaningful surface flow before infiltration. It is expected that the virtually un-trafficked rough grassland surface will remain sufficiently permeable and to maintain the land drainage status quo.

3.2 The British Geological Survey describes the general soils of the area as loamy and clayey soils of coastal flats.

3.3 The soil classification is given as WRAP type 2 permeable type soils. Refer to **Appendix E** for Hydrological Data.

3.4 Although the NPPF mentions a preference for infiltration systems it does not refer to a design methodology for infiltration systems other than that required by Building Control (BRE Digest 365). Also, it is announced that National Standards for SuDS will not take place until late 2014. Accordingly, the use of swales has been considered using the CIRIA Report 156 'Infiltration drainage-Manual of good practice'. Refer to **Appendix F** for Swale calculation sheets.

3.5 The nature of the site sub-soils is permeable. Using data from infiltration testing on similar soils and the guidance from CIRIA Report 156 an infiltration factor of 0.05m/s has been taken to critically represent the potential near to surface infiltration rate. This rate should be confirmed by infiltration testing at the site.

3.6 The transformer and inverter houses are proposed to be positioned, evenly spaced, at six locations. Given the large separations, lack of intervening cross-slopes and the indicated soil types it will not be possible for the swales to interact or affect each other.

3.7 Using the indicated data the swale requirement for each transformer and inverter house location has been calculated using CIRIA 156 methodology. The resultant swale size; to be formed as shallow depression, is 1.0m long x 1.60m base width and 0.30m deep. Refer to **Appendix F** for swale calculation sheet.

3.8 It is intended to provide formal drainage for the glasshouse roof areas by directing roof waters, via piped systems to flow controls and associated necessary balancing storage volumes.

3.9 North Level District Internal Drainage Board requires that all new development does not discharge surface waters above the equivalent rate of 1.40 lts/s/Ha. Accordingly, using standard Institute of Hydrology (IoH) methods to calculate peak flow rainfall events in comparison with attenuation control rate of 1.40 lts/s/Ha, a maximum balancing volume of 4285.0m^3 is calculated. Refer to **Appendix G** for calculation sheets.

3.10 The generally flat topography will not provide natural gradients for surface water drainage systems, nevertheless the receiving watercourse is sufficiently deep to allow the provision of pipe gradients and the construction of the balancing lagoon to outfall above the normal water levels of the receiving watercourse.

4.0 CONCLUSIONS

4.1 From the above, it is shown that flooding risks from fluvial and tidal sources; following the failure of extant flood defences, can easily be countered by constructing at levels above predicted flood levels.

4.2 The proposal will not require personnel to attend in the event of flooding although access and egress route are above the predicted peak flood levels.

4.3 This Flood Risk Assessment concludes that the proposed redevelopment with construction levels positively above 1.93m ODN cannot be reasonably defined as being at, or may cause, harmful flood risk from 1:100 or 1:1000 year return period flood events, following the complete failure of flood defences, including climate change allowances, within the parameters given by the National Planning Policy Framework and the associated Technical Guidance.

4.4 This Flood Risk Assessment concludes that the proposed redevelopment, which will not increase surface water discharge rates above those allowed, cannot be reasonably defined as being at, or may cause, harmful flood risk within the parameters given by the National Planning Policy Framework.

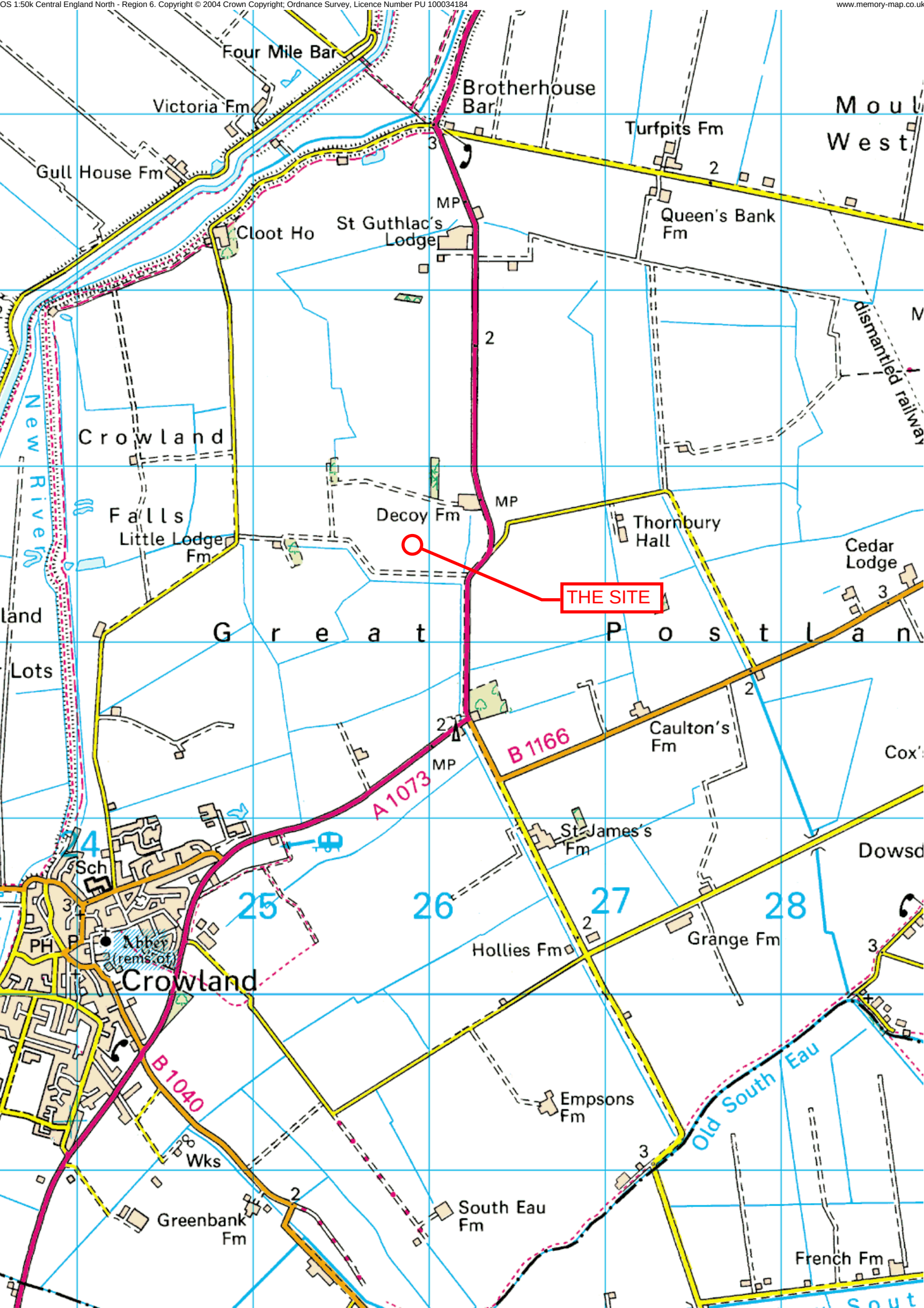


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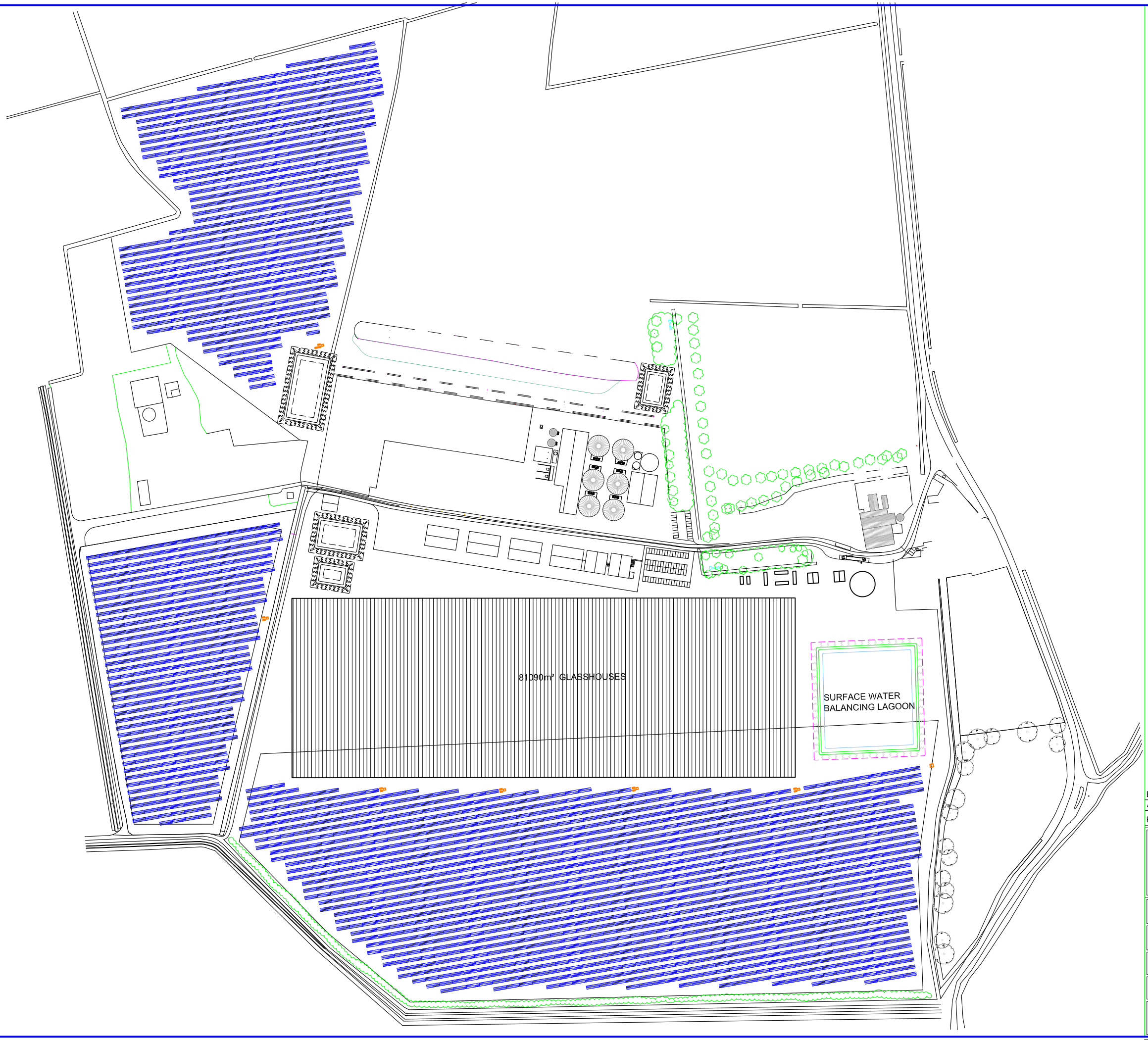
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Appendix A

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Appendix B



Key

- Approved Digestion Plant and associated uses
- Proposed Area for Solar panels
- Proposed Glass Houses (Utilising Waste Heat)
- Surface water Lagoon and Wildlife Habitat
- Welfare Facilities
- Car Parking

N

0 20 40 60 80 100m

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Rev.	By	Notes	Date
B	JB	Welfare & parking area amended	29-11-12
A	JB	Solar panels area amended	07-11-12

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Client: CLIENT

Project: PROJECT

Drawing title: TITLE

Drawing No.	Rev.	Drawn
NUMBER	REV.	DRAWN

Scale	Date	Checked
SCALE	DATE	CHECKED

All measurements should be checked against on site conditions and any discrepancies should be brought to the attention of the Robert Doughty Consultancy.

Appendix C

Environment Agency

Enter a postcode or place name:

Crowland, Lincolnshire Go

Other topics for this area...

Risk of Flooding from Rivers and Sea

Risk of Flooding from Rivers and Sea

Map legend

Click on the map to see what is the Risk of Flooding at a particular location.

Flood Maps

- Flooding from rivers or sea without defences
- Extent of extreme flood
- Flood defences (Not all may be shown*)
- Areas benefiting from flood defences (Not all may be shown*)
- Main rivers

X: 525,603;Y: 312,908 at scale 1:15,000

Data search Text only version



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Appendix D

SFRM Framework

Fenland Flood Zone Improvements

February 2007

FINAL REPORT

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REVISION HISTORY

Revision Ref./ Date Issued	Amendments	Issued to
Final report 8 February 2007	Minor corrections	Elizabeth Coulling One digital and one paper copy
Draft report 2 January 2007		Elizabeth Coulling Digital and paper copies of draft report

CONTRACT

This report describes work commissioned by the Environment Agency under Commission Reference AN711 of 17 July 2006. The Environment Agency's representative for the contract was Elizabeth Coulling. Duncan Faulkner, David Kearney and John Rampley of JBA Consulting carried out the work.

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PURPOSE

This document has been prepared solely as a report on Flood Zone improvements for the Environment Agency. JBA Consulting accepts no responsibility or liability for any use that is made of this document other than by the Client for the purposes for which it was originally commissioned and prepared.

ACKNOWLEDGMENTS

Thanks are extended to those at Halcrow, Faber Maunsell, Mott Macdonald and Atkins who provided model outputs for use in this project. We are also grateful to Elizabeth Coulling of the Environment Agency for supplying data and background information.

EXECUTIVE SUMMARY

This report describes a project to improve the Environment Agency's Flood Map in Fenland, a large flat area of land around the Wash in the east of England. The present Flood Zones shown on the Flood Map are thought to cover too small an area, for example they do not include the lowest-lying parts of the Fens.

The Agency's policy is to map Flood Zones as if flood defences were not present. The Fens owe their very existence to a long history of land drainage and flood defence engineering, with the majority of the area drained by pumping into high-level embanked rivers. In this project the Fens have been represented as they were hundreds of years ago before drainage (although with present-day ground levels). A water balance model was used to simulate the long-term average water level in the absence of drainage, and then flood events were introduced into the already-flooded fens.

The resulting flood outlines, derived for annual exceedence probabilities of 1% and 0.1%, cover the majority of the study area and are generally more extensive than the existing fluvial Flood Zones.

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CONTENTS

Page

REVISION HISTORY *i*
CONTRACT *i*
PURPOSE *i*
ACKNOWLEDGEMENTS *i*
EXECUTIVE SUMMARY *iii*
CONTENTS *v*

1 INTRODUCTION ---------- 1
1.1 Project Brief and Aims 1
1.2 Study Area 1
1.3 Technical Approach 2
1.4 Purpose and Contents of Report 3
1.5 Available Data 3

2 LONG-TERM EQUILIBRIUM WATER LEVEL ---------- 4
2.1 Inflows and Outflows 4
2.2 Water Balance Model 6
2.3 Results 7

3 FLOOD ESTIMATION ---------- 9
3.1 Introduction 9
3.2 Flood Hydrographs from Models 9
3.3 Joint Probability of Inflows 11
3.4 Direct Rainfall 14

4 JFLOW MODELLING ---------- 15
4.1 Digital Terrain Model 15
4.2 Modification of JFLOW 16
4.3 Rain Event Simulation 16
4.4 Five Fluvial Model Simulations 16

5 MODEL RESULTS ---------- 18
5.1 Deriving Flood Outlines 18
5.2 Discussion of Outlines 19
5.3 Results Provided to the Environment Agency 19

6 CONCLUSIONS AND RECOMMENDATIONS ---------- 21
6.1 Conclusions 21
6.2 Implications for Other Studies 21

APPENDIX A: - INFLOW HYDROGRAPHS

LIST OF FIGURES

Figure 1-1 Topography of the study area....2
Figure 2-1: Main catchments draining to the Fens....4
Figure 2-2: Conceptual model of Fens for simulating equilibrium level....5
Figure 2-3: Sample period from the tide series at the four outfalls....6
Figure 2-4: Results of the water-balance model run: water level in the Fens....7
Figure 2-5: Area below 1.42mAOD (flooded in equilibrium model)....8
Figure 3-1 Hydrographs resulting in 1% water levels in the Fens....10
Figure 3-2 Hydrographs resulting in 0.1% water levels in the Fens....11
Figure 3-3 Correlation between peak flows on Rivers Nene and Welland....12
Figure 3-4 Location of flow gauges used in analysis....13
Figure 5-1: Comparison of new 1% AEP flood outline with existing Flood Zone 3....20

LIST OF TABLES

Table 2-1: Inputs to the water balance model....5
Table 2-2: Sill levels of outfalls used in the model....6
Table 3-1 Deriving scaling factors....10
Table 3-2 Peak flows on each wtarecourse....11
Table 3-3 Flow gauges on the study watercourses....12
Table 3-4: Ratios of flow volume at each station (during major floods at other stations) to the volume during the highest 10-day event on record at the same station....14

ABBREVIATIONS

ABD	Area Benefiting from Defences
AEP	Annual Exceedance Probability
ARF	Areal Reduction Factor
FEH	Flood Estimation Handbook
GS	Gauging Station
IDB	Internal Drainage Board
ISIS	Hydrology and hydraulic modelling software
JFLOW	2-D hydraulic modelling package developed by JBA
LiDAR	Light Detection And Ranging
mAOD	metres Above Ordnance Datum
ReFH	Revitalised Flood Hydrograph method
SAR	Synthetic Aperture Radar
SFRM	Strategic Flood Risk Management

1 INTRODUCTION

1.1 Project Brief and Aims

This project was commissioned under the Strategic Flood Risk Management (SFRM) Framework. The Environment Agency's requirement was to produce a map of the fluvial floodplain in the Fens ignoring the effect of flood defences. This is in accordance with the Environment Agency's Flood Map policy which states that flood zones should ignore the presence of raised walls and embankments, barrages, engineered flood storage areas and pumping stations.

The current fluvial flood zones 2 and 3 in the fenland area around the Wash are thought to cover too small an area, for example they do not include the lowest-lying parts of the Fens. This arises from the way in which they were derived, using national-scale 2-D floodplain inundation modelling.

The Fens are an unusual area in that their very existence depends on a long history of flood defence engineering. Significant parts lie below sea level. Large areas are drained by pumping into perched artificial drainage channels which discharge to the sea.

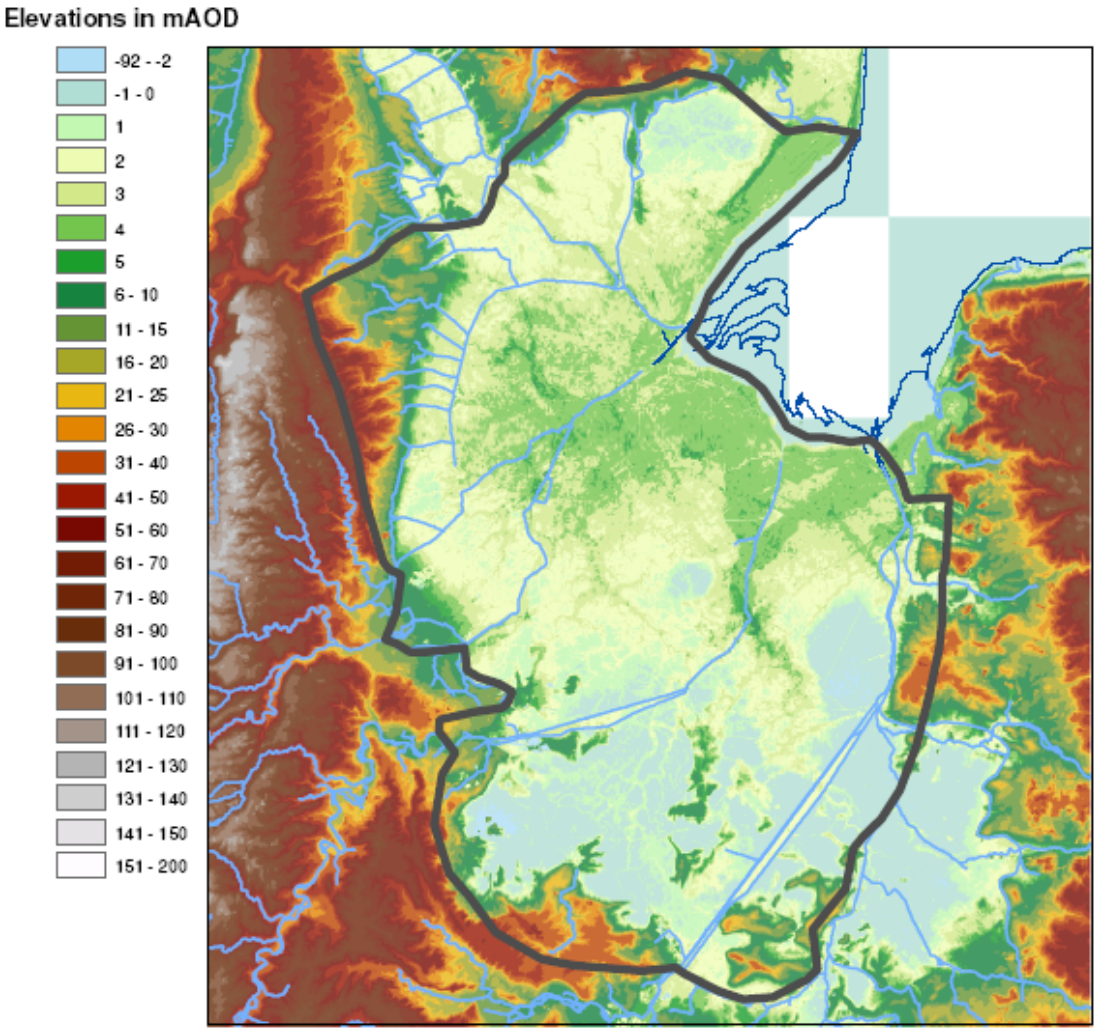
The aim of the study is to improve flood zones 2 and 3 across the study area. The study followed the Environment Agency's Flood Mapping Specification (v1.2, September 2006), although not all of the specification applied since it is not a standard flood mapping study.

1.2 Study Area

The study area covers some 3,700km^2 of Northern and Central Areas in Anglian Region, from Sleaford and Boston in the north to Ely in the south. Figure 1-1 shows the topography of the area, almost all of which lies below 5mAOD. The lowest-lying areas, 2-3m below sea level, are found inland, towards the south of the study area.

Contrary to what might be expected, the highest ground in Fenland is found along the coast of the Wash and along the courses of current or former river channels. The reason is thought to be that before the Fens were drained, silt deposits were created by the rivers that ran through the area and along the Wash from tidal deposition. After drainage, these silt areas did not shrink in the same way as the peaty soils elsewhere, which subsided to form the lowest-lying parts of the present-day landscape. The raised features that form the beds of extinct rivers are known locally as rodhams or roddons.

Figure 1-1 Topography of the study area



1.3 Technical Approach

A technical approach was suggested in the Environment Agency's initial Outline Brief. This was refined after discussion at the pre-contract meeting on 21 June 2006, and the final approach was set out in JBA's Brief and Proposal dated 29 June 2006. In brief, it involved:

- Simulating the long-term equilibrium water level over the Fens (in the absence of fluvial defences) using a water balance model;
- Modifying the JFLOW software so that it could use the equilibrium level as a starting condition for flood simulations;
- Generating realistic combinations of flood flows on the various rivers entering the Fens, together with direct rainfall;
- Running the above inflows through a JFLOW model to derive flood extents and depths, assuming that tidal defences remained in place so that only fluvial flooding was modelled (because tidal flooding is being examined in a separate contract)

This approach clearly involves modelling a completely hypothetical situation, but this is necessary to be in accordance with Environment Agency policy.

1.4 Purpose and Contents of Report

This report covers the data collection, flood estimation, modelling and floodplain mapping aspects of the project, and is arranged as follows:

- **Introduction** – This puts the study in context and summarises the background and data sources.
- **Initial Conditions** – Initial conditions for the JFLOW model are derived using an equilibrium model.
- **Flood Estimation** – Flood flows into the Fens and rainfall depths are presented and appropriate hydrographs produced for each model run.
- **JFLOW Modelling** – Flood outlines are derived from the inflows using a 2-D model.
- **Model Results** – The results of the model runs are presented.
- **Conclusions** – The findings of this study are discussed and recommendations made.

1.5 Available Data

LiDAR and SAR (NextMap) data were made available by the Environment Agency to create a single Digital Terrain Model of the study area for use in JFLOW. Hydraulic models have been built or are being developed by other SFRM framework consultants for the Rivers Nene, Welland, Witham and Great Ouse. Contacts at these consultants were provided by the Environment Agency.

Hydrometric data from gauges in the study area was also available.

2 LONG-TERM EQUILIBRIUM WATER LEVEL

2.1 Inflows and Outflows

The first stage of the study involved simulating the average water level in the Fens as it would be in the absence of fluvial defences.

There are six main inflows into the Fenland area: the Rivers Witham, Glen, Welland, Nene, Bedford Ouse and Ely Ouse. With a combined area of some 11,200km^2 (upstream of the boundary of the study area), these six rivers account for some 95% of the land area draining to the Fens (Figure 2-1). It was also necessary to consider direct rainfall on to the study area, which covers some 3,700km^2. As stated in the Outline Brief, the flow out of the Fens was simplified into the four largest tidal outfalls, i.e. Rivers Witham, Welland, Nene and Great Ouse. This is shown schematically in **Figure 2-2**.

Figure 2-1: Main catchments draining to the Fens

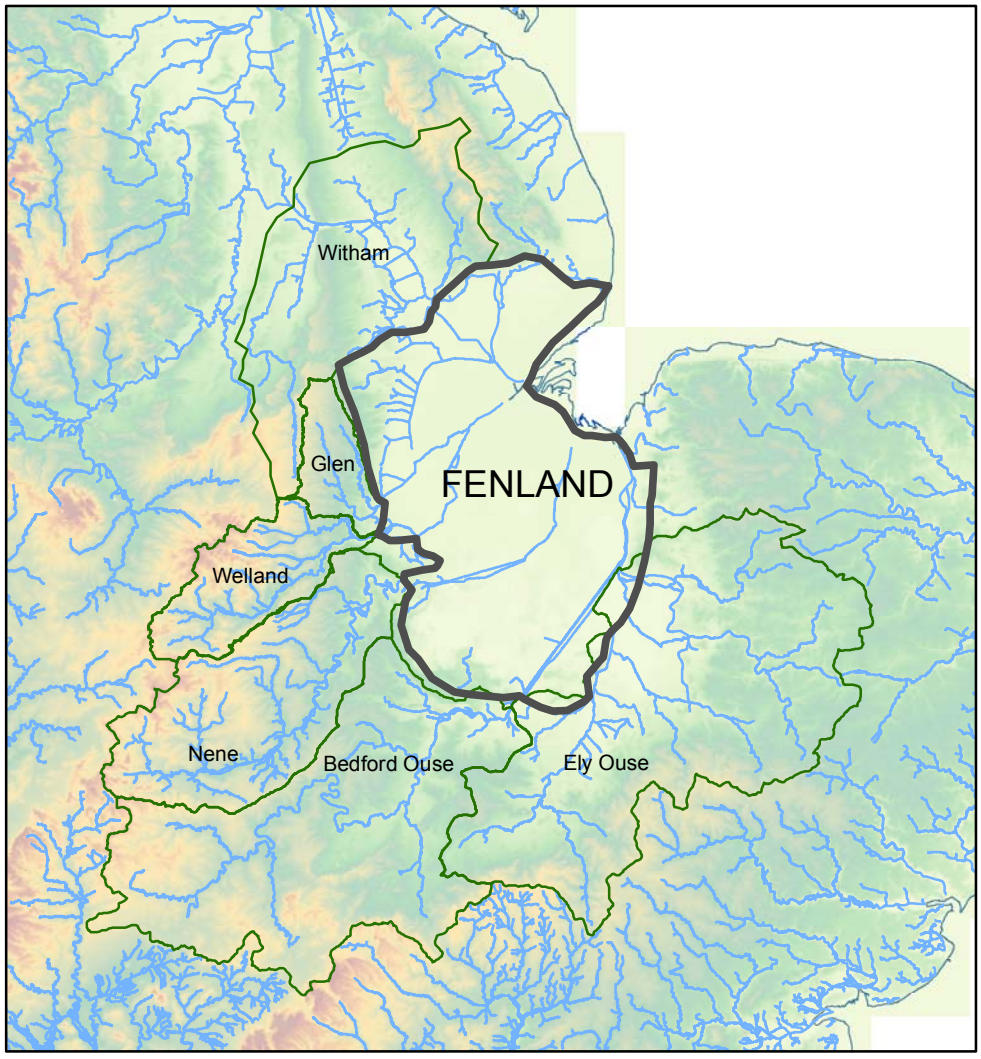
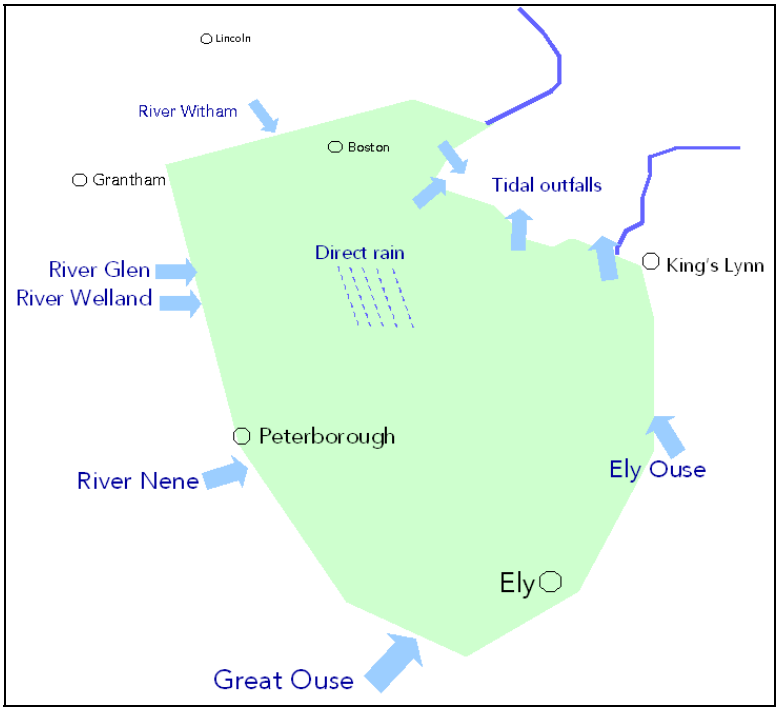


Figure 2-2: Conceptual model of Fens for simulating equilibrium level



Inputs to the system were simulated as constant values equal to the long-term mean flow and rainfall. The flow for the Rivers Glen, Welland, Nene, Bedford Ouse and Ely Ouse was obtained from measured data[1], as was the rainfall over the study area[2] (Table 2-1). There is no flow gauging station on the lower Witham, so runoff was estimated from rainfall. Losses (to evaporation etc.) were assumed to be the same as those calculated for the adjacent Welland catchment, where the daily mean flow equates to an annual mean runoff of 163mm. The mean annual rainfall over the Welland catchment is 634mm, giving a percentage runoff of 27.1%. This was applied to the mean annual rainfall over the Witham, 603mm, giving a mean annual runoff of 163mm. Converting into a volumetric flow rate gives a daily mean flow of 9.7m^3/s for the Witham catchment.

Table 2-1: Inputs to the water balance model

Input	Data source	Area (km^2)	Daily mean flow into Fens (m^3/s)
River Glen	Kates Bridge GS	342	1.2
River Welland	Tallington GS	717	3.9
River Nene	Orton GS	1634	9.3
River Bedford Ouse	Brownshill Staunch GS	3030	14.4
River Ely Ouse[3]	Denver Sluices GS	3430	10.9
River Witham	Estimated	1872	9.7
Total input from rivers	**Sum of above six**	**11,025**	**49.4**
Direct rainfall	FEH CD-ROM	3700	16.5
Total input, rivers and rain	**Sum of above two**	**14,725**	**66.0**

[1] From the Hydrological Data UK register produced by CEH Wallingford.

[2] From the FEH CD-ROM, taking an average over various catchments contained within the study area.

[3] Although the Ely Ouse has a larger catchment than the Bedford Ouse, its flow is smaller because its catchment is more permeable.

2.2 Water Balance Model

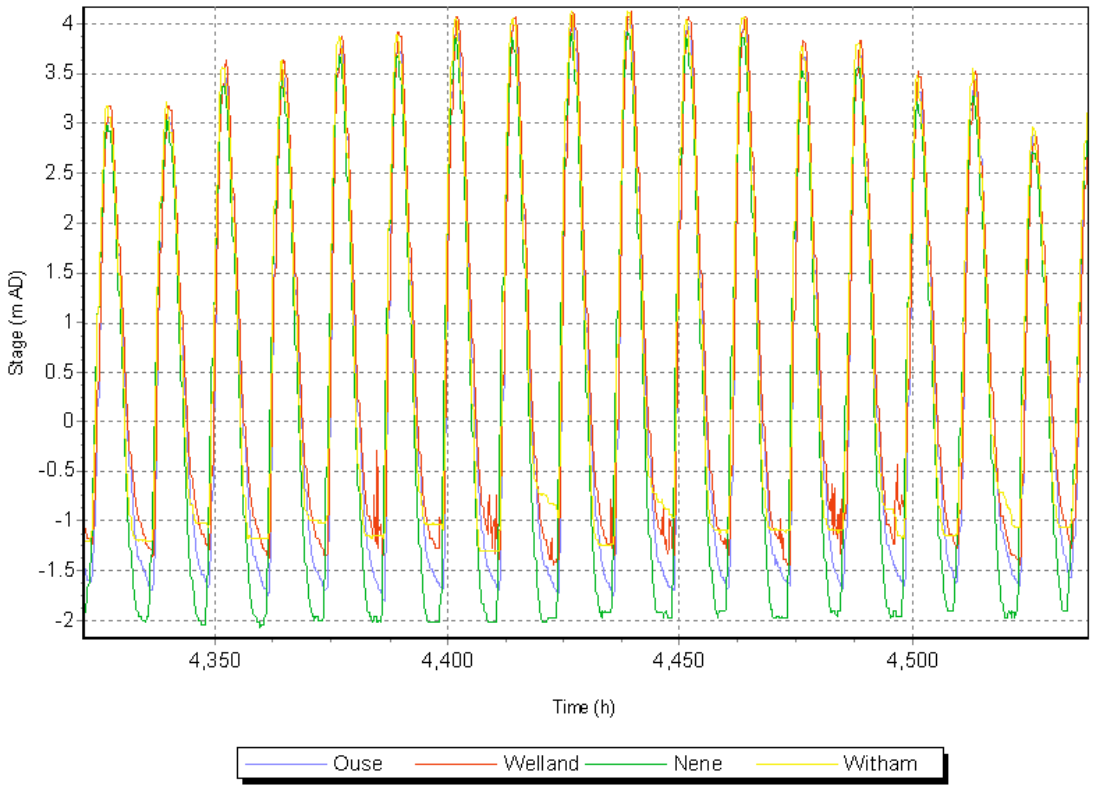
There are several ways in which the Fenland system could be modelled. For this study it was agreed to try a very simple approach, assuming a uniform water level over the whole study area which means it can be modelled using a level pool routing algorithm. This was done in ISIS. The Fens were represented using a reservoir unit, with an elevation-area relationship taken from the NEXTMap elevation model. The four main outflows were modelled as spill weirs, 50m wide (as stated in the Outline Brief) with crest levels set equal to the sill levels of the present-day outfalls, which were provided by the Environment Agency (Table 2-2). In reality it is possible that the sill levels would be different if the fluvial defences were not present, for example due to increased siltation, so using the present-day levels was an approximation.

Table 2-2: Sill levels of outfalls used in the model

River	Outfall	Level (mAOD)
Witham	Grand Sluice	-1.0
Welland	Marsh Road Sluice	-0.3
Nene	Dog in a Doublet Sluice	-2.0
Ouse	Brownshill Sluice	-0.2

Water levels on the seaward side of the outfalls were set to a typical tidal time series, obtained from recorded tide data during the years 2000 and 2001. This was represented in the model with a 15-minute time step (Figure 2-3).

Figure 2-3: Sample period from the tide series at the four outfalls



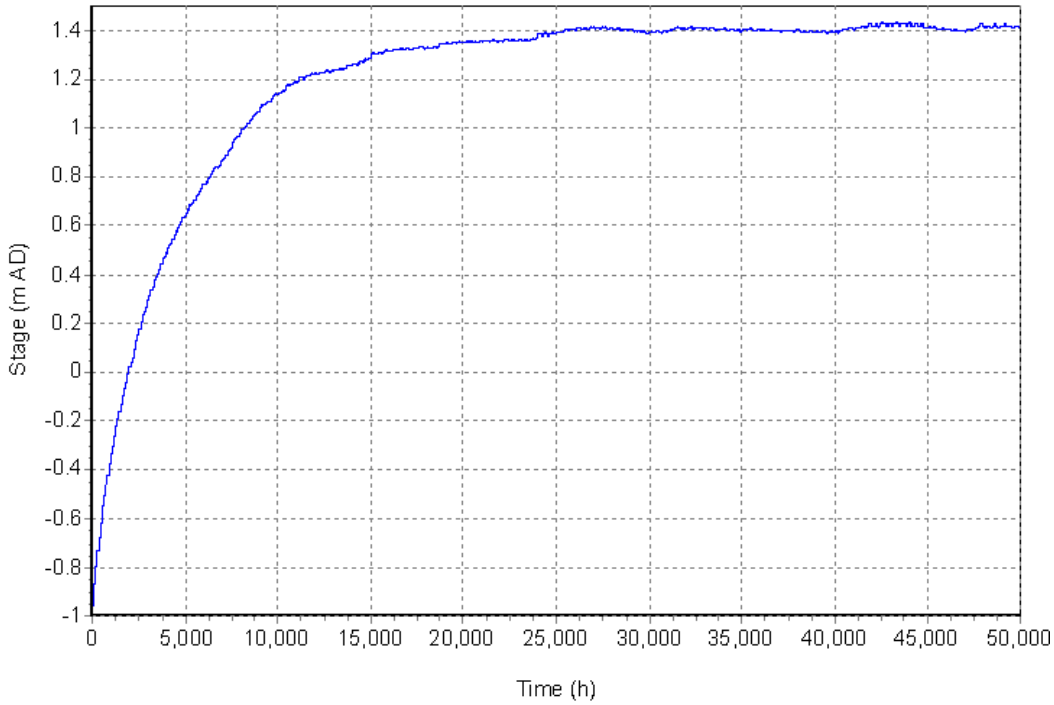
The model ignored any losses of water within the Fenland study area due to infiltration, which is likely to be low due to the high water table which will result from flooded conditions. It also ignored losses from evaporation, which may be partly offset by groundwater discharging into the Fens having recharged aquifers in the upstream catchments outside the study area.

The model was run, starting from the present-day drained condition, until it reached a stable water level.

2.3 Results

The model reached an equilibrium level of 1.42mAOD after 3.0 years of run-time. Figure 2-4 shows how the water level increased from an initial dry condition, rapidly at first and then more gradually after the first 15,000 hours (20 months). These results imply that, if the pumping stations were all turned off, the Fens would revert to flooded conditions within 1-2 years.

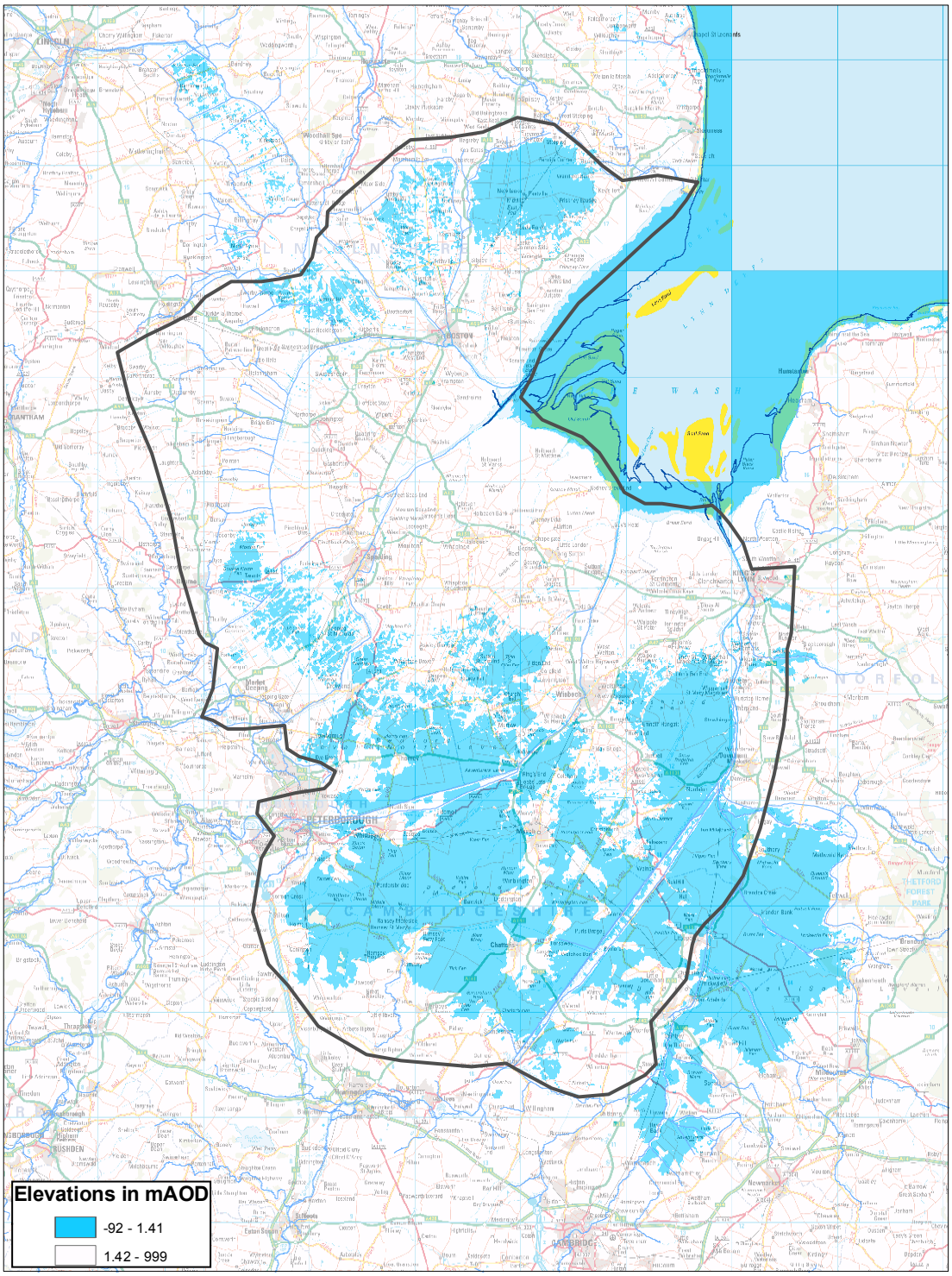
Figure 2-4: Results of the water-balance model run: water level in the Fens



The resulting wet area is shown in **Figure 2-5**. There are two separate areas of water: a much larger one to the south in Cambridgeshire between Peterborough and Mildenhall and a smaller one to the north in Lincolnshire, north of Boston.

The ISIS model assumes that water can flow to all parts of the study area, to attain a level surface. To test the effects of this assumption, a different version of the model was constructed, with two separate reservoir units representing the south and north low-lying areas. The results were within 80mm of those from the combined model, so it was decided to run the subsequent analysis using a uniform 1.42mAOD to represent the long-term average water level over the Fens.

Figure 2-5: Area below 1.42mAOD (flooded in equilibrium model)



Digital map data © Bartholemew

3 FLOOD ESTIMATION

3.1 Introduction

Flood hydrographs for the 1% and 0.1% annual exceedance probability events were needed at 6 locations around the Fens. These were where the Rivers Nene, Welland, Witham, Glen, Great Ouse and Ely Ouse enter the study area. The design water level at some locations within the Fens may depend on the combination of inflows from several of the rivers (and direct rainfall), meaning the interaction between flooding from different rivers has to be taken into account. This section describes how this joint probability problem was approached.

3.2 Flood Hydrographs from Models

On conventional gravity-draining watercourses, the 1% water level generally corresponds closely to the 1% peak flow. However, in this study area water levels will depend more on the volume and duration of inflows than on their peaks. All six watercourses have been, or are currently being, modelled using 1D hydrodynamic models by other SFRM consultants. JBA have been supplied with hydrographs that are thought to result in the 1% probability water levels on the parts of the Rivers Welland, Witham, Glen and Great Ouse that flow through the Fens. The model for the Ely Ouse was not readily available, meaning no hydrographs were obtained for this watercourse. The 1% probability hydrograph on the River Nene could not be obtained, however a hydrograph representing an increase in flow of 20% on the 1% event was supplied, and this was scaled down to obtain the 1% event. At the time of this study a hydrograph resulting in the 0.1% probability water level in the Fens was only available for the River Nene.

Limited information regarding the methods of flow estimation was available for the models, however checks were made that the critical duration used in each of the models was appropriate for the Fens. The Great Ouse hydrographs have a much larger volume compared with those on the other watercourses flowing into the Fens. This may be due to different methods of flood estimation being used for the Great Ouse model. For example, it is possible that the FEH rainfall – runoff method was used for this model with the FEH statistical method being used on other watercourses. It was beyond the scope of this study to revisit the hydrology and after discussions with WS Atkins who developed the Great Ouse model it was decided to accept the hydrograph provided.

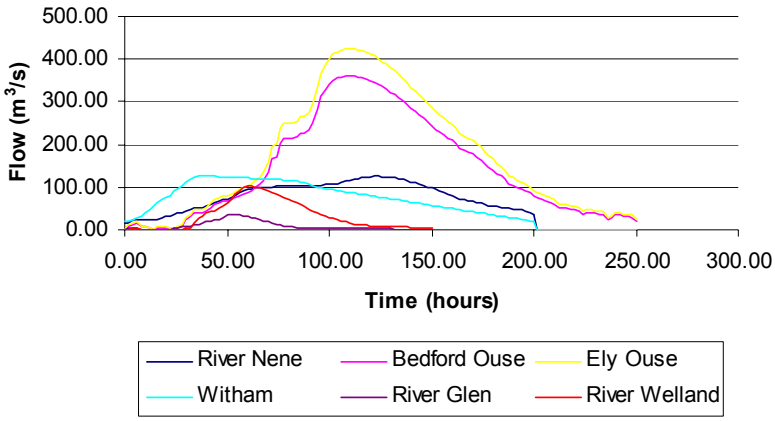
3.2.1 1% Hydrographs

The 1% hydrographs supplied by the SFRM consultants were used as they were supplied where possible, however some alterations to the modelled hydrographs were necessary as detailed below:

- The hydrograph from the Nene model was scaled down by a factor of 1/1.2 so it would give rise to 1% probability water levels in the Fens.
- The hydrograph from the Witham model was averaged over a 12 hour window to remove the effect of a tidal boundary condition that had been used in the model.
- The hydrograph for the Ely Ouse was estimated by scaling the hydrograph obtained from the Great Ouse model by catchment area. This resulted in the Great Ouse hydrograph being scaled by a factor of 1.18 to represent flow on the Ely Ouse.

This gave six flow hydrographs that could be used as a basis for the inflows to JFLOW models; these are shown in Figure 3-1, with the peak flows also shown in Table 3-2.

Figure 3-1 Hydrographs resulting in 1% water levels in the Fens



3.2.2 0.1% Hydrographs

Only one of the SFRM consultants could supply a 0.1% probability hydrograph, and this was for the River Nene. In consultation with the Environment Agency it was decided that the 1% probability hydrographs for the remaining watercourses could be scaled up to give hydrographs that would result in approximate 0.1% probability water levels in the Fens.

The scaling factors used were derived by JBA from some work undertaken for Anglian Region reviewing FEH application in Northern Area[4]. This included deriving the 1% and 0.1% AEP peak flows using the ReFH method for the gauges on the River Nene at Wansford and River Welland at Tallington. The growth factors were calculated as shown in Table 3-1.

Table 3-1 Deriving scaling factors

Location	A 1% peak flow	B 0.1% peak flow	B/A Scaling Factor
31004 Welland at Tallington	163.4	275.7	1.69
32010 Nene at Wansford	238.6	393.7	1.65

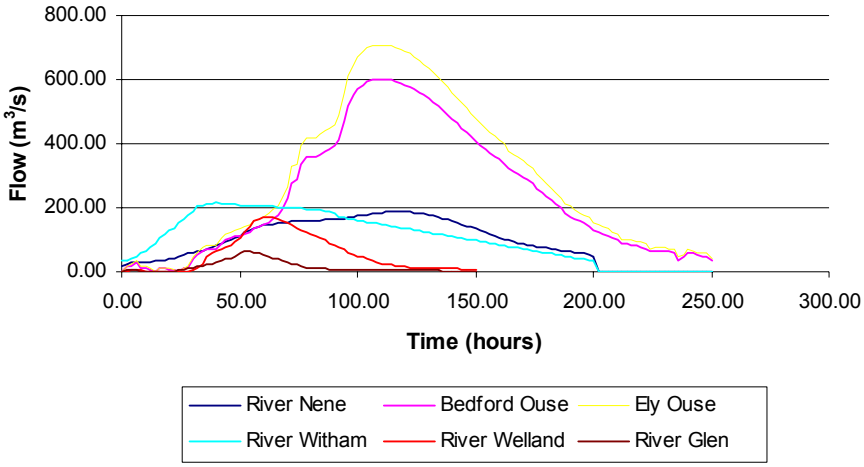
The 1% AEP hydrographs were scaled using these factors, to give the 0.1%AEP hydrographs shown in Figure 3-2. The Rivers Witham, Welland and Glen have been scaled using the factor derived for the Welland at Tallington. An average of the two factors was used to scale the hydrographs for the Great Ouse and Ely Ouse catchments. The 0.1%AEP peak flows for each watercourse are presented in Table 3-2.

[4] JBA Consulting (2006) Review of Flood Estimation Handbook Application in Anglian Region Northern Area.

Table 3-2 Peak flows used for each watercourse

Watercourse	1% peak flow (m^3/s)	0.1% peak flow (m^3/s)
River Nene	125	187
River Witham	127	215
River Welland	102	172
River Glen	37	63
Bedford Ouse	360	602
Ely Ouse	423	707

Figure 3-2 Hydrographs resulting in 0.1% water levels in the Fens

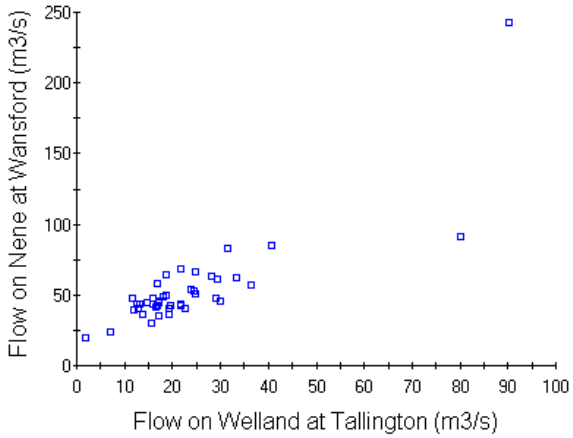


3.3 Joint Probability of Inflows

Modelling inflows from each river separately could lead to underestimation of water levels because it would neglect any interactions between flood water from the various rivers. This is the joint probability effect referred to in section 3.1. Issues of joint probability are particularly difficult to resolve when the input variables are partially dependent, as they are in this case[5]. For example, a 1% flood on the River Nene will not coincide with a 1% flood on the River Welland, but neither will it occur during mean flow conditions on the Welland, as shown by Figure 3-3. There is inevitably a dependence between the two catchments because any storm extensive enough to cause flooding on the Nene will also affect at least part of the Welland catchment.

[5] Appendix B of Volume 1 of the Flood Estimation Handbook gives an introduction to joint probability problems.

Figure 3-3 Correlation between peak flows on Rivers Nene and Welland



Given the coastal location of the study area, there is potentially an added complication of dependence between river floods and sea surges which can mean that high flows tend to coincide with high tides. However, this has been found to be insignificant for large catchments on the east coast[6] because they respond slowly to rainfall, and thus the flood peak arrives at the coast after the surge has dissipated.

It was decided that an approximation of flow on other watercourses during 1% and 0.1% probability events on each of the main watercourses could be made by assessing the typical magnitude of flows on the other watercourses during large events on each river. Of the six watercourses to be used as inflows to the JFLOW model, all but the River Witham are gauged close to where they enter the Fens, as described in Table 3-3 and shown in Figure 3-4.

Table 3-3 Flow gauges on the study watercourses

Watercourse	Gauge	Period of record provided	Comments
River Witham	-	-	No gauge
River Glen	Kate's Bridge	1981 - 2006	Includes flow measured at King Street
River Welland	Tallington Total	1981 - 2006	Includes parallel channels gauged at Lolham and West Deeping
River Nene	Wansford Combined	1996 – 2006	Ultrasonic station shortly upstream of Orton, where low flows are measured
Great Ouse	Offord	1971 – 2006	Only daily mean flows are reliable
Ely Ouse	Denver Sluices	1971 - 2006	Only daily mean flows are available, and much missing data

Flow data from these gauges was used to assess the annual maximum volumes for the period from 1981 to present. Volumes were accumulated over a 10-day duration, which was thought to be a typical event duration for the study area. Comparisons were made between flow volumes on each

[6] Hawkes, P. and Svensson, C. (2003). Joint probability: dependence mapping and best practice. Technical report on dependence mapping. Defra/Environment Agency Flood & Coastal Defence R&D programme, R&D Technical Report, FD2308/TR1.

of the watercourses during the period of the largest five annual maximum volume events at each site (where five large events were available).

To take the River Nene as an example: the largest annual maximum volume was the April 1998 flood, the highest 10-day period being 9-19 April. Flow volumes on all other rivers were obtained for the same 10-day period. On the Welland, the April 1998 volume was 0.93 times the highest on record for the Welland (which was in November 2000). This analysis was repeated for several more of the highest events on the Nene, which resulted in a mean factor of 0.91 for the Welland. In other words, on average during major floods on the Nene, the volume on the Welland is 91% of what it is during major floods on the Welland.

This analysis was repeated for all other combinations of rivers, and the results (Table 3-4) were used as scaling factors for obtaining inflows for the JFLOW model runs. It is an approximate treatment of the joint probability problem, the principal assumption being that the scaling factors derived for a selection of observed events can be applied to design events with AEPs of 1% and 0.1%.

It was assumed that the River Witham behaves similarly to the River Welland and the scaling factors for the River Welland were also used to scale the hydrographs for the River Witham inflow to JFLOW models of the other four watercourses.

The hydrographs used in each model run are presented in Appendix A: -Inflow Hydrographs.

Figure 3-4 Location of flow gauges used in analysis



Table 3-4: Ratios of flow volume at each station (during major floods at other stations) to the volume during the highest 10-day event on record at the same station

Station with Highest Event	Stations for Comparison				
	Nene at Wansford	Welland at Tallington	Bedford Ouse at Offord	Glen at Kate's Bridge	Ely Ouse at Denver Sluice
Nene at Wansford		**0.91***	0.63	0.59	0.76
Welland at Tallington	0.79		0.68	0.64	0.79
Bedford Ouse at Offord	0.68	0.81		0.56	0.85
Glen at Kate's Bridge	0.50	0.73	0.58		0.69
Ely Ouse at Denver Sluice	0.58	0.62	0.54	0.52	
* See worked example in text above					

3.4 Direct Rainfall

The study area is large enough to receive a significant volume of direct rainfall in addition to the flow that enters from the rivers described above. Direct rainfall was applied to each JFLOW model during the design runs. The volume and duration of rainfall were estimated approximately by examining previous events and using the FEH rainfall statistics.

It was found that during some of the largest events on record for the rivers flowing into the Fens, the mean duration of rainfall was approximately 13 days, 9 days of which were before the river flow started to rise (while the floods were being generated within the upstream catchments). The FEH rainfall profiles are not appropriate for such long events, and so as an approximation a constant rainfall intensity was adopted.

The depth of rainfall was estimated from a rough-and-ready assumption that the rain over Fenland during the 1% AEP inflow from each tributary could be derived using a 1% AEP point rainfall depth reduced by an areal reduction factor assuming a storm over Fenland and **all** the tributary catchments, i.e. 15,000km^2. The areal reduction factor (ARF) was derived from the formula in FEH Volume 2, giving a factor of 0.93.

13-day point rainfall depths were derived from FEH statistics at a location in the centre of Fenland, giving:

- 1% AEP: 140mm * ARF = areal rainfall of 130mm
- 0.1% AEP: 210mm * ARF = areal rainfall of 195mm

These rainfall depths were spread out over a duration of 13 days and applied as a grid to the JFLOW model, as discussed in the next section.

No losses were subtracted from the rainfall depths, because much of the rain would be falling on standing water in the already wet Fens, and so there would be little scope for infiltration.

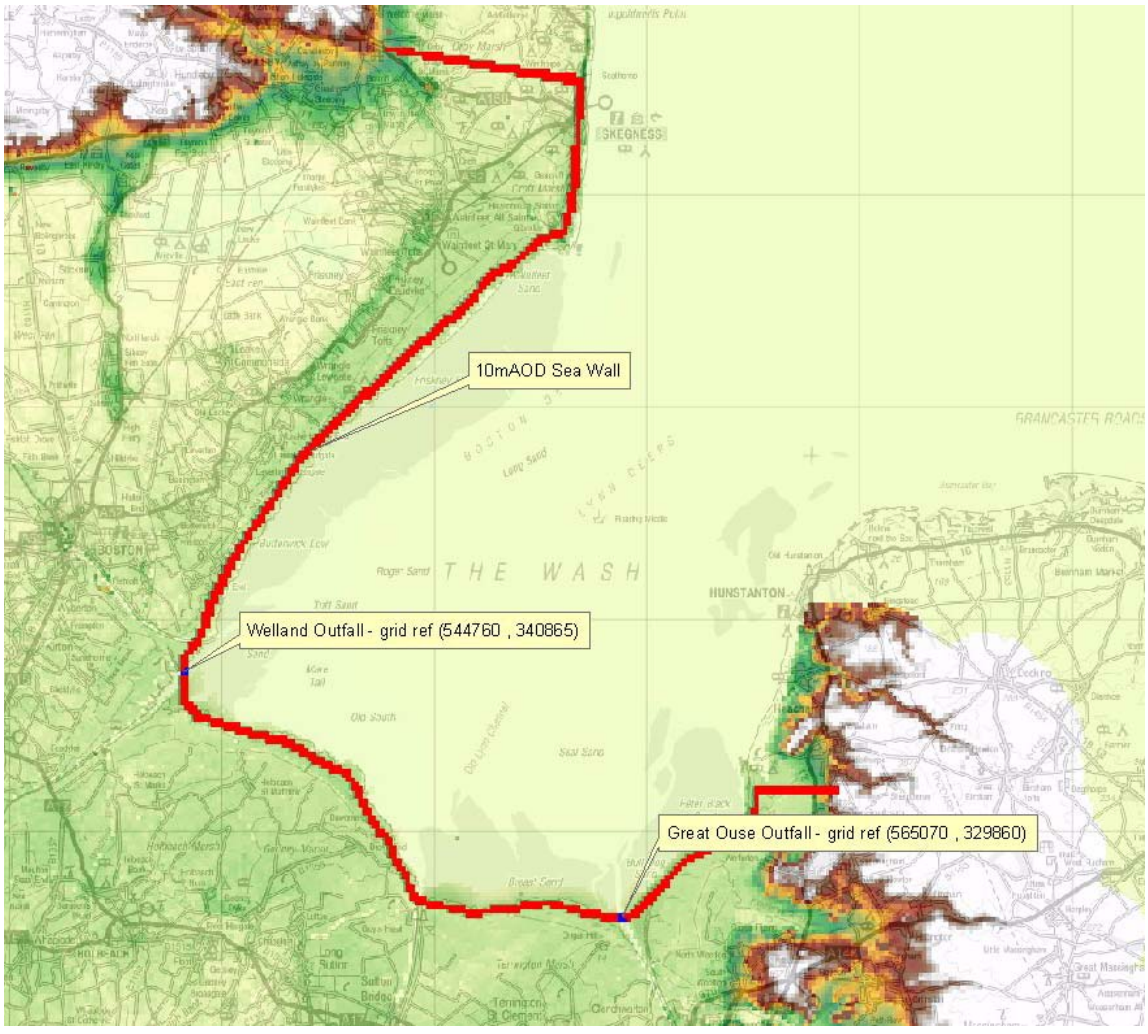
4 JFLOW MODELLING

4.1 Digital Terrain Model

The starting point of the model was the 5m NextMap SAR data, which was resized to 200m because of time and computational constraints. A sea wall 10m high was stamped into the DTM, which was punctured by two 200m wide openings, as shown in Figure 4.1. The project specification required there to be four 50m wide outfalls, however this was not possible to achieve with a 200m DTM. It was thought preferable to use two outfalls rather than one, even though this resulted in a total width greater than that required.

The two outfalls were situated at the mouths of the rivers Welland (which outfalls near the River Witham) and Great Ouse (which outfalls not far from the River Nene). They were set to long-term average tide levels of 0.55mAOD and 0.48mAOD respectively; see Figure 4.1. For the purposes of the JFLOW modelling, only SAR data was used. LiDAR data was provided but only used for the purposes of plotting the results.

Figure 4-1 Location of sea wall and outfalls



This map is reproduced from Ordnance Survey material with the permission of Ordnance Survey on behalf of the Controller of Her Majesty's Stationery Office. © Crown copyright. Unauthorised reproduction infringes Crown copyright and may lead to prosecution or civil proceedings. Environment Agency 100026380. 2007.

4.2 Modification of JFLOW

JFLOW is a topographically-driven flood routing model, a distributed processing version of which was used to produce the original Flood Map. The nature of this project required the stand alone desktop version of the software to be used and several modifications to the software had to be made.

The ability to re-start JFLOW with results from an earlier simulation was designed primarily for this project. The main reason behind this development was because of the need to start modelling the fluvial event upon an equilibrium level of 1.42mAOD. Previously, the fluvial JFLOW run would start with a 'dry' DTM, the volume of water to create the equilibrium level would have been added, followed by a lengthy period of processing to allow a steady water surface to develop, before the pluvial and fluvial events could be run. The recent development of JFLOW now enables a predefined water level to be applied to the DTM in an instant, thus cutting out what would have otherwise been several extra weeks of processing. Further development work for this project included making it possible to take results from one simulation and use them for the starting point of another simulation. This enabled the production of just one 0.1% and one 1% AEP rainfall event which could then be used to form the basis of the five fluvial model runs.

Due to the size and duration of the model runs, there was significant potential for the processing to be disturbed by hardware issues (for example, power cuts). It was deemed important to be able to re-start a simulation from a point before a problem was encountered. In short, the software was designed to write results out at a specified time interval, with each set of results superseding the previous set. Superseding existing results was necessary so as to avoid the Microsoft Access results database reaching the maximum size limit. In the event of a hardware problem, the simulation could be started from the last set of results rather than from the beginning of the simulation. Thus only a few hours worth of processing would be lost rather than several weeks' worth.

4.3 Rain Event Simulation

As described in Section 3.4, a 13-day rainfall event had to be simulated. It was necessary to simulate the rainfall in a separate run from the flow simulations, partly because of the need to use a coarser grid for rainfall, and also because that enabled the rain simulation to be carried out only once for each AEP, after which the five fluvial simulations could follow. This was inevitably an approximation: in reality there will be interactions between water derived from direct rainfall and that derived from fluvial inflows.

For the 1% AEP event, a volume of 32,500m^3 of rain was calculated to fall over an area measuring 500m by 500m in a 13 day period. The water was applied to the DTM via 27,000 inflow points, placed every 500m at a rate of 104.17 m^3/hour for 13 days. The respective values for the 0.1% AEP event are 48,750m^3 of rainfall per 500m^2, applied at a rate of 156.25 m^3/hour. The initial wetted level of 1.42mAOD was used as the starting condition for the rainfall event. The rainfall event lasted for a duration of 312 hours, yet the JFLOW simulation was allowed to run for a further 900 hours to ensure that the rain water had completed its migration from point of input to the areas where water would pond. This could be measured by monitoring the number of wet cells and wet cell activity. The product of this stage was a JFLOW results table, on top of which the fluvial simulations were run.

4.4 Five Fluvial Model Simulations

It was decided from discussions between the Environment Agency and JBA that there should be five separate simulations run for the Fenland basin, one for each of the major rivers (i.e. excluding the River Glen). There were six inflow points located towards the periphery of the study area on the rivers Nene, Welland, Glen, Witham, Bedford Ouse and Ely Ouse. Each simulation had the estimated 1% or 0.1% AEP event running down one river and a scaled down hydrograph on the other five rivers, see Section 3 for details on the hydrographs. The flood hydrographs had a duration of 256 hours and the simulations were allowed to run for a further 1000 hours, to ensure that the model had stabilised and flat water surface levels had developed. The product of Section 4.3 was used as the starting point for the fluvial flood simulations. As described in Section 4.2, this

was made possible because of a JFLOW re-start function that had been developed for this project. In total ten model runs were processed, five for each AEP.

5 MODEL RESULTS

5.1 Deriving Flood Outlines

To obtain the required deliverables the 200m JFLOW results were mapped on to 5m LiDAR and SAR data. As discussed in Section 4.1, the DTM had to be resized to a 200m resolution for computational reasons. If modelling a smaller area it would have been possible to simply supply JFLOW with a 5m DTM and let it use its internal functionality to re-size the DTM to a coarser resolution, doing this would have enabled results to be written out at the original DTM resolution. However, this approach was not possible for two reasons: Firstly the internal cell size multiplier is only suitable for DTM simplification factors in the order of 2 to 6, whereas this project required a simplification factor of 40; Secondly, if results were written out at 5m the database would far exceed the maximum size that a Microsoft Access database can become. Due to these limitations, an alternative method of producing depth grids and extent polygons had to be implemented.

Two outlines were required, one for the 1% AEP and one for the 0.1% AEP event. However, each AEP event was simulated using five different scenarios, a composite maximum of the five therefore had to be calculated. All pre-processing of the JFLOW results were carried out using ESRI's ArcMap GIS package. The methodology for the 1% and 0.1% outline was identical, but for purposes of describing the applied methodology this section will only refer to the 0.1% AEP outline. The following paragraphs describe how water surface level data at a 200m resolution was used to produce depth data at a 5m resolution.

The raw JFLOW results comprised of points attributed with Depth, Water Surface Level, Velocity and Velocity direction, each located in the centre of each 200m DTM grid cell. Using ArcMap functionality a Water Surface Level grid dataset was produced for each of the 5 scenarios. As the project required a maximum extent, the five Water Surface Level grids were merged together to produce a Water Surface Level grid which represented the maximum water level value and the maximum extent. The maximum Water Surface Level grid was then converted back to a point data set.

A single point data set of Water Surface Level for all the scenarios now existed, but this was too extensive. Large areas of the Wash were covered and because of the wholesale application of rainfall across the DTM, flooding had occurred in regions outside the Study Area. Furthermore, residual rainfall flooding was still present on the slopes around the Fenland Basin. This residual rainfall is a function of the way in which JFLOW works, it always leaves a volume of $0.01m^3$ in each grid cell that was wetted. Rainfall also collected, on some of the slopes surrounding the Fenland Basin, because the DTM simplification had blocked off some the normal drainage paths. Results on the bounding Fenland slopes and in the Wash were removed, so that their respective high and low Water Surface Level values would not skew the results. Therefore, result points which had Water Surface Levels of less than 1.59mAOD and greater than 3.009mAOD were selected and removed.

The selected Water Surface Level points were converted back to a Water Surface Level grid dataset and displayed so that areas of uniform Water Surface Level could be identified. Twelve such areas of uniform Water Surface Level were identified, these regions were bounded by elevated topography in the DTM. A shapefile was produced which comprised of one polygon for each of the twelve regions. The joins between adjacent polygons were seamless to ensure that the resultant depth grid would not have gaps in it. The Water Surface Level points which fell within each polygon were selected and exported to Microsoft Excel. Within Excel, the mode Water Surface Value for each polygon was calculated. Mode was preferred over mean, as the mean values were higher for each polygon because they were affected by the Water Surface Levels from points located round the edge of each topographically defined region. What was actually desired however, was the flat Water Surface level that had developed, within JFLOW, at the centre of each region. This value was the mode value.

The twelve polygons were then attributed with the calculated modal values and fed into a routine to produce a single 5m depth grid for the entire Fenland Basin. The process involved the use of Python Scripting language within ArcMap. The routine enabled the required string of Spatial Analyst commands to be automated and to run on each of the twelve polygons in the shapefile. The basis of the method was to take each polygon and make a Water Level Grid with an extent of the whole polygon and a Water Surface Level value of the calculated mode. This uniform Water Surface Level grid then had the underlying (5m) DTM subtracted from it. The underlying DTM at this stage contained all the LiDAR that was supplied by the Agency. The subtraction calculation produced positive values (where the DTM was lower than the Water Surface Level) and negative values (where the DTM was higher than the Water Surface Level). Only the positive values were selected and transferred to the next stage of processing. Once twelve depth grids were produced they were joined together to form a complete grid for the entire basin. Therefore, any area with a DTM value lower than the calculated modal Water Surface Level will have had flooding generated for it.

The next stage of the process was to make the extent polygon. The depth grid was converted to a polygon and all internal polygon boundaries were dissolved. So that the outlines conform with Flood Map standards, all flooding polygons with areas of less than 750m^2 had to be removed from the outline and all internal dry islands with areas less than 750m^2 were filled in. When this process was completed, the outline still contained many areas of isolated flooding, because they had areas greater than 750m^2.

5.2 Discussion of Outlines

The 1% and 0.1% AEP outlines are very similar to each other in most places. This can be explained by the topography of the Fens, which are almost flat with a distinct edge where the ground rises by 20m within a distance as little as 2km (Figure 1-1). The only location where there is a significant increase in the 0.1% AEP outline is around Boston.

Both outlines show extensive flooding covering most of the study area apart from a 10-12km wide coastal fringe between Spalding and King's Lynn.

Figure 5-1 compares the new 1% AEP outline with the existing fluvial Flood Zone 3 (only showing the results of JFLOW runs, not including any alterations made from historic outlines or detailed modelling studies). In general there is more flooding shown than on the existing flood map, particularly away from the main rivers, along which the existing flood zones are concentrated. There are large areas of additional flooding to the south-east and north-east of Peterborough and the south-west and north of Boston.

The main decreases in the flood outlines are around Spalding and in the area north of Wisbech. Although these areas are close to major rivers (the Welland and the Nene, respectively), they generally contain higher ground, above 3mAOD. In the absence of pumping these areas are less likely to flood than the lower-lying areas further inland or away from the rivers.

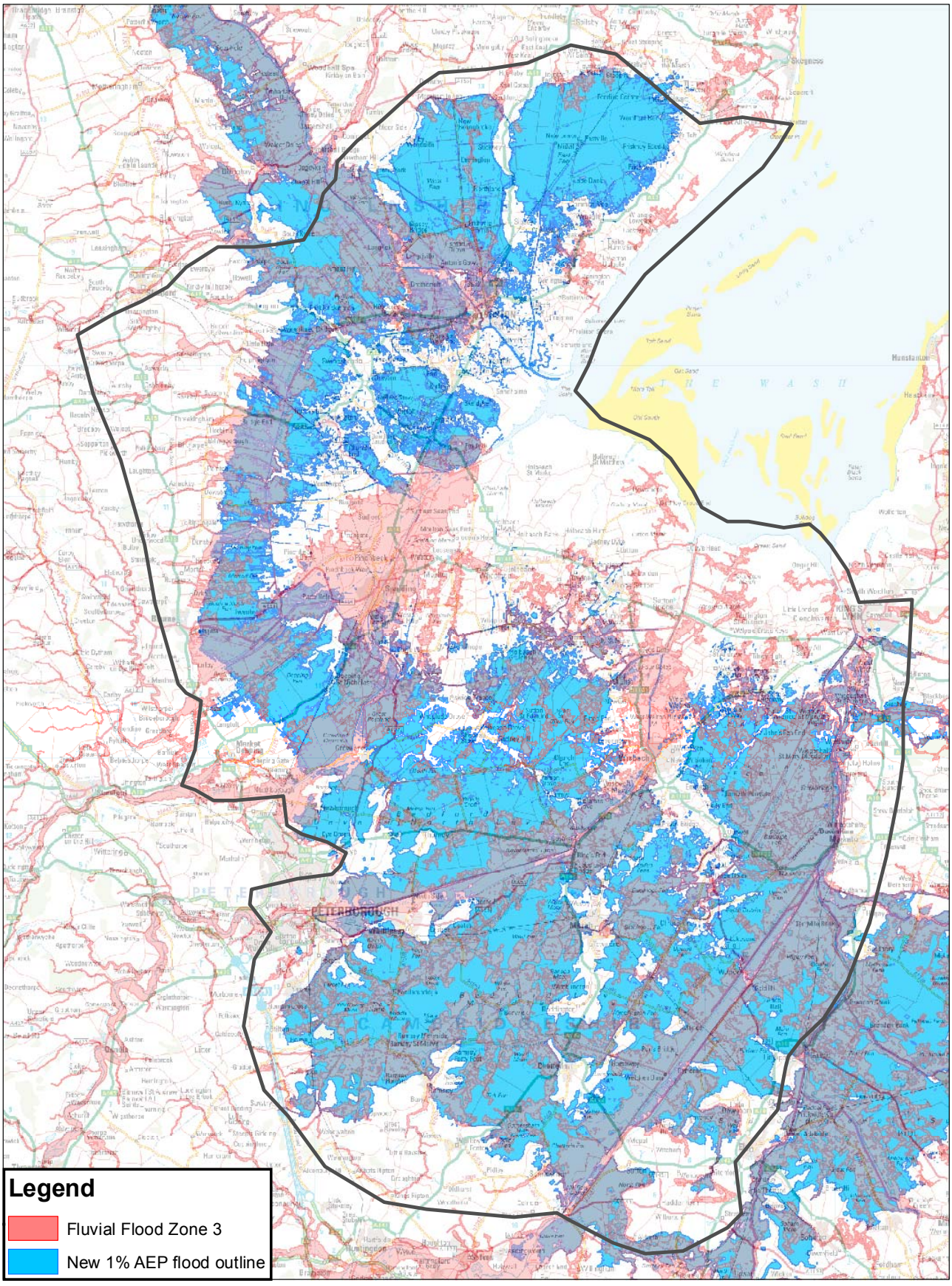
These differences occur because the existing flood map does not truly represent a "no defences" scenario on the Fens.

5.3 Results Provided to the Environment Agency

The following datasets have been provided digitally:

- Extent of wet area from equilibrium model run.
- Flood outlines (as polygons) for 1% and 0.1% AEP events, with dry islands (less than 750m^2) removed.
- Grids of depth from which the outlines were derived.
- Results of JFLOW runs as grids (200m cell size) giving flood level, depth and velocity at the maximum level.

Figure 5-1: Comparison of new 1% AEP flood outline with existing Flood Zone 3



Digital map data © Bartholemew

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This project has developed and implemented a technique for mapping the extent of the "natural" fluvial floodplain in an area heavily influenced by artificial drainage. The resulting flood outlines are based on a scientific assessment tailored to the specific characteristics of Fenland, and they comply with the Environment Agency policy of ignoring the effects of flood defences. As a result, however, they represent a totally hypothetical situation. One of their benefits is to highlight the importance of the land drainage and flood defence infrastructure and the high degree of risk should the defences fail or be removed.

6.2 Implications for Other Studies

6.2.1 Flood zones for rivers flowing into the Fens

It will be necessary to merge the revised flood zones with the existing flood zones for rivers that flow into the study area. There are also some low-lying areas outside the study area which have been included in the revised flood zones, particularly in the Witham catchment, north towards Lincoln, and the Ely Ouse catchment east towards Lakenheath.

At the locations where the Rivers Witham, Nene, Bedford Ouse and Ely Ouse enter the study area, the revised flood zones are similar to the current ones, and so it should be fairly straightforward to merge them. The outlines are rather less consistent on the River Welland, where more effort will be needed to achieve a smooth transition while maintaining consistency.

The study area defined in the Outline Brief includes some higher ground, particularly along the western edge between Market Deeping and Sleaford. This is drained by rivers such as the Welland, Car Dyke, Pointon Lode etc. whose floodplains are included in the current Flood Zones. These portions of the Flood Zones should be retained as they have not been replaced with anything in the present study. As a general guide, it is suggested that all existing Flood Zones on land around the edges of the study area higher than approximately 2.5mAOD should be retained, while those on lower-lying ground should be replaced with the results of this project.

6.2.2 Areas benefiting from defences

Much of the area identified as floodplain in this study is likely to be defended to a standard sufficient to be classed as an area benefiting from defences (ABD). In order to focus flood management measures on the areas where there is a residual risk of flooding even when all the defences work as intended (as they usually do), it will be important to identify the extent of ABDs within the new flood outlines.

Recent work has been carried out[7] to define ABDs for tidal areas of North Norfolk and fluvial flood zones between the River Great Ouse and the River Nene. The study included an assessment of the storage capacity of the internal drainage systems and determined that the storage capacity of these systems was more than sufficient to contain a 1% AEP rainfall event. Flood Zone 3 in this area was therefore 'tidied up' by removing the flood risk polygons associated with all IDB channels. This present study has treated the Fens in an undrained state and thus ignored any storage available in IDB drains.

It will be necessary to revise the findings of the fluvial parts of the ABD study in the light of the new results. In general, any areas that were identified as benefiting from defences and remain in the flood zones after the modifications described in this report are likely to remain as ABDs. However,

[7] JBA Consulting (2006) Norfolk Tidal Areas Benefiting from Defence. Main Assessment Report. Environment Agency Anglian Region, Central Area.

some work will be needed to assess whether new portions of the flood zones identified in this study can be classed as ABDs.

6.2.3 Flood warning improvements

It will be necessary to revise flood warning procedures to be compatible with the new flood zones. A flood warning improvement project is currently under way in the Ely Ouse catchment[8]. So far it has covered the upper catchment (River Lark and Little Ouse), which is outside of the extent of the present study. The next stage will cover the lower catchment of the Ely Ouse, which extends into the extent of the present study. The new flood outlines developed in the present project, which cover a slightly larger area than the current Flood Zones, should be used for defining flood risk areas on the Ely Ouse.

6.2.4 Flood zone improvements in other locations

There is no other artificially drained area of England and Wales nearly as extensive as Fenland. However, when improving the Flood Map for other low-lying drained areas it may be worth considering an approach similar to that derived for this study, to ensure consistency between Environment Agency Areas.

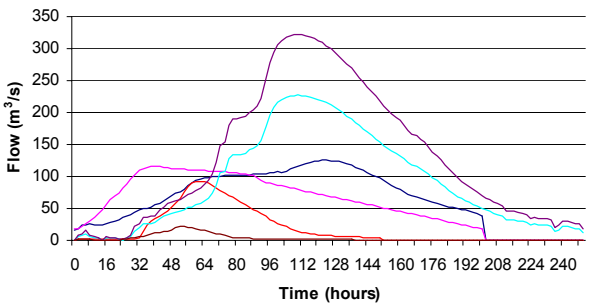
[8] Environment Agency Anglian Region, Central Area. Fenland and Ely Ouse Flood Warning Improvements. Consultant: JBA Consulting

Appendix A: - Inflow Hydrographs

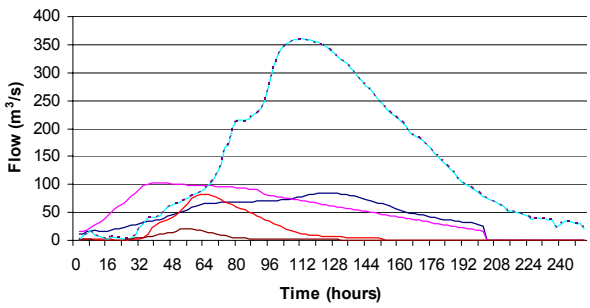
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A.1 INFLOW HYDROGRAPHS

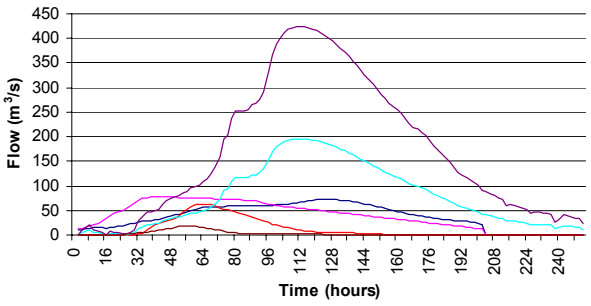
A.1.1 1% Probability Event



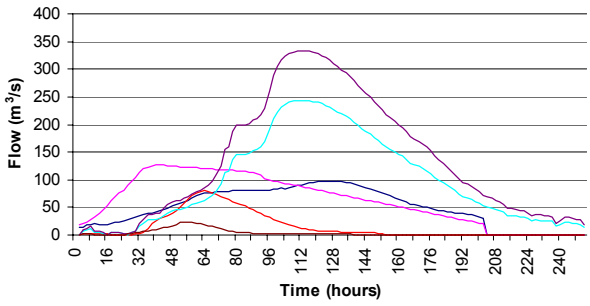
Nene Model



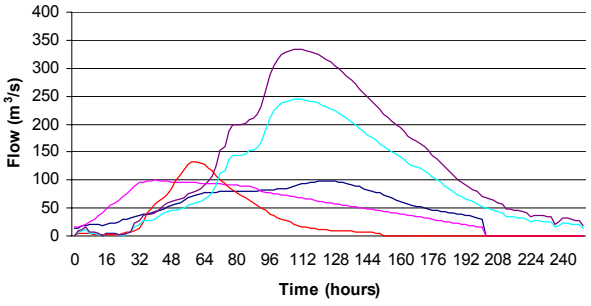
Bedford Ouse Model



Ely Ouse Model



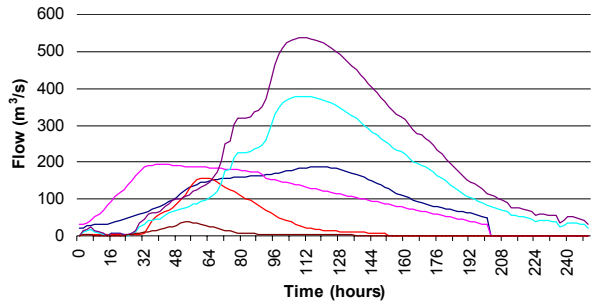
Witham Model



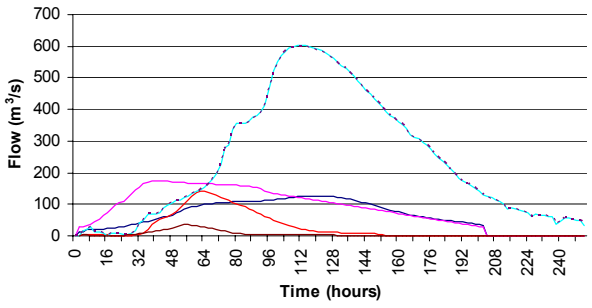
Welland Model



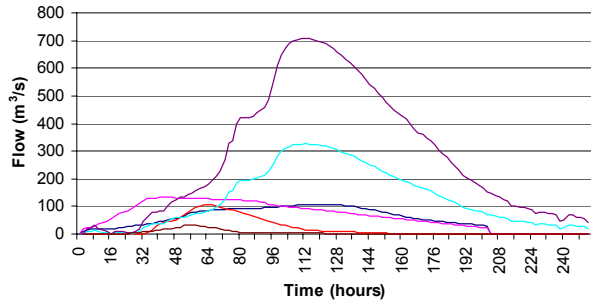
A.1.2 0.1% Probability Event



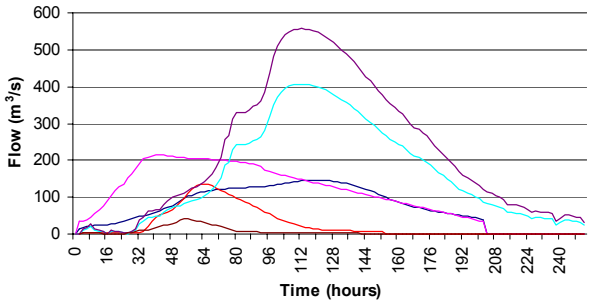
Nene Model



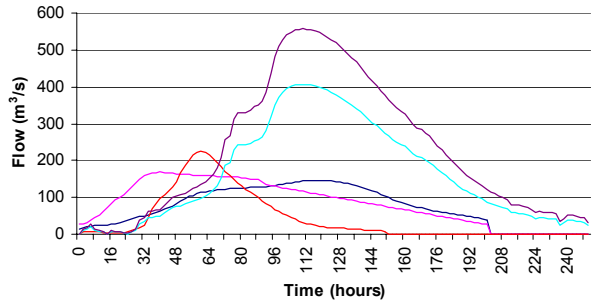
Bedford Ouse Model



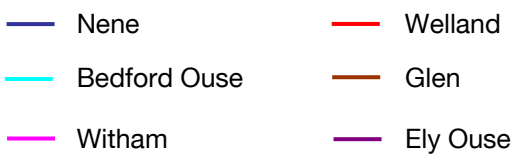
Ely Ouse Model



Witham Model



Welland Model



Appendix E

MasterDrain
HY 8.66

A E Designs Ltd.

Consulting Civil Engineers
20 Short Rd, Stretham, Ely, CB6 3LS
Tel: 01353 649002

e-mail: ae-design@timetalk.co.uk

Job No. 1295			
Sheet no. 1			
Date 26/07/13			
Project Decoy Farm, Crowland	By AR	Checked	Reviewed
Title Hydrological data for Crowland			

Data:-

FSR values

Location	= Crowland	Grid reference	= TF2512
M5-60 (mm)	= 19.0	SAAR (mm/yr)	= 550
r	= 0.40	Soil	= 0.30
Long reference	= 525312	Area	= England and Wales
Hydrological area	= 5	Hydrological zone	= 1

Soil classification for WRAP type 2
i) Very permeable soils with shallow ground water;
ii) Permeable soils over rock or fragipan, commonly on slopes in western Britain associated with smaller areas of less permeable wet soils; (fragipan - a natural subsurface horizon having a higher bulk density than the solum above. Seemingly cemented when dry but showing moderate to weak brittleness when moist. The layer is low in organic matter, mottled and slowly or very slowly permeable to water. It is found in profiles of either cultivated or virgin soils but not in calcareous material).
iii) Moderately permeable soils, some with slowly permeable subsoils.

FEH values

No FEH data available in this file.

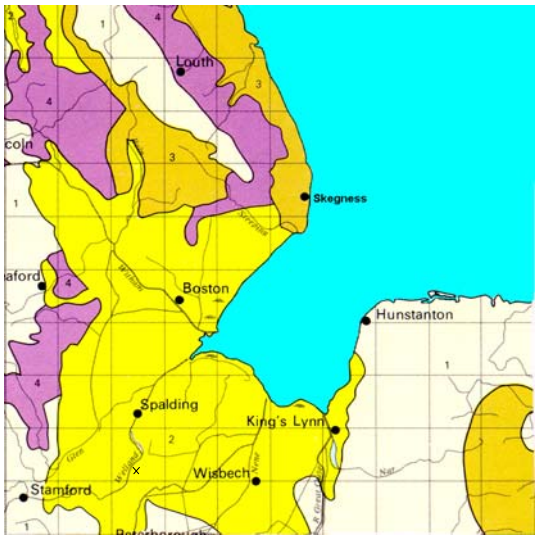
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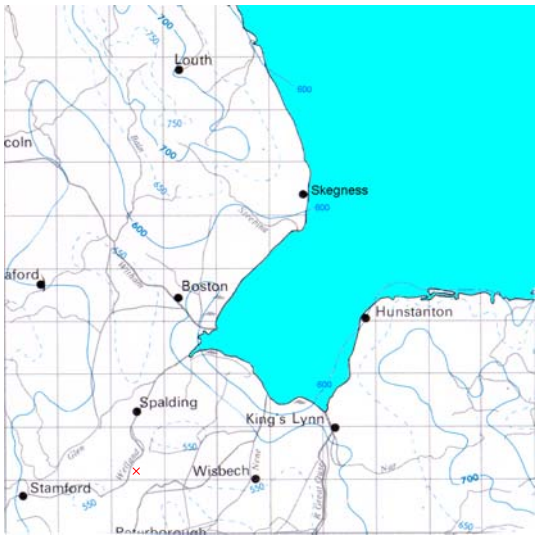
Job No. 1295			
Sheet no. 2			
Date 26/07/13			
Project Decoy Farm, Crowland	By AR	Checked	Reviewed
Title Hydrological data for Crowland			



<- Soil

M5-60 ->





<- SAAR

r x 100 ->



Appendix F

MasterDrain SW 12.83	**A E Designs Ltd.**	Consulting Civil Engineers 20 Short Rd, Stretham, Ely, CB6 3LS Tel: 01353 649002 e-mail: ae-design@timetalk.co.uk	Job No. 1310 Sheet no. 1 Date 16/10/13		
	Project Decoy Farm		By AR	Checked	Reviewed
	Title Swale design calcs for Crowland				

Hydrological data:-

FSR Hydrology:-

Location	= Crowland	Grid reference	= TF2312
M5-60 (mm)	= 19	r	= 0.40
Soil index	= 0.30	SAAR (mm/yr)	= 550
WRAP	= 2	Area	= England and Wales
Return period	= 100	WRAP	= 2
Storm duration	= 20 hrs.		

Soil classification for WRAP type 2

i) Very permeable soils with shallow ground water;

ii) Permeable soils over rock or fragipan, commonly on slopes in western Britain associated with smaller areas of less permeable wet soils;

iii) Moderately permeable soils, some with slowly permeable subsoils.

Design data:-

Area drained	= 9 m²	% Impervious area	= 100 %
Swale gradient	= 0 %	Initial width	= 2.0 m
Swale length	= 1.00 m	Swale depth	= 0.300 m
Side slope	= 1 in 3	Infiltration coeff	= 0.050 m/hr

Target Manning's constant = 0.25

Calculation method:-

The program performs a series of iterations calculating the value of Manning's constant. By reducing or increasing the base width or flow depth, the calculated value can approach the target value within fine limits.
This gives a revised base width within the range 1 to 3 metres, or a depth not exceeding 100mm. Depths in excess of 100mm indicate that the swale is serving too great an area, and the initial design needs to be re-evaluated.
The flow velocity is calculated using a similar equation.

Manning's equation:-

$$n = A \cdot HMD^{0.666} \cdot S^{0.5} / Q$$

where:-

n = Manning's constant
A = Cross-sectional area of flow
HMD = Hydraulic mean depth
S = gradient
Q = volume of flow

Results:-

Revised base width	= 1.60 m	Depth of flow	= 5 mm
Rainfall intensity	= 3.8 mm/hr	Calculated runoff	= 0.01 l/s
Flow velocity	= 0.001 m/s	Total rainfall	= 0.69 m³
Infiltration volume	= 1.68 m³ in 20 hrs.	Swale empty within 24 hrs.	
Land take	= 2 m²	Land take	= 17.9 %

Calculated Manning's const = 0.252

General Data:-

Manning's roughness coefficient (n) for overland sheet flow

Smooth asphalt	0.011
Smooth concrete	0.012
Ordinary concrete lining	0.013
Good wood	0.014
Brick with cement mortar	0.014
Vitrified clay	0.015
Cast iron	0.015
Corrugated metal pipe	0.024
Cement rubble surface	0.024
Fallow soil	0.050
Cultivated soils	
Residue cover <= 20%	0.06
Residue cover > 20%	0.17
Natural grasslands	0.13
Grass	
Short grass	0.15
Dense grass	0.24
'Bermuda' grass	0.41
Woods *	
Light underbrush	0.40
Dense underbrush	0.80

* When selecting n, consider cover to a height of about 30mm.
Note also that n will vary with the degree of submergence.

Reproduced from Urban Drainage Design Manual produced by the U.S. Department of Transportation; Chapter 3: Urban Hydrology Procedures (3-9)

Appendix G

MasterDrain SW

A E Designs Ltd.	Consulting Civil Engineers 20 Short Rd, Stretham, Ely, CB6 3LS Tel: 01353 649002 e-mail: ae-design@timetalk.co.uk	Job No. 1310		
		Sheet no. 0		
		Date 15/10/13		
Project Decoy Farm		By AR	Checked	Reviewed
Title Peak flow storage calcs for Crowland				

Data:-

FSR Hydrology:-

Location = Crowland
M5-60 (mm) = 19
Soil index = 0.30
Return period = 100
UCWI = 51.4

Grid reference = TF2612
r = 0.42
SAAR (mm/yr) = 550
WRAP = 2

i) Very permeable soils with shallow ground water;
ii) Permeable soils over rock or fragipan, commonly on slopes in western Britain associated with smaller areas of less permeable wet soils; (fragipan - a natural subsurface horizon having a higher bulk density than the solum above. Seemingly cemented when dry but showing moderate to weak brittleness when moist. The layer is low in organic matter, mottled and slowly or very slowly permeable to water. It is found in profiles of either cultivated or virgin soils but not in calcareous material).
iii) Moderately permeable soils, some with slowly permeable subsoils.

Runoff factor (RF) = 74.0, calculated from:-

Runoff factor = (0.829*PIMP)+(25*SOIL)+(0.078*UCWI)-20.7
where
PIMP = Impervious Area*100/(Impervious Area+Pervious Area)
UCWI = Calculated value for Wetness Index

Design data:-

Imperv. area = 81090 m²
Total area (TA) = 81090 m²
Discharge to drain = 11.353 l/s
Additional flow = 0.00 l/s

Pervious area = 0 m²
Equiv area = 60007 m² (TA x RF).
Areal reduction factor = 0.915
Climate change factor = 20

Calculated data:-

Time to max = 1300.0 mins
Rainfall at max = 3.98 mm/hr
Pipeline storage = 0.0 m³
Offline storage = 0.0 m³

Storage volume = 4285.0 m³
Discharge rate per Ha = 1.40 l/s/Ha
Available MH storage = 0.0 m³

Rainfall intensities calculated using the Wallingford Procedure

Storage lengths for initial calculation (x 1.1, 1.2, 1.3 or 1.5 as above if required) :-

Diam	Len	Diam	Len
100	545687.6	1125	4311.6
150	242527.8	1200	3789.5
225	107790.2	1275	3356.8
300	60632.0	1350	2994.2
375	38804.5	1425	2687.3
450	26947.5	1500	2425.3
525	19798.2	1575	2199.8
600	15158.0	1650	2004.4
675	11976.7	1725	1833.9
750	9701.1	1800	1684.2
825	8017.4	1875	1552.2
900	6736.9	1950	1435.1
975	5740.3	2025	1330.7
1050	4949.5	2100	1237.4

Ovoid	Len
400 x 600	23805.6
600 x 900	10365.3
800 x 1200	5829.6

Box culvert	Len
500 x 500	17140.0
500 x 750	11426.7
500 x 1000	8570.0
750 x 1000	5713.3
750 x 1200	4761.1
750 x 1500	3808.9
1000 x 1000	4285.0
1000 x 1200	3570.8
1000 x 1500	2856.7
1000 x 1800	2380.6
1000 x 2000	2142.5
1500 x 1500	1904.4
1500 x 1800	1587.0
1500 x 2000	1428.3

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e-mail: ae-design@timetalk.co.uk

Job No. 1310
Sheet no. 1
Date 15/10/13

MasterDrain SW

Project Decoy Farm

Title Peak flow storage calcs for Crowland

By AR | Checked | Reviewed

Data:-

Time (mins)	Rain mm/hr	Inflow (m3)	Outflow (m3)	Balance (m3)
100	31.0	3114.710	68.118	3046.592
200	18.0	3652.618	136.236	3516.382
300	13.0	3960.656	204.354	3756.302
400	10.0	4177.292	272.472	3904.820
500	9.0	4356.986	340.590	4016.396
600	8.0	4506.755	408.708	4098.047
700	7.0	4635.443	476.826	4158.617
800	6.0	4748.426	544.944	4203.482
900	5.0	4849.227	613.062	4236.165
1000	5.0	4940.285	681.180	4259.104
1100	5.0	5023.362	749.298	4274.064
1200	4.0	5099.780	817.416	4282.364
1300	4.0	5170.546	885.534	4285.012
1400	4.0	5236.456	953.652	4282.804
1500	4.0	5298.146	1021.770	4276.376
1600	3.0	5356.130	1089.888	4266.242
1700	3.0	5410.835	1158.006	4252.829
1800	3.0	5462.617	1226.124	4236.493
1900	3.0	5511.776	1294.242	4217.534
2000	3.0	5558.566	1362.360	4196.206
2100	3.0	5603.207	1430.478	4172.729
2200	3.0	5645.888	1498.596	4147.292
2300	2.0	5686.776	1566.714	4120.062
2400	2.0	5726.014	1634.832	4091.182
2500	2.0	5763.732	1702.950	4060.782
2600	2.0	5800.042	1771.068	4028.974
2700	2.0	5835.046	1839.186	3995.860
2800	2.0	5868.833	1907.304	3961.529
2900	2.0	5901.485	1975.422	3926.063
3000	2.0	5933.076	2043.540	3889.536
3100	2.0	5963.670	2111.658	3852.012
3200	2.0	5993.331	2179.776	3813.555
3300	2.0	6022.110	2247.894	3774.216
3400	2.0	6050.060	2316.012	3734.048
3500	2.0	6077.225	2384.130	3693.095
3600	2.0	6103.648	2452.248	3651.400
3700	2.0	6129.367	2520.366	3609.001
3800	2.0	6154.419	2588.484	3565.936
3900	2.0	6178.837	2656.602	3522.235
4000	2.0	6202.651	2724.720	3477.931
4100	2.0	6225.890	2792.838	3433.052
4200	1.0	6248.581	2860.956	3387.625
4300	1.0	6270.747	2929.074	3341.673
4400	1.0	6292.412	2997.192	3295.220
4500	1.0	6313.599	3065.310	3248.289
4600	1.0	6334.325	3133.428	3200.897
4700	1.0	6354.611	3201.546	3153.065
4800	1.0	6374.477	3269.664	3104.813
4900	1.0	6393.936	3337.782	3056.154
5000	1.0	6413.003	3405.900	3007.104
5100	1.0	6431.697	3474.018	2957.679
5200	1.0	6450.029	3542.136	2907.893
5300	1.0	6468.012	3610.254	2857.758
5400	1.0	6485.662	3678.372	2807.290
5500	1.0	6502.987	3746.490	2756.497
5600	1.0	6520.000	3814.608	2705.392
5700	1.0	6536.711	3882.726	2653.986
5800	1.0	6553.130	3950.844	2602.286
5900	1.0	6569.268	4018.962	2550.306
6000	1.0	6585.131	4087.080	2498.052

Storage volume (m^3) = 4285.0 m^3

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Job No.	1310
Sheet no.	2
Date	15/10/13

MasterDrain SW

Project	Decoy Farm	By	Checked / Reviewed
Title	Peak flow storage calcs for Crowland	AR	

