The accuracy of Robert Saxton's survey and map of Manningham, dated 1613 [post-print]

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An assessment is made of the accuracy of the map and written survey, which is essentially a list of land-holders and the areas held by each, and of their mutual consistency. The geometry of the map is compared quantitatively with that of the first edition (1852) Ordnance Survey 6-inch (1:10560) map. The Saxton map is found to have a scale of 1:5140, leading to the conclusion that the perch used in the scale bar represents $7^{1}/_{9}$ yards or thereabouts. The areas quoted in the written survey are consistent with acres based on this value. The positional accuracy of points on the map is found to be about 20 m, and areas of typical plots determined from the map are uncertain by between about 4% and 12%. The relationship between these two facts can be understood through a detailed study of the statistics of the errors in separations of points on the map. The written survey is found to omit a substantial number of plots of land from its listings. The map thus appears to be more reliable overall than the written survey.
Keywords: planimetric accuracy, manuscript map, map symbols, customary measure, perch

Introduction

The years 1550-1800 cover roughly the period between the emergence of the scale map in England, with its increasing use in mapping estates and other land holdings, and the first maps at one inch to the mile (1:63360) produced by the Ordnance Survey (OS) in Britain and Ireland. It was not until 1840 that the OS began to produce maps at 6 inches to the mile (1:10560) for England, the first OS maps at a scale in any way comparable with those generally used in property mapping, which ranged from about 8-20 inches to the mile. Prior to 1550 a land survey was often little more than what is expressed by the simplest dictionary definition of the verb 'survey' : 'to view or consider in a comprehensive or general way', with the result being a list of land holders and estimated areas and or values of holdings, together with perhaps a description of boundaries and suggestions for improvements in land management. Maps, if they were produced at all, were simply sketches intended to convey topological and topographical information for use, for instance, in legal disputes about boundaries. Harvey (1993) has described how estate maps came to be drawn to scale in England in the second half of the 16th century and Delano-Smith & Kain (1999) have discussed the various factors leading to the use of such maps.

As land was increasingly valued as a commodity to be bought and sold, the need for accuracy in surveying increased, and this led to the writing of a large number of books on surveying and the development of new instruments in the years 1550-1650 (Richeson, 1966). Large sections of these books were usually devoted to explaining methods of calculating the areas of pieces of land of various shapes The earlier of these methods were frequently crude and even when correct were frequently misunderstood. Early instruments used for surveying included the cross-staff and the geometrical square. The theodolite was first described in English by Leonard Digges (1571) and the plane table by Cyprian Lucar (1590). The principles of triangulation were described by Bourne (c.1572) and Ralph Agas (1596) recommended the use of the theodolite in preference to the plane table. Nevertheless, cross-staves were still being used for surveying in England in the early seventeenth century (Roche, 1983) and later in the century George Atwell was still recommending the use of the chain and plane table rather than any other instruments (Atwell, 1658).

Whatever the method used, it was often the case until well into the 17th century that a survey was reported only in the written form, with no corresponding map, thus forfeiting the precise definition of boundaries that a map can provide. If such a survey is to be used, for instance, in trying to understand the agricultural economy of the corresponding region, particularly in

reference to the size of land holdings, it is clearly necessary to know what units it uses and how accurate the measurements were in that unit. The acre and the linear unit on which it was based, the perch, were notoriously variable throughout Britain, and indeed for different purposes in the same locality. The acre could, in fact, vary in area by a factor of two or even more (Dilley, 1975).

Quantitative comparison of a map and written survey of the same area, together with comparison of the map with a modern map, can provide information about units and accuracy and also suggest what confidence can be placed in written-only surveys by surveyors of the time. The inclusion of a scale bar on his map by a cartographer implies a claim to planimetric accuracy, and a full appreciation of his work must consider what accuracy he did achieve in this respect, as well as the topological and topographical accuracy of the map within the limitations of its purpose, where this is known. In addition, studies of this kind, when sufficient data have been accumulated, might throw light on the methods of survey actually used during the period when the map was made. The present paper represents the first part of what is intended to be a detailed study of the surveys and maps of Robert Saxton (c.1585-1626), with particular emphasis on their accuracy, and is a contribution to such a program.

Robert Saxton and his work

Robert was the son of the famous Christopher Saxton who produced the first atlas of the counties of England and Wales in 1579. He is known to have undertaken 20 surveys in the years 1607 to 1619, all but two within or on the borders of the former West Riding of Yorkshire, and these two not far outside them. Unlike his father he does not seem to have produced any printed maps or plans.

Six of the 20 surveys are extant only as written surveys (three of which are not in Saxton's hand), seven only as manuscript maps, three as both maps and surveys and there are four for which there is only written evidence that they were undertaken. Three of the extant maps are not originals prepared by Saxton, but copies, although the written survey accompanying one of them, that of Gomersal, is in Saxton's hand. Table 1 summarises these facts and Figure 1 shows the locations and approximate areas covered by the maps as determined by preliminary investigations, and the locations of the surveys. Robert was working at a very interesting time in the development of surveying practice and produced all his work in a very restricted geographical region. In addition, the total extant corpus of his work, while being of the diverse nature described, is of manageable proportions, so that a complete study seems possible and worthwhile.

All but three of the surveys and maps have been described by Evans and Lawrence (1979), who give the background details relating to them, as well as their locations where known. The three maps not described are those of Lindley cum Quarmby of 1609, of an estate at Hullen Edge (Elland) of 1614 and of Potteric Carr, near Doncaster, which Robert Saxton surveyed with William Goodman in 1616. The first of these is held at the West Yorkshire Archive Service, Kirklees (DD/T/PL/4) and is a copy of Saxton's map made in 1801. The second map is held by the West Yorkshire Archive Service, Calderdale (MP40) and is an original purchased by the Archives in 1986 from Sotheby's. The third map is held as a copy amongst the Smeaton papers in the Archives of the Royal Society of London (JS/6/127) and there are also copies at Doncaster Archives (DZ/MD/224c, DZ/MZ/137, MB/Plan/3/1). These maps will be described elsewhere.

The written survey and map of Manningham were chosen for the start of the project because both survive in a very good state of preservation and are both almost completely legible. The original written survey of Gomersal survives, but the map is a copy of only part of the area surveyed, while the map of Tanshelf shows very little surviving detail compared with that of Manningham. The Manningham map and written survey (henceforth simply 'the survey') thus provide a unique pair for which a detailed assessment of the consistency of the map and survey and of their accuracy can be made.

The Manningham map and survey

The original map and survey are at The National Archives of the UK (TNA) (ref. MPC1/210). A reproduction of the map and a qualitative description of it have been given by Robertshaw (1940), who also transcribed the written survey. A much reduced version of the map is shown in *The Illustrated History of Bradford's Suburbs* (Birdsall *et al*., 2002) and a brief qualitative study of it has been given by Richardson (1976), who lays emphasis on the survival of the system of narrow strips in the fields and its relevance for the alignment of the minor street pattern in the 19th century; almost the whole of Manningham is now a built-up area. His somewhat schematic illustration of the locations of the ancient fields does not agree with their locations and sizes as deduced in the present work, although it may represent an earlier state. A half-sized reproduction of a section of the original map is shown in Figure 2 and a reduced tracing of the whole map showing various features to be described later is shown in Figure 3.

The map measures approximately 77½ cm E-W by approximately 52 cm N-S within the inner lines of the border (it is very nearly, but not exactly, rectangular). The scale is given as 20 perches to the inch by means of a scale bar showing 60 perches in 3 inches. This converts to an 'apparent scale' of 16 inches to the mile if statute measure (1 perch = 5.5 yards = 198 inches) is assumed, or 1:3960. The map, which has survived in remarkably good condition apart from some fading of colour, is extraordinarily detailed. Nearly 300 plots of land are drawn and the names of the landholders are given on the map, either for each individual plot or sometimes for groups where a given holder has contiguous plots. The survey is not quite so detailed, because frequently total areas are given for several plots of land held by one person.

Methodology

The map was first compared numerically with a 'modern' map in order to determine its planimetric accuracy and it was then compared in detail with the survey. Giordano and Nolan (2007) have recently given a brief review of the methods used in the study of the accuracy of historical maps. The method used here is essentially the one in which point features are compared, but comparisons of areas as indicated by the map and survey and by the 'modern' map have also been used.

The Saxton map was obtained as a colour digital image at 150 dpi from TNA. Measurement of the scale indicator superimposed by TNA, in an image-processing program and directly on a 2× printout, gave the nominal length to 0.3% or better. Similar measurements on Saxton's scale bar gave a length of 3.03 inches, suggesting that it was meant to be 3 inches and also that the map showed no appreciable shrinkage. The 'modern' map used was the earliest 6-inch (1:10560) OS map of the area, that of 1852, which includes field boundaries and generally shows the shapes of individual buildings. Sections of sheets 201 and 216 of this map were photocopied, digitally scanned at 300 dpi and joined in an image-processing program to obtain a digitised map covering the same area as the Saxton map.

The maps were compared using the *MapAnalyst* computer program (Jenny & Weber 2005/8, Jenny *et al*., 2007) which allows two maps to be placed side by side on the computer screen and to be viewed individually magnified or reduced. It is then possible to link together common points on the two maps and the program calculates the scale and distortion of one of the maps from the assumed known scale of the other. The final numerical results quoted here are deduced from the simplest type of comparison, the Helmert four-parameter fit: the 'test' map is scaled, shifted and rotated homogeneously to obtain the best fit to the 'standard' map. This is the simplest affine transformation, used, for example, by Giordano and Nolan (*loc. cit.*). More complicated affine transformations are also available in the *MapAnalyst* program: a five-parameter fit, which allows independent scaling in two directions at right angles, and a six-parameter fit, which allows in addition independent rotation of two axes at right angles in the 'standard' map. Results from these transformations are discussed briefly.

Before comparing the Saxton map with the 6-inch map the latter was compared with a modern 1:25 000 map (OS Explorer 288, edition A, rev. 1999) in order to allow for any reduction or

distortion in photocopying. Its scale was found to be 1:10700, or 5.92 in/mile, and it was rotated 1° clockwise with respect to the 1:25 000 map (oriented to true north within about ¼°).

The scale of the map and its overall accuracy

In comparing the map with the 6-inch map, 27 common points were used initially (see Figure 3). These points may be described as follows: 10 track/road junctions, 5 intersections of plot boundaries and streams, 3 plot boundary angles, 2 plot boundary junctions, 2 points where a plot boundary meets a road, and one each of stream bend, township boundary angle, sharp road bend, bridge, house.

Using the Helmert four-parameter fit, the mean scale of the map was found to be 1:5140, or 12.3_3 inches to the mile. The map was found to be slightly rotated with respect to the 1:25 000 map, by 4° counter-clockwise, on average. Fits made using five or six parameters showed no significant reduction in goodness of fit and showed that the mean horizontal and vertical scales differed by no more than 2 parts in 500 The six-parameter fit showed that there was possibly a slight overall skew, amounting to one degree difference between the rotations of the horizontal and vertical axes. In view of this small overall departure from rectangularity it was decided to use only the four-parameter fit when quoting numerical results.

In spite of the low overall skew, the map is slightly distorted and, in order to get some idea of the uncertainty in its scale, it was divided into three sections, western, central and eastern, each containing nine of the original 27 points of comparison. The average scales for the three sections were found to be 1:5200, 1:5100 and 1:5060, respectively. These differ from the overall average scale by 1.2, 0.8 and 1.6 per cent, respectively, differences that are comparable with the accuracy of the fitting program, which is stated to be 1%. This does not, however, mean that smaller regions may not differ more greatly in scale, as will appear later. The three sections were rotated by 4°, 4° and 6°, respectively, counter-clockwise with respect to the 1:25 000 map. In 1613 the magnetic declination was approximately 8°E (Jackson *et al*. 2000), so that Saxton's mean 'north' orientation, 4°±1°E, is about half way between true north and the magnetic north of the time.

The comparison showed a standard deviation σ of 21 m for the 27 points, corresponding to a distance of approximately 4 mm on the Saxton map or about 2 mm on the OS 6-inch map. The probability that a point lies in any infinitesimal unit area at distance r from its true position is proportional to $\exp[-r^2/(2\sigma^2)]$ and falls to half its maximum value when $r = 1.18\sigma$. The practical meaning of this degree of accuracy for the delineation of the streets and lanes is illustrated in Figure 3.

Database for the map and survey

The map

The areas of all the individual plots of land, the total area within the boundary of the township and the area of the medieval fields within it were determined from the digitised map. The latter were located as explained below. The data for the individual plots were entered into a database with the landholder's name and the type of land holding. The colours on the map that indicate the categories of landholding (free-/copyhold; old/new land) have faded considerably, but are usually still distinguishable and the types of holding were identified as accurately as possible and the information was entered into the map table of the database.

The survey

Before entering them into the database, the areas given by Saxton in the survey were first converted from acres, roods, dayworks and (square) perches to acres and decimal fractions. The relationships between the units ($1{:}^1/_4{:}^1/_{40}{:}^1/_{160}$) follow from the maximum numbers appearing for individual entries in the survey and from additions made therein.

Assuming that the scale bar on the map and the areas in the survey are based on the same perch length, as subsequently confirmed, the survey areas can be converted to equivalent statute acres

by multiplying them by the square of the ratio of the apparent scale to the actual scale i.e. $(16/12.33)^2 = 1.68_4$. These values are used throughout.

Comparisons between the map and the survey I: Overall area comparisons

At the end of the survey Saxton gives a number of total areas, as shown in the second column of Table 2. Columns three, and four show, respectively, totals found by summing the areas of individual plots listed in the survey and individual plots measured on the map. Inspection of columns two and three show discrepancies within the survey data: in column two, some totals and individual values are inconsistent and there are significant differences between the totals given in columns two and three. The greatest discrepancy is, however, that the overall total area as measured from the map is 112 acres, or about 9.5%, greater than the area found by summation of the areas given in the survey.

Part of this discrepancy could possibly be accounted for by noting two things. First, that there are areas on the map not accounted for in the detailed listings of the survey, including the Garths and land held by four people whose names do not appear at all in the survey[†], totalling 56.9 acres . On the other hand, a total of 6.1 acres of land is listed in the survey for two holders whose names do not appear at all on the map[††]. The difference of about 51 acres is roughly equal to the difference between the overall totals in columns two and three, and may explain the difference, because a sentence following Saxton's final total could be taken to imply that it is the total area of the township excluding 'the laines and hye waies'. It is shown below that the most likely explanation for the remaining discrepancy of about 60 acres, or about 5% of the total area of plots represented on the map, is that Saxton accidentally omitted from the final written survey some of the plots of land held by a number of landholders who held more than one plot.

Comparisons between the map and the survey II: Comparison of individual plot areas

A complete correlation of the map and the survey cannot be made but it is possible to identify certain plots in both. This is because some plots are identified in the survey as lying in specific medieval fields. Identification of these fields on the map then permits correlation of plots where a holder has only one plot in a given field. Equally, the other group of holdings for which correlation is possible is for those outside the fields where only one plot is shown for a given holder in both map and survey or where a plot is given a specific identifying description.

The fields will here be called Brecks, Cliffe, High, Middle, Old Manningham, Panewell, West and Whetley fields, although the spellings of the names vary somewhat in various parts of the map and survey.

The identification of the medieval fields

On the map the fields are only indicated in a rather vague manner, their names being simply written across some of the plots belonging to them; no specific medieval field boundaries are shown as such. In several cases, however, other individual plots on the map are specified as being within a particular field. By taking note of both these indications and also of plot boundaries that seem to form smooth curves when taken together, it is possible to be fairly certain where the original field boundaries were. The areas included within the fields deduced in this way are indicated in Figure 3.

Column 2 of Table 3 shows the area of each field as determined from the survey by adding the appropriate individual areas given by Saxton, and at the bottom are shown the overall total and the total stated by Saxton at the end of the survey. As previously indicated, Saxton's individual areas do not add up to his stated total. Columns 3 shows areas determined from the map.

The total of the measured areas agrees within 3 acres, or 1%, with the figure stated by Saxton. This suggests three things. First, that the perch length used for the map and survey are indeed

[†] William Crabtree, Nycholas Hollins, Richard Jawet and Cristofer Pighilles.
[††] John Walshe and Richard Waterhouse.

the same, secondly, that the fields have been correctly identified, and thirdly, that Saxton may have measured the total areas of the fields directly as well as measuring individual plots. Alternatively, it could mean that in his fair copy of the survey he omitted to take account of some of the plots within each field, having previously added them up correctly, or that he simply did not specify that some plots were within the fields.

Identification of individual plots and comparison of their areas from survey and map

It was possible to correlate 56 plots in the map with those in the survey, 29 within the fields and 27 outside. Figure 4 shows a comparison of the areas as given by the map and survey. The curve shown is a best fit hyperbola to the data, and takes the form $y^2 = a^2x^2 + b^2$, where $a = 0.99_4$ and $b = 1.12_4$. Such a hyperbolic fit allows for the fact that on the map very small plots, particularly those that are very narrow, are on average likely to be shown slightly too large because of the difficulty in drawing them. The three open points deviate from the fit to the remaining 53 points by more than three times the root-mean-square (standard) deviation of these remaining points from the fit and have therefore not been included in the fit.

The value of a is the asymptotic gradient at very large plot sizes, and the fact that it is so close to unity indicates once again that the scales of the map and survey are the same within 1% and also that the reason for the discrepancy of 5% between the total areas of the map and survey must be mainly due to the understatement in the survey of the total area of land held by those 25 holders who have more than one plot shown on the map.

The discrepancy in total areas of map and survey

About half the discrepancy, nearly 32 acres, could be accounted for by the omission of four plots out of 41 held by the largest landholder, William Lister, who held 18% of the total land. The survey actually shows only 14 holdings, so that there is a great deal of lumping together here. A detailed study shows that the remaining discrepancy can probably be accounted for by about 20 further omissions or misassignments, usually of no more than two per landholder, for about 17 landholders.

Considering that there are 285 plots in total held between about 44 landholders, this does not seem an excessive number of errors, particularly when the total time taken from the commissioning of the survey to the delivery of the map was only fourteen days. Allowing for travelling, drawing and writing time, Evans & Lawrence (1979) suggest that only a week was available for surveying. In this case 40 plots must have been surveyed per day, on average. A formidable achievement!

The accuracy of the individual areas shown by the map and survey

It is possible that, apart from the correct layout of the tracks and lanes, Saxton intended that the map should only show the approximate layout of the individual plots of land for identification purposes, the actual areas being specified in the survey, and the precise boundaries and shapes being identified solely on the ground itself. Some of the plots are, however, shown with very elaborately-shaped boundaries that are clearly intentionally drawn. This does not square well with an intention to give a merely schematic representation. The standard deviation of 0.44 acres for the hyperbolic fit referred to above does not tell us anything directly about the accuracy of the areas quoted by Saxton in the survey or of the areas that can be determined from the map, but only about the differences between them. The accuracy of the areas of individual plots shown on the map is therefore now considered.

Estimation of accuracy by approximating plot shapes; upper limit to the accuracy

It seems likely that the areas were measured by Saxton from the raw survey data, which were probably in the form of partial plots of the map made on a plane table in the field or made in the 'office' from data obtained in the field. These plots would certainly not be to a scale less than that of the final map. The areas may have been determined by approximating the actual plot shapes by combinations of simpler straight-sided shapes, a method suggested, for example, by Benese (1537) and used, for example, by Langdon in 1605/6 (Woolgar 1985). In order to

estimate the accuracy that might be achieved, measurements were made in this way of seven plots of land on a full-sized printout of Cliffe field. The results suggested that using this method an accuracy of about 0.16 acres, or about 4%. might be attained with care, so that this may be taken as a likely lower limit to Saxton's errors.

Direct comparison with the 6-inch map

In order to obtain a more precise idea of the accuracy of the areas of individual plots as shown on the map, comparisons were made with the 6-inch map. Only 41 individual plots could be found which seemed to be, at least approximately, corresponding plots on the two maps. There was a lack of such plots in the southern and eastern regions of the map, but five composite corresponding areas were identified in these regions. The limiting gradient of a hyperbolic fit to the plot of Saxton's areas against the 6-inch map areas was 0.97. The gradient should be slightly less than unity because the areas of the lanes occupied about 8% of the total area of Manningham in Saxton's day, but the roads were narrower, on average, by 1852. The smallest 30 of the 41 individual plots had average area 4.27 acres, comparable to the average of 4.45 acres for the 56 plots used in the comparison of map and survey. The standard deviation of the fit for these 30 plots was 0.53 acres, or 12%, somewhat larger than the 0.44 acres found in the latter comparison.

Estimates of errors from map distortion

Once the fitting to corresponding points has been done, *MapAnalyst* produces a distortion grid calculated by the multiquadratic interpolation method (*see e.g.* Beineke, 2007). The map and distortion grid for a set of squares of area 7 acres (side 168 m) was printed out, rescaled to the same scale as the original and the areas of all (distorted) squares lying wholly or very nearly wholly within the boundary of the mapped area were measured. The percentage errors were then calculated and plotted, as shown in Figure 5. The results are consistent with the gross variation of scale across the map found earlier, and the standard deviation of the actual areas was found to be 0.25_5 acres. This is much smaller than the standard deviation found in the comparison with the 6-inch map. On almost any assumption, the actual error in area will decrease as the area becomes smaller, so that this method of estimating the errors is clearly inadequate. It will be shown elsewhere that reliable estimates of the errors can only be made when the mean separation of the points used in the fitting is comparable with the linear dimensions of the areas under consideration, because the precise form of the correlations, or lack of correlations, of displacements of points must be correctly accounted for.

Conclusions about the accuracy of the areas

The results above suggest that for a plot of the average size of 4.13 acres the accuracy of the area as shown on the Saxton map is about 0.5 acres, or about 12%. This should be taken as an upper limit on the possible error because it does not take into account any real changes in the plot boundaries between 1613 and 1852. The lower limit is about 4%.

The comparison of the areas of identified plots on the map and survey showed a standard deviation of 0.44 acres. Combining these errors suggests a lower limit for the accuracy of area of a typical plot in the survey of $\sqrt{(0.5)^2 + (0.44)^2} = 0.67$ acres, or about 16%, but this is again likely to underestimate the accuracy because of the possibility of real changes in plot boundaries and because of errors in producing the fair copy map from the raw survey data. It must, however, be remembered that the detailed survey listing has errors of omission corresponding to at least 5% of the total area shown on the map, in addition to some inconsistencies in the stated totals.

The surveying methods and measurement scale

How could Saxton have performed such a surprisingly accurate survey, particularly as represented by the map, in such a short time? Only a suggestion can be made, bearing in mind the surveying methods and instruments used at the time (*see e.g.* Richeson, 1966). A possible explanation lies in the large numbers of roads or tracks crossing the area. It would be relatively easy to survey these by traverse – measuring distances and angles – and so obtain a skeleton

plan on which to hang the delineation of the plots. Many of the plots of land could then be 'anchored' by the intersections of their boundaries with the tracks and their shapes determined by chain measurement and/or plane table survey.

The measuring scale used – the length of the perch

The actual scale of the map is 12.3_3 in/mile, whereas the apparent scale is 16 inches to the mile, assuming the statute perch of 5.5 yards. The perch used must therefore have been $5.5 \times 16/12.3_3 = 7.14$ yds. Taking the range of scales found when the map was divided into three sections leads to a perch lying between 7.03 and 7.22 yds. These values bracket the value of $7^1/_9 = 7.11$ yds attested as one of the lengths used in Cumberland and Lancashire (Dilley, 1975). It is interesting to note, however, that preliminary studies of the other maps of Robert Saxton indicate perches of approximately the following numbers of yards: 5.5 (Baildon, statute), 5.9 (Farsley), 6.1 (Lindley cum Quarmby), 6.8 (Oakworth) and 7.6 (Tanshelf). These and the present value are all consistent with the fact that customary perches were nearly always greater than statute perches (*see e.g.* Dilley, *loc. cit.*). The Elland and Gomersall maps do not have scale bars, the scale bar is missing from the surviving section of the Hatfield map, and there are problems in interpreting the scale bars on the copies of the Potteric Carr map.

Qualitative features of the map

Apart from marking tracks and streams, the map shows two other kinds of features, houses and gates. Twenty-six houses are indicated, in addition to the nine in the Garths, and are distributed as shown in Figure 3. Saxton adopted a standard pictorial symbol for a house (*see e.g.* Figure 2, left of centre) and appears to have made no attempt to illustrate the actual appearances of different houses, which were surely not all identical.

The houses in the Garths are not attributed to an occupier and there are two other houses on the map whose owners are not clearly indicated. The survey mentions 23 houses, 18 of which can be reasonably matched to houses on the map[†]; it does not appear to list any of those in the Garths. Four houses mentioned in the survey cannot be found on the map and the fifth may have been wrongly assigned on the map or survey to William or Thomas Crabtree. Because the map shows more houses than are listed in the survey it is possible that all those listed in the survey are in fact marked on the map but there is some misattribution on one or the other. Robertshaw (1940) suggested that Saxton probably recorded all the existing houses on the map; the comparisons made here show that the possibility that a small number were omitted cannot be ruled out.

Turning to the gates, there are nine marked with a simple pictorial N-like symbol (*see e.g.* Figure 2, left of centre, plot of William Lister). Six of these are on tracks passing between plots, usually at the entrances to the track, two are on tracks leading through plots and one leads directly into a plot. It seems most likely that there were actually far more gates, particularly leading directly into plots, so that in this respect the map is probably deficient.

Summary and Conclusions

Robert Saxton's map and survey represent a very substantial piece of work completed in a very short time. Their accuracy and the units used have been determined. The map provides a full picture of land holding, street or lane layout and house distribution in the Manningham of the early seventeenth century. On the whole it is probably more reliable quantitatively than the survey, although comparison of the two allowed some conclusions to be drawn that could not have been drawn from the map alone and some discrepancies between the map and survey could not be resolved. The survey is definitely deficient in that some land holdings have been omitted from its detailed listings. This gives pause for thought when considering the results of written surveys not accompanied by maps, as does the fact that the acres used are frequently not statute acres, as found here.

[†] Numbers 1, 2, 3, 6, 7, 8, 11, 12, 14, 15 or 16, 17, 20, 21, 22, 23, 24, 25, 26 in Figure 3.

It is shown that the accuracy of areas indicated on a map cannot necessarily be estimated from a knowledge of the mean accuracy of point placement. Account must be taken of the relative displacements of points separated by distances comparable with the linear dimensions of the areas under consideration, and further work on this aspect of map accuracy is desirable.

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Table 1. The known maps and surveys of Robert Saxton

Date	**Place**	**Map or survey**	**Status of map or survey**
1607	Sandal	S	not in Saxton's hand
1608	Wakefield Old Park	S	not in Saxton's hand
1609	Farsley	M	original
1609	Lindley cum Quarmby	M	copy
1610	Airmyn		evidence only
1610	Baildon	M	original
1610	Ellington Moor		evidence only
1611	Tanshelf	M S	original original
1612	Esholt	S	original
1612	Thornhill	S	not in Saxton's hand
1613	Manningham	M S	original original
1614	Elland	M	original
1614	Liversedge	M	evidence only
1615	Hatfield	M	original
1616	Ledston	S	original
1616	Potteric Carr	M	copy
1616	Sutton	S	original
1617	Oakworth	M	original
1618	Wensleydale		evidence only
1619	Gomersal	M S	copy original

Table 2. The overall areas

	survey stated	from survey by summation	from map by summation
Freehold land in the old inclosures other than the fields	154.23	103.30†	173.5
Copyhold land within the old enclosures other than the fields	324.74	374.72*	352.8
Total in the old inclosures other than the fields	478.97	478.02	526.3
Freehold in the fields	154.23	75.32	79.4
copyhold within the fields	172.22	210.44*	258.3
The 7 [sic] fields old land	334.84	285.76	337.7
Freehold within the new land	71.48	67.91	73.0
Copyhold in the new land	234.38	230.21*	236.6
total new land	305.86	298.12	309.6
overall total	1116.30	1061.90	1174

† Including 1.58 acres freehold of John Nichols, 'close with a lane', not specified as old or new and 2.53 acres of William Clayton, 'close in newly erected' not specified as old or new or as free or copyhold

* Including areas not specified as freehold or copyhold

Table 3. The areas of the eight medieval fields

Field	Sum of survey areas, statute	Field measured as unit on map	Sum of plot areas from map
Brecks	44.50	48.70	48.93
Cliffe	30.90	26.48	26.54
High	35.62	52.43	52.24
O. Manningham	31.43	32.00	32.01
Middle	33.48	35.35	35.41
Panewell	24.24	32.79	32.63
West	57.70	71.06	70.96
Whetley	27.89	39.13	38.98
Total	**!Syntax Error,)**285.76	337.94	337.7
Stated total	334.84		

Figures

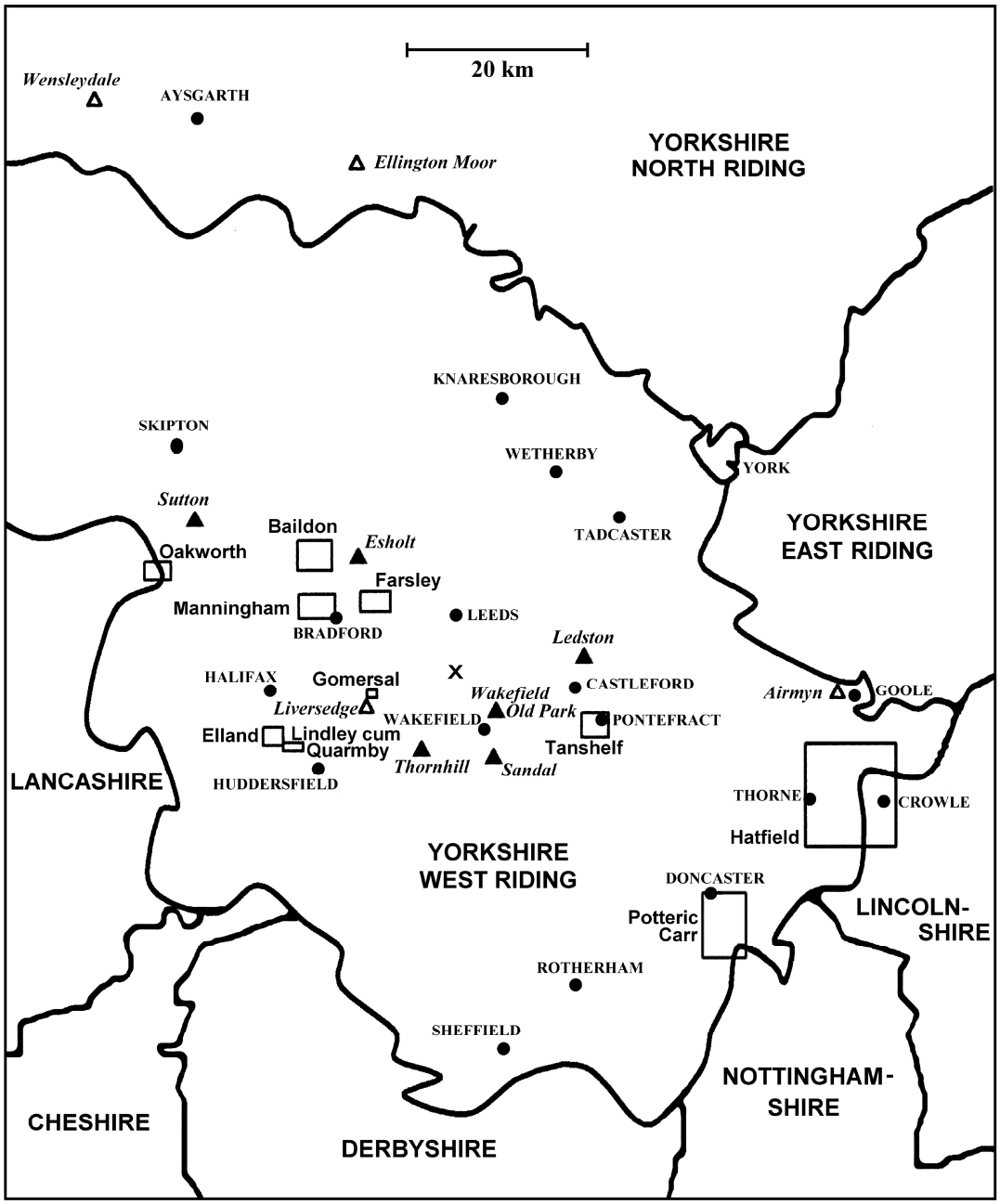

Figure 1. Map showing locations of surveys and locations and approximate areas covered by extant maps of Robert Saxton. □, **map**: ▲, ***extant survey***; △, ***survey or map*** known only from other evidence; ●, **TOWN OR VILLAGE**; ×, Dunningley, the home of the Saxtons. The rectangle shown for each map represents the approximate region included within the frame of the map. Where there is no frame, as for Lindley cum Quarmby and Gomersal, an appropriate frame has been imagined.

Figure 2. Part of the map of Manningham by Robert Saxton, 1613, reproduced at half-size. *The National Archives of the UK, ref. MPC1/210.* [

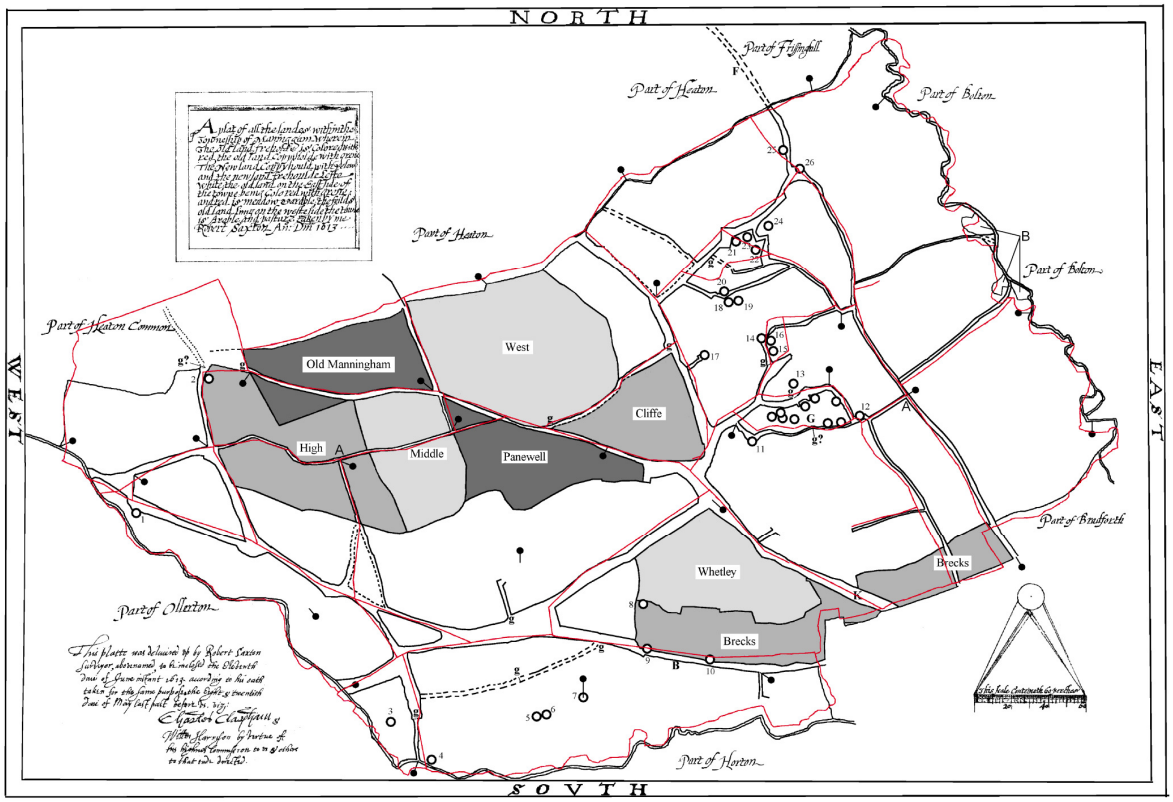

Figure 3. Outline of the map of Manningham by Robert Saxton, 1613, showing the eight medieval fields. **O**, the locations of the houses; ●—, point used in the comparison with the 6-inch map (tip of line); g, gate; K, *The kinges hye streete*; F, *The way from Manniggam to frizingall*. In red, the approximate centres of the roads from the 6-inch map of 1852; A, A, the points used in locating and scaling the two maps (the best-fitted points in the *MapAnalyst*

comparison); B, regions belonging to Bolton. The Ward boundary shown on the 6-inch map has changed slightly in the NW from the Township boundary shown by Saxton. Note the slight relative anticlockwise rotation of the eastern section of the Saxton map with respect to the rest.

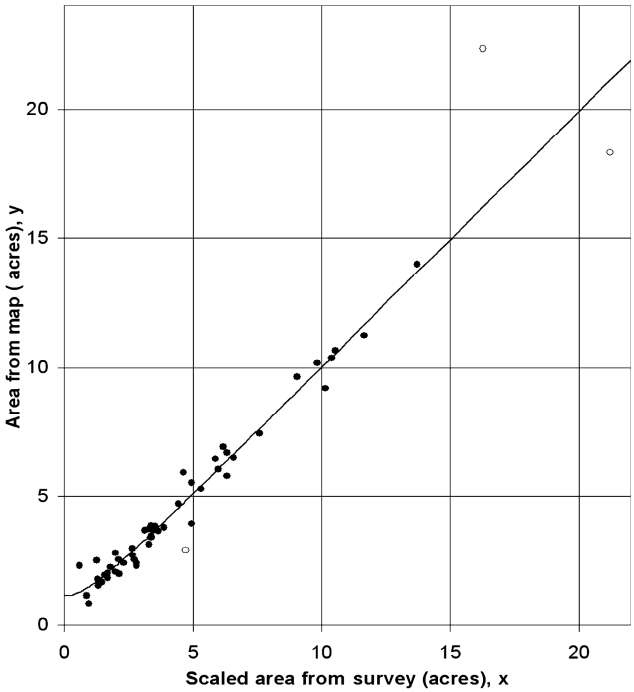

Figure 4. Comparison of areas of identified plots from the survey and map. The line shows the hyperbolic best fit (see text).

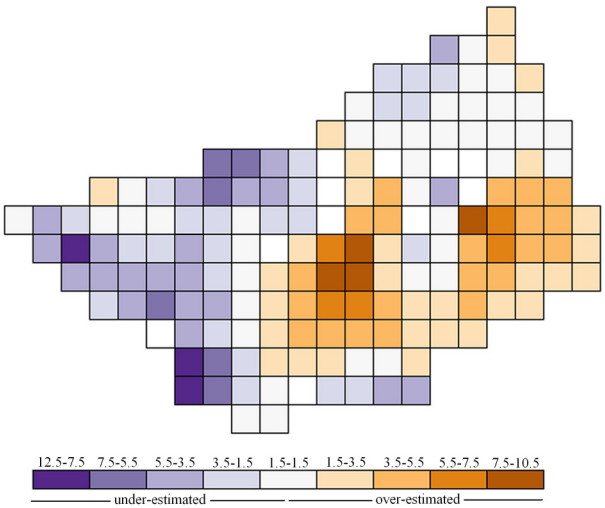

Figure 5. Percentage errors in area for 7-acre squares as deduced from *MapAnalyst* fit. These errors are underestimates (see text).