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Investigation of *Fli-map* system for Flood Defence asset monitoring

Report for O&M Concerted Action

R&D Technical Report W5A-059/1/TR

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Department for Environment
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Investigation of “Fli-map” System for Flood Defence Asset Monitoring

R&D Technical Report W5A-059/1/TR

Research Contractor: Tim Burgess, Posford Haskoning Ltd

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Environment Agency, Rio House, Waterside Drive, Aztec West, Almondsbury, Bristol BS32 4UD Tel: 01454-624400 Fax: 01454-624409

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Statement of Use
This report provides an assessment of the capability of the Fli-map system of airborne laser-scanning for the inspection of flood defences. It was produced under the R&D Concerted Action on O&M. It is available for general information to Flood Defence practitioners, but is not intended as an operational or management guide.

Keywords
Asset survey, asset inspection, condition assessment, data capture, digital terrain modelling, laser scanning, LiDAR, remote sensing, topographic survey, flood defence, coastal defence

Research Contractor
This report was produced under R&D Project W5A-059 by: Posford Haskoning, Rightwell House, Bretton Centre, Peterborough, PE3 8DW. Author: Tim Burgess Tel: 01733-334455 Fax: 01733-333369

Defra / Environment Agency Project Manager
The Environment Agency's Project Manager for Project W5A-059 was:
Dr Mervyn Bramley, Flood Defence Development Manager

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1 INTRODUCTION

Posford Haskoning were approached by the Environment Agency (the Agency), as part of their involvement in the Concerted Action on Operation and Maintenance (O&M) of Flood and Coastal Defences, to consider whether Fli-map would be a suitable tool for use in flood defence O&M. Fli-map is a proprietary remote sensing system operated in the UK by the survey firm OiS.

The Agency had already commissioned a series of trials of the system. This study was to look at the data from these trials and evaluate both the quality of the data (by comparison with other surveys) and the potential feasibility of using the system within the Agency as an asset inspection tool.

This report covers the results of the study. Section 2 covers a brief description of the system, based on our observations and understanding. Section 3 covers the evaluation of the system in the light of the O&M framework. Section 4 covers the extent of the trials and the data supplied to Posford Haskoning as part of this study. Section 5 describes the qualitative analysis of the system against other survey techniques. Section 6 draws together conclusions from the study.

2 DESCRIPTION OF FLI-MAP

Fli-map is an air-borne remote sensing technique for surveying linear features and small areas. The system is based on a laser-scanner system linked to differential GPS and mounted in a helicopter. The system is currently operated in the UK by OiS plc Survey Division who are based in Stockton, Cleveland.

The principle of the system is as follows:

- The helicopter flies along the feature to be surveyed at low altitude (between 60 and 170m) and the scanning laser measures distances from the helicopter to the ground over a swath around 60-70m wide (for a flight at 60m elevation).
- At the same time the position of the helicopter is accurately fixed in space by the use of twin differential GPS receivers together with conventional aircraft inertia measurements.
- These measurements are combined to provide a high density of placed points on the ground, each defined in three dimensions, together with a measure of the intensity of the returned laser pulse.
- The measurements are made to the first reflective surface met, so the results are "top surface" or digital elevation rather than always giving values from the ground (digital terrain).
- During the flight, video is also captured simultaneously with the laser-scanner data. This data is both downward looking and forward looking so that it can be used for positioning the flight data, and for asset identification and condition assessment.

The data can be displayed in specialised software which will allow for the display of plans and elevation of the point cloud data, the display of the video, plus various data processing routines.

The data quantity has been described as around 12-16 points per m^2 with a vertical accuracy of around ±60mm.

3 EVALUATION OF TECHNIQUE FOR USE IN FLOOD DEFENCE OPERATIONS

3.1 Concepts

The Fli-map system is an innovative use of existing remote-sensing technology, that of airborne laser-scanning. Capturing data at low level from the relatively manoeuvrable platform of a helicopter gives flexibility as to where data can be collected, and the high rate of data capture ensures that all but the smallest features can be identified,

3.2 Products

The raw data product is a “point cloud” in National Grid co-ordinates (or other suitable co-ordinate system). This cloud on its own can be used to “visualise” data, but is not particularly easy to handle because of the very large number of points collected. However the data can be converted to a digital terrain model (DTM) by either the creation of a regular grid or by the creation of a triangulated irregular network (TIN), from which sections, contour plans or other displays can be created. The resolution of the DTM needs to be set, probably at around 0.5m, to allow sufficient detail to be displayed, but to maintain manageable file sizes.

3.3 Uses in Operational and Maintenance Activities

The Agency collects data on two major types of asset, defences and structures. Potentially, Fli-map has a primary use in collecting data on defences rather than structures because of its more remote surveying technique and its inability to look beneath objects.

Fli-map could be used for the following activities:

* Linear defence surveys, especially in undeveloped areas where access is difficult.
* Coastal defence and beach surveys.
* Revetment surveys – especially rock armour where access can be a problem for conventional techniques.
* Shallow cliff surveys – because of the sweeping nature of the laser-scanner the system has been shown to collect data on the front of properties flown past. This could be utilised for surveying small cliff faces, and by repositioning of the instrument it may be possible to look at higher cliffs.
* Post event surveys to identify problems on long lengths of defences (either fluvial or tidal), such as bank slips or erosion of the defence due to wave action or overflow.

* Repeat surveys to investigate changes in the defences over time – such as bank erosion, slippage etc.
* Use of video images for condition surveys.

Benefits of Fli-map over conventional techniques for data collection.

* Quick to carry out survey and quick to process captured data.
* Large lengths of asset can be surveyed in a short period.
* High level of detail captured.
* The ability to display photographic (video) and survey data simultaneously, enabling office based asset and defect identification.
* Can survey areas with difficult access, such as mud flats or remote defences.
* The data once captured is flexible in its display formats and can be re processed or enlarged to aid in asset maintenance activities.
* Savings in manpower relating to ground surveys and visual inspections of long lengths of defences.

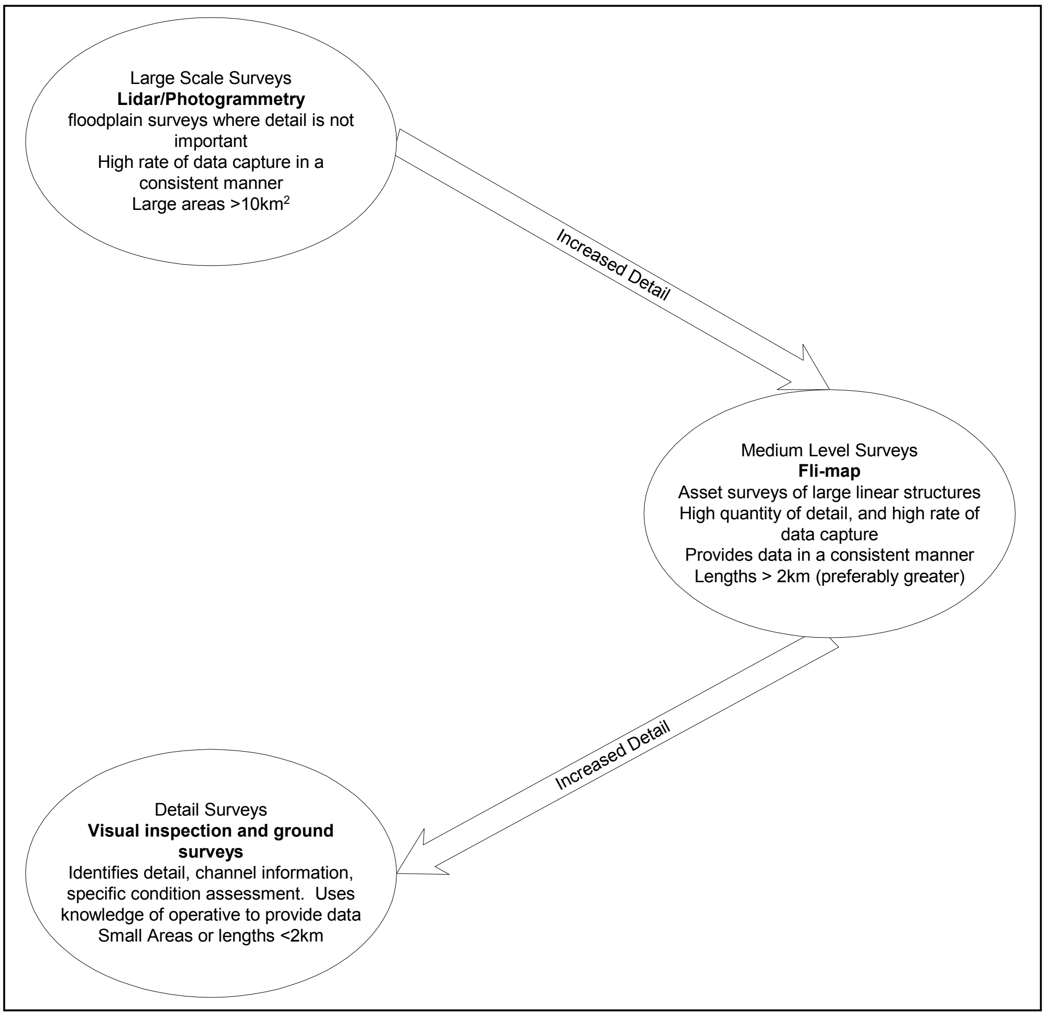
Disadvantages of Fli-map over other techniques (such as ground surveying)

* Cannot give ground levels under dense tree cover (although may give better penetration than Lidar because of higher point density and the ability to penetrate from the sides). It can also have problems returning ground levels in dense urban areas because of shadowing effects with the scanning laser.
* Cannot penetrate water and therefore cannot provide a continuous survey across a river or channel.
* Expensive to mobilise for short isolated lengths of survey.
* Collects only around 60-70m on each pass so may require several passes to survey larger assets. Wider swathes can be achieved with reduced point density (up to 200m)
* Not suitable for collecting detailed data on structures other than positional information as detailed asset surveys of structures need more than just top surface position and level.

It is envisaged that its most effective use will be in the collection of medium quality topographic data on linear defences (such as embankments). This will enable the majority of asset inspections to be made in the office and to target site inspections to areas where there is a need for knowledgeable officers to visit the site.

The technique is seen as fitting within the Agency's current asset survey techniques. Figure 3.1 shows in diagrammatic form how Fli-map would fit within the current framework.

Figure 3.1 – Asset Survey Hierarchy



4 ENVIRONMENT AGENCY EVALUATION SURVEY

4.1 Concept

The Agency has been considering the use of Fli-map for Operational activities for a while and took a decision to practically evaluate the system on real flood defences. The sites to be surveyed were selected within the North East Region of the Agency and in general for areas that had previously been surveyed by other techniques. The sites were also selected for their variation in type of defence and also for a business need to improve data in some of the locations.

4.2 Sites Surveyed

The following sites were selected for surveying using the Fli-map system:

Lower River Aire Washlands
Rawcliffe Village
Gowdall Village
Woodhouse Mill Washland
Meadowgate Washland – River Rother
Ulrome Sands – North of Spear Point
River Ouse – Swinefleet
Humber at South Ferriby
Barton Haven – Off Humber

A map showing the Fli-map survey together with the above site names is given as Figure 4.1.

The sites were flown in May/June 2001 and preliminary results were presented to the Agency and Posford Haskoning at a meeting on the 28th June 2001. Final results as xyz files were sent to Posford Haskoning from mid July to mid August 2001.

5 COMPARISONS WITH OTHER SURVEYS

5.1 Other Surveys Available

The following surveys were supplied by the Agency for use in comparing Fli-map's accuracy.

- Lidar surveys for:
  - * Rawcliffe to Beal – Polygon P1828
  - * Swinefleet – Polygon P1660
  - * Barton upon Humber – Polygon P1661
- Conventional Surveys data for Gowdall – Survey Phases 1 to 3

The Lidar data was supplied in standard Agency format (i.e. in 2km * 2km tiles in unfiltered and filtered formats together with the filter mask). Vertical accuracy of Lidar has been established in the past to be ±250mm.

The conventional survey data was supplied as xyz ASCII text files. Conventional survey data was taken as the baseline.

5.2 Gowdall Comparisons

Two sites were selected within the area covered by the Gowdall conventional survey for comparison with the Fli-map and Lidar surveys. Because of the large size of the Fli-map data files, only small areas were compared.

5.2.1 First Site

The first site considered was centred around SE60812371 and was an irregular shape approximately 115m by 100m in size. Survey data was available for 122 points within the area. Lidar covered the whole area giving around 2500 points from the 2m * 2m grid, whilst Fli-map covered the majority of the area with around 156,000 points.

The Fli-map data was converted to a TIN using ArcView's 3D Analyst function and then converted to a grid at 0.1m intervals. Data from this surface was then extracted at each of the conventional survey points. A similar process was carried out for the Lidar grid. Appendix A gives the results for the 122 conventional survey points, including comparisons for each point and statistical analysis of the results. The results are summarised in Table 5.1 below.

Table 5.1 – Statistical Results from Site 1

	Lidar - Survey	**Flimap – Survey**
Average Difference	-80mm	+130mm
Standard Deviation	±170mm	±80mm

5.2.2 Second Site

The second site was centred around SE62252254 and was an irregular shape approximately 80m by 50m in size. Survey data was available for 36 points within the area. Lidar covered the whole area giving around 700 points from the 2m * 2m grid, whilst Fli-map covered the area with around 55,000 points. These points were derived from more than one file of Fli-map data that had been flown in different directions. The data was all collected in the same flight.

The data was processed in the same way as for site one, and the detailed results are presented in Appendix A. The site results are summarised in Table 5.2.

Table 5.2 – Statistical Results from Site 2

	Lidar - Survey	Fli-map – Survey
Average Difference	+170mm	+190mm
Standard Deviation	±310mm	±140mm

5.3 Barton on Humber Comparison

A further comparison was undertaken for an area within the data collected for Barton on Humber. In this location a series of parallel Fli-map runs were undertaken to survey an area wider than the 60-70m achievable with one pass.

An area of around 115m by 115m was considered, covering a number of data passes. In this location only Lidar data was available for comparison. The data was initially colour shaded by elevation for sensibility checking and this showed up a potential issue in overlapping areas. In some areas it picked up differences between adjacent points which were recorded on different passes of >300mm. Figure 5.1 shows the differences within a 1 m square located within the check area.

This issue was raised with OiS. Their response is presented in full in Appendix B. This response does not, in our opinion, satisfactorily answer the apparent differences at this location between overlapping swaths of data, and it is suggested that further investigation be undertaken as a joint exercise to resolve the possible overlap issues at this location.

Statistically the differences are as presented in Table 5.3 below. The comparison was undertaken by extracting the relevant Lidar elevation for each Fli-map point. In total 182,000 points were used.

Table 5.3 – Statistical Results from Barton on Humber Site

	Lidar – Fli-map
Average Difference	-50mm
Standard Deviation	±388mm

5.4 Comment on Quantitative Analysis

The average difference between Fli-map and the ground survey for Gowdall at the two sites compared is around 160mm with Fli-map being above the ground survey values. The variance (standard deviation) is around 110mm. This does not seem as good as first expected from the literature supplied by OiS on Fli-map. However some allowance needs to be made for the techniques used, i.e. that Fli-map measures to top surfaces, and therefore may be affected by grass etc, whilst ground surveys are taken to hard surfaces.

For two of the three sites analysed, Lidar and Fli-map gave very comparable results, with average difference of no more than 50mm. One site (the first site at Gowdall) however, gave larger average errors when comparing Lidar and Fli-map than from comparing either of the two remote sensing sources with the ground survey.

Within the realms of remote sensing techniques for topographic surveying the results from Fli-map are generally in agreement with those from Lidar, but are different to the ground surveys. Whether this difference is significant for use by the Agency is discussed in the following chapter. The overlap issue needs some further review to establish whether the site at Barton on Humber was a "one off" problem which would have been identified in a more rigorous quality control process before issue, or whether it is a significant issue which requires addressing.

6 CONCLUSIONS

6.1 Conclusions

The technique evaluated in this project, that of low level laserscanning, and in particular the 'Fli-map' system operated by OiS, seems to provide a potentially valuable tool within the asset survey framework. It provides detailed topographic data of linear assets to a quality that enables defects to be detected either from a single survey or between surveys over the same area undertaken at different times.

Final product development, in terms of addressing the detailed needs of the Agency's Area and Regional staff still needs to be established. The product supplied should enable operational staff to view both conventional survey output (cross-sections, plans etc.) and work with the data in an interactive digital environment, so that it can be coupled with the simultaneous video.

6.2 Future Development

The following are some of the issues that will need to be addressed before the system could be used within the Agency.

- Establish system for viewing a version of the data within the Agency's offices. This needs to access the simultaneous video plus a condensed version of the topographic data. The product will need to be available at an Agency Area level.
- Develop the DTM product, together with tools for the extraction of plans, cross-sections and long-sections. Plans and sections may also become products for direct supply under a data collection contract.
- Look into how comparisons could be undertaken between two separate surveys. Is this an in-house exercise or does it need to be part of the surveying contract?

- Enhance the video to enable better visual inspection of the assets to reduce need to send staff on site.

* Establish routines for filtering data to give a higher density of points in locations of rapid elevation change and a lower density for flatter areas.

* Undertake a Quality Analysis of overlaps on a hard surface (such as a runway) to demonstrate the reliability of results on overlaps. This process should be undertaken at the start and end of each sortie as a calibration/verification of the data collected.

* Undertake a "repeatability" exercise by flying the same area twice with a short period in between (1 or 2 weeks). This would establish repeatability of results and test vertical accuracy without the danger of real changes in topography that could occur over, say, a 12-month period.

APPENDIX A

Detailed Results for Gowdall Survey Sites

Gowdall Survey – site 1

X (m)	Y (m)	Survey Elevation (m)	Fli-map Elevation (m)	Lidar Elevation (m)	Fli-map - Survey (m)	Lidar - Survey (m)	Fli-map - Lidar (m)
460718.1	423720.9	5.543	5.71	5.41	0.17	-0.13	0.3
460721.1	423727	5.615	5.7	5.54	0.08	-0.08	0.16
460723.8	423732.8	5.731	5.94	5.79	0.21	0.06	0.15
460723.8	423732.9	5.876	5.94	5.79	0.06	-0.09	0.15
460724.5	423734.3	6.198	6.36	6.42	0.16	0.22	-0.06
460725.3	423735.7	6.695	6.84	6.42	0.14	-0.28	0.42
460725.2	423735.7	6.695	6.84	6.42	0.14	-0.28	0.42
460725.8	423736.9	7.046	7.23	6.77	0.18	-0.28	0.46
460726	423737.5	7.088	7.19	6.92	0.1	-0.17	0.27
460726.3	423737.9	7.133	7.16	6.92	0.03	-0.21	0.24
460726.8	423739.2	7.037	7.1	6.89	0.06	-0.15	0.21
460728.5	423742.3	5.951	6.1	5.65	0.15	-0.3	0.45
460729.6	423744.4	5.231	5.23	5.33	0	0.1	-0.1
460729.6	423744.5	4.992	5.23	5.33	0.24	0.34	-0.1
460732.3	423749.6	5.112	5.16	4.93	0.05	-0.18	0.23
460735	423754.9	4.997	5.06	4.89	0.06	-0.11	0.17
460750.3	423700.6	5.307	5.45	5.16	0.14	-0.15	0.29
460754.5	423707.2	5.395	5.58	5.28	0.19	-0.11	0.3
460758.3	423713.1	5.476	5.78	5.66	0.3	0.18	0.12
460759.2	423714.4	5.855	6.06	5.94	0.2	0.08	0.12
460759.2	423714.4	5.854	6.06	5.94	0.21	0.09	0.12
460760.3	423716	6.569	6.79	6.89	0.22	0.32	-0.1
460760.8	423716.7	6.981	7.14	6.89	0.16	-0.09	0.25
460761.3	423717.5	7.072	7.11	6.89	0.04	-0.18	0.22
460762.2	423718.9	6.921	7.08	6.69	0.16	-0.23	0.39
460763.9	423721.7	5.906	6.1	6.26	0.19	0.35	-0.16
460765	423723.2	5.399	5.55	5.34	0.15	-0.06	0.21
460765.6	423724	5.093	5.24	5.34	0.15	0.25	-0.1
460768.5	423728.2	4.929	5.08	4.86	0.15	-0.07	0.22
460772.3	423732.7	4.705	4.84	4.69	0.13	-0.01	0.15
460751.9	423699.5	5.369	5.44	5.18	0.07	-0.19	0.26
460758	423695.9	5.318	5.47	5.28	0.15	-0.04	0.19
460763.2	423692.5	5.404	5.48	5.32	0.08	-0.08	0.16
460767.7	423689.5	5.442	5.93	5.52	0.49	0.08	0.41
460768.5	423689.2	5.611	5.88	5.66	0.27	0.05	0.22
460769.5	423688.6	5.789	6.02	5.66	0.23	-0.13	0.36
460770.8	423687.7	6.547	6.69	6.71	0.14	0.16	-0.02
460771.8	423687.1	7.014	7.19	6.71	0.18	-0.3	0.48
460772.7	423686.5	7.153	7.29	7.16	0.14	0.01	0.13
460773.8	423686.1	7.011	7.21	7.16	0.2	0.15	0.05
460776.3	423684.6	5.939	6.08	5.81	0.14	-0.13	0.27
460777.7	423683.9	5.41	5.7	5.43	0.29	0.02	0.27
460778.1	423683.7	5.386	5.49	5.11	0.1	-0.28	0.38

X (m)	Y (m)	Survey Elevation (m)	Fli-map Elevation (m)	Lidar Elevation (m)	Fli-map - Survey (m)	Lidar - Survey (m)	Fli-map - Lidar (m)
460778.2	423683.7	5.183	5.44	5.11	0.26	-0.07	0.33
460782.4	423681.3	5.166	5.29	5.08	0.12	-0.09	0.21
460717.1	423763.7	5.02	5.05	4.91	0.03	-0.11	0.14
460714.7	423759	5.142	5.14	5.02	0	-0.12	0.12
460712	423753.5	5.045	5.14	5.27	0.09	0.22	-0.13
460712	423753.4	5.276	5.15	5.41	-0.13	0.13	-0.26
460710.8	423751.1	5.957	6.09	5.9	0.13	-0.06	0.19
460709.4	423748	7.013	7.1	6.69	0.09	-0.32	0.41
460708.9	423746.8	7.106	7.24	7.01	0.13	-0.1	0.23
460708.6	423746.2	7.092	7.11	7.01	0.02	-0.08	0.1
460708.5	423746.1	7.015	7.06	7.01	0.04	0	0.05
460708.4	423745.9	6.99	7.15	6.73	0.16	-0.26	0.42
460708.4	423745.8	6.988	7.17	6.73	0.18	-0.26	0.44
460707.6	423744.1	6.473	6.69	6.61	0.22	0.14	0.08
460706.8	423742.6	6.038	6.24	6.15	0.2	0.11	0.09
460706.3	423741.7	5.794	5.95	5.65	0.16	-0.14	0.3
460752.4	423745.2	4.962	5.12	4.88	0.16	-0.08	0.24
460749.4	423739.3	5.138	5.16	5.02	0.02	-0.12	0.14
460747.2	423735.1	4.958	5.1	5.31	0.14	0.35	-0.21
460747.1	423735	5.175	5.16	5.31	-0.01	0.13	-0.15
460745.8	423732.5	6.027	6.16	6.03	0.13	0	0.13
460744.4	423730.1	6.958	7.18	6.6	0.22	-0.36	0.58
460744.1	423729.5	6.991	7.17	6.86	0.18	-0.13	0.31
460743.7	423728.6	7.079	7.29	6.84	0.21	-0.24	0.45
460743.6	423728.3	7.064	7.23	6.84	0.17	-0.22	0.39
460743.5	423728.1	6.995	7.19	6.84	0.2	-0.16	0.35
460743.2	423727.7	7.014	7.18	6.59	0.17	-0.42	0.59
460743.1	423727.3	6.969	7.12	6.59	0.15	-0.38	0.53
460742.4	423726.3	6.465	6.65	6.59	0.19	0.13	0.06
460741.7	423724.9	5.984	6.15	5.86	0.17	-0.12	0.29
460740.8	423723.6	5.583	5.81	5.6	0.23	0.02	0.21
460737.2	423716.9	5.487	5.62	5.43	0.13	-0.06	0.19
460734	423711	5.497	5.49	5.36	-0.01	-0.14	0.13
460798.6	423703.4	5.044	5.11	4.95	0.07	-0.09	0.16
460792.5	423703.7	5.044	5.07	4.99	0.03	-0.05	0.08
460789.6	423704.8	5	5.08	4.94	0.08	-0.06	0.14
460786.5	423705	5.698	5.79	5.61	0.09	-0.09	0.18
460783.6	423705.2	6.541	6.69	6.76	0.15	0.22	-0.07
460781.4	423705.2	7.22	7.23	7.06	0.01	-0.16	0.17
460778.9	423705.3	7.165	7.28	7.09	0.12	-0.08	0.19
460777.2	423705.1	7.187	7.32	7.07	0.13	-0.12	0.25
460774.8	423704.8	7.029	7.2	6.86	0.17	-0.17	0.34
460773.6	423704.7	6.853	7.06	6.69	0.21	-0.16	0.37
460771.4	423704.4	6.487	6.68	6.24	0.19	-0.25	0.44
460769.2	423704.1	5.969	6.1	5.84	0.13	-0.13	0.26

X (m)	Y (m)	Survey Elevation (m)	Fli-map Elevation (m)	Lidar Elevation (m)	Fli-map - Survey (m)	Lidar - Survey (m)	Fli-map - Lidar (m)
460767.7	423704	5.584	5.8	5.58	0.22	0	0.22
460760.1	423703.5	5.355	5.52	5.24	0.16	-0.12	0.28
460752.9	423702.7	5.266	5.44	5.2	0.17	-0.07	0.24
460746.2	423680.2	5.356	5.54	5.19	0.18	-0.17	0.35
460762.9	423729.1	5.043	5.11	4.95	0.07	-0.09	0.16
460766.4	423726.8	5.169	5.21	4.98	0.04	-0.19	0.23
460770.1	423724.7	5.116	5.28	5.02	0.16	-0.1	0.26
460772.3	423722.9	5.4	5.45	5.3	0.05	-0.1	0.15
460775.5	423720.4	5.96	6.01	5.54	0.05	-0.42	0.47
460779.1	423718.1	6.587	6.76	6.42	0.17	-0.17	0.34
460782.2	423716	7.23	7.28	7.17	0.05	-0.06	0.11
460783.1	423715.6	7.281	7.38	7.17	0.1	-0.11	0.21
460784.7	423714.6	7.317	7.38	6.98	0.06	-0.34	0.4
460786.6	423713.5	6.552	6.76	6.38	0.21	-0.17	0.38
460788.9	423712.1	5.46	5.67	5.5	0.21	0.04	0.17
460790.7	423711.1	4.846	5.09	4.88	0.24	0.03	0.21
460796.6	423708.1	4.888	4.97	4.71	0.08	-0.18	0.26
460802.5	423704.9	5.02	5.23	4.93	0.21	-0.09	0.3
460769	423743.5	4.611	4.67	4.5	0.06	-0.11	0.17
460774.3	423740.9	4.578	4.64	4.45	0.06	-0.13	0.19
460777	423739.6	4.501	4.53	4.49	0.03	-0.01	0.04
460781.1	423737.6	5.274	5.32	5.06	0.05	-0.21	0.26
460785.3	423735.9	6.099	6.26	5.94	0.16	-0.16	0.32
460788.3	423734.5	6.869	7.08	6.77	0.21	-0.1	0.31
460790.2	423733.6	7.307	7.36	7.23	0.05	-0.08	0.13
460791.5	423733.1	7.369	7.46	7.23	0.09	-0.14	0.23
460793	423732.4	7.361	7.35	7.16	-0.01	-0.2	0.19
460795.4	423731.4	6.489	6.73	6.44	0.24	-0.05	0.29
460798.5	423729.6	5.129	5.29	4.63	0.16	-0.5	0.66
460800.2	423728.7	4.36	4.46	4.45	0.1	0.09	0.01
460806.3	423725.5	4.387	4.48	4.31	0.09	-0.08	0.17
460812.5	423722.3	4.443	4.6	4.35	0.16	-0.09	0.25
460813.8	423743.7	4.072	4.1	3.87	0.03	-0.2	0.23
460807.4	423746.6	4.111	4.22	4.48	0.11	0.37	-0.26

Mean	0.13	-0.08	0.21
Std Dev	0.08	0.17	0.17
Max	0.49	0.37	0.66
Min	-0.13	-0.5	-0.26

Gowdall Survey - Site 2

X (m)	Y (m)	Survey Elevation (m)	Fli-map Elevation (m)	Lidar Elevation (m)	Fli-map - Survey (m)	Lidar - Survey (m)	Fli-map - Lidar (m)
462283.5	422525.4	3.73	3.92	3.9	0.19	0.17	0.02
462266.2	422535.6	3.65	3.75	3.71	0.1	0.06	0.04
462260	422525.9	3.76	3.89	3.91	0.13	0.15	-0.02
462253.9	422516.4	4.22	4.45	4.61	0.23	0.39	-0.16
462253.6	422515.9	4.51	4.99	4.87	0.48	0.36	0.12
462248.8	422546.5	3.86	3.97	3.95	0.11	0.09	0.02
462242.2	422536.4	3.93	4.06	3.95	0.13	0.02	0.11
462236.3	422527.4	4.46	4.65	4.55	0.19	0.09	0.1
462236.2	422527.1	4.73	4.93	4.55	0.2	-0.18	0.38
462235.8	422526.6	4.88	5.27	4.86	0.39	-0.02	0.41
462235.4	422525.9	4.88	5.27	5.25	0.39	0.37	0.02
462235	422525.3	5.27	5.44	5.25	0.17	-0.02	0.19
462233.8	422523.5	5.94	5.99	6.13	0.05	0.19	-0.14
462232.6	422521.6	6.66	6.71	6.55	0.05	-0.11	0.16
462231.9	422520.6	6.69	6.78	6.65	0.09	-0.04	0.13
462231.3	422519.7	6.67	6.74	6.38	0.07	-0.29	0.36
462230.9	422519.1	6.35	6.52	6.38	0.17	0.03	0.14
462230.3	422518.2	6.02	6.15	6.38	0.13	0.36	-0.23
462229.4	422516.7	5.45	5.78	5.68	0.33	0.23	0.1
462228.6	422551.3	4.18	4.32	4.24	0.14	0.06	0.08
462222.8	422542.3	4.44	4.52	4.49	0.08	0.05	0.03
462220.1	422538.1	4.51	4.58	4.52	0.07	0.01	0.06
462219.6	422537.2	5.04	5.3	5.28	0.26	0.24	0.02
462219.1	422536.4	5.12	5.78	5.28	0.66	0.16	0.5
462217.9	422534.5	5.89	5.93	5.76	0.04	-0.13	0.17
462216.9	422533.1	6.34	6.43	6.39	0.09	0.05	0.04
462216.5	422532.3	6.59	6.69	6.39	0.1	-0.2	0.3
462215.9	422531.4	6.63	6.66	6.52	0.03	-0.11	0.14
462215	422530.1	6.59	6.64	6.52	0.05	-0.07	0.12
462214.1	422528.6	5.97	6.11	6.33	0.14	0.36	-0.22
462212.8	422526.5	5.22	5.4	5.59	0.18	0.37	-0.19
462211.7	422524.9	4.65	4.87	5.37	0.22	0.72	-0.5
462211.2	422524	4.6	4.96	5.37	0.36	0.77	-0.41
462210.5	422522.9	4.49	4.72	5.39	0.23	0.9	-0.67
462210.4	422522.8	4.26	4.64	5.39	0.38	1.13	-0.75
462214	422564.5	4.18	4.27	4.18	0.09	0	0.09

Average	0.19	0.17	0.02
St Dev	0.14	0.31	0.27
Max	0.66	1.13	0.5
Min	0.03	-0.29	-0.75

APPENDIX B

OiS Response to Adjacent Point Differences

ELEVATION VARIATION IN LASER POINTS CLOUD

The following should be considered when comparing any individual points in the cloud: -

1) At a specific location, the random spread of points from the surface they represent is typically +/- 40mm 99%CI. Hence in the worst case, two neighbouring points could be 80mm apart.
2) The tolerance of the system is +/- 50mm 99%CI in relative position between any items in the survey, and so two representations of the same surface (e.g. swath overlap) could be not coincident by up to 100mm in the worst case.
3) When looking at neighbouring points (i.e. within 100mm of each other in plan) where the terrain is uneven (e.g. fields), the actual surface may undulate within that region by 150mm or greater (e.g. large stone or rut).

So it is feasible to find examples of neighbouring points from a single data-set differing by more than 200mm due to the cumulative effects of 1) and 3), and from multiple data-sets (e.g. swath overlap) by 300mm and more, due to 1), 2) and 3).

But note that in the above examples, 150mm of the difference is due to the actual variation in the surface being measured. And of the other two components (i.e. 1) and 2)), each has a likelihood of an estimated 1 in 100 occurrence. So the probability of them occurring at the same time and with the same sign (i.e. either positive or negative) is: -

$$0.01 \times 0.01 \times 0.5 = 0.00005 \text{ or } 1 \text{ in } 20000$$

Hence the occurrence of these two random errors combining to maximise the discrepancy in the data, will be very infrequent, and will not in practice affect the validity of the survey.