Three Georges and one Richard Holden: The Liverpool tide table makers

Philip L. Woodworth

Starting in 1770, the brothers Richard and George Holden published some of the first high-quality, publicly-accessible tide tables in the UK. Their Liverpool tables continued to be produced by family members for almost 100 years, and the 'Holden Almanack and Tide Table' was published by different owners for a further century. These tide prediction tables were so much of an improvement on what was available before that they have a small but important place in the history of UK tidal science.[1] They are of special interest in that they came about in what has otherwise been described as the 'doldrums of UK tidal science', when post-Newton developments in this country were modest, and the intellectual leadership of the field had passed to Europe.[2]

In spite of the doldrums, two major achievements took place at the port of Liverpool. The first was the acquisition of the UK's first sustained measurements of the heights and times of high waters by William Hutchinson. This data set eventually spanned 1764–93 with almost no gaps. It was employed intensively within nineteenth century tidal research and is still of scientific interest today.[3] The

[1] A. T. Doodson & H. D. Warburg, *Admiralty manual of tides* (London, 1941); J. R. Rossiter, 'The history of tidal predictions in the United Kingdom before the twentieth century', *Proceedings of the Royal Society of Edinburgh*, B73 (1972), pp. 13–23; D. T. Pugh, *Tides, surges and mean sea-level: A handbook for engineers and scientists* (Chichester, 1987).

[2] Rossiter, 'History of tidal predictions'; D. E. Cartwright, *Tides: A scientific history* (Cambridge, 1999).

[3] P. L. Woodworth, 'A study of changes in high water levels and tides at Liverpool

second achievement was the production of the Holden tables, which, it will be seen, would have been impossible without both the scientific insight acquired by the brothers, and the availability of the first section of Hutchinson's data, by which they fine-tuned their methods.

In addition to their part in the history of science, the tables also form part of Liverpool's local history, being well-known to generations of port users. At one time the tables could be found everywhere: reproduced in newspapers, printed as calendars for offices, and, most famously, published as the main component of a diary-like almanac for each year (sometimes printed in postage-stamp size miniature form for the smallest pockets).

Accurate tide tables were (and are) essential to the port of Liverpool. Both the mean tidal range (6.5 metres) and tidal currents (exceeding 2 m/sec (4 knots) opposite Liverpool and 3.5 m/sec (7 knots) in some channels) are large, and were major factors in port operations. Even in the days of the Old Dock, the most heavily-loaded ships could enter in only a short period around high tide, while 'getting neaped', a tedious and sometimes dangerous wait in mid-river for spring tides to provide sufficient water over entrance sills, became a common problem in the nineteenth century as vessels became larger. Throughout the port's history there are cases of major losses in the approach channels by either sailing ships or under-powered steamers incapable of resisting the tide. Occasional groundings also took place on the entrance sills of the docks as the captains misjudged the falling tide. The problems posed by the tide, together with difficulties caused by weather conditions (especially winds and fog or smog) and river congestion, would always be a major factor in port safety.[4]

Therefore, by the mid-eighteenth century the expanding port desperately needed accurate tables.[5] In a section called 'Observations

during the last two hundred and thirty years with some historical background', *Proudman Oceanographic Laboratory Report,* No. 56 (1999); Woodworth, 'High waters at Liverpool since 1768: The UK's longest sea level record', *Geophysical Research Letters,* 26 (1999), pp. 1589–92; Woodworth & D. L. Blackman, 'Changes in extreme high waters at Liverpool since 1768', *International Journal of Climatology,* 22 (2002), pp. 697–714.

[4] A. Jarvis, 'Safe home in port? Shipping safety within the port of Liverpool', *The Northern Mariner/Le Marin du Nord,* 8 (1998), pp. 17–33.

[5] The first Liverpool 'wet dock' (the Old Dock) opened in 1715, Salthouse (or South) Dock in 1753, George's Dock in 1771, followed by many more: N. Ritchie-

on the Tides' of his *Treatise on Practical Seamanship* the distinguished mariner and dockmaster William Hutchinson remarked, by way of leading up to praise of the Holden tables:

At Leverpool (*sic*) I have observed ships coming in at neap tides about the quarters of the moon, when instead of meeting with high water, as expected by the common way of reckoning, they have found it about a quarter ebb, that for want of water enough they have often struck or come aground and laid upon the bar, when lots of great damage has often been the consequence.[6]

Although the historical significance of the tables is widely recognised, the credit for them has usually been assigned simply to the 'Rev. George Holden' or sometimes to the 'Rev. George Holden, Vicar of Horton-in-Ribblesdale' who was the son of the first George. This confusion between Georges can be forgiven as there were in fact three of them (father, son and grandson), whom I shall denote as George-1, -2 and -3. All three were ordained; all had personal histories which spanned the Lancashire-Yorkshire border in the Pennines; Georges-2 and-3 each helped their fathers to compute the tables, and even held their fathers' clerical positions for short periods; and by all accounts Georges-1 and -2 were physically similar. The lack of credit given to Richard is more unfortunate because it will be seen that his contribution was essential. One aim of this research was to obtain sufficient biographical information so that any confusion between the different members of the family could be removed. That objective has been met by means of a set of biographical notes to be found in Annex 1 of this paper.

However, the major aim was to establish how the Holdens obtained the idea of producing the tables, and acquired the scientific insight to accomplish the task. In addition, I wanted to determine the actual method that they used. The method always remained a closely-guarded family secret, in common with those of the other British 'tide table entrepreneurs' who followed. This secrecy frustrated William Whewell, John Lubbock and other members of the nineteenth-century scientific establishment who believed that the

Noakes, *Liverpool's historic waterfront,* (London, 1984); A. Jarvis, *Liverpool central docks 1799–1905: An illustrated history* (Stroud, 1991).

[6] W. Hutchinson, *A treatise on practical seamanship* (1777, repr. London, 1979 from an original copy by permission of the Syndics of Cambridge University Library).

secrets should be disclosed 'in the interests of science'. The secrets were never disclosed by the family, but this paper will demonstrate what they were.

Essential scientific connections

It is important to realise that Richard and George-1 were not 'scientists' (to use the term invented by Whewell). However, they do appear to have been fortuitously connected with people who could convey new ideas in tidal theory and provide data to refine those ideas. The two key people were James Ferguson, who was almost certainly the main conveyor of scientific ideas, including those developed by Daniel Bernoulli some years before, and William Hutchinson who provided the essential tidal data sets. Brief descriptions of these two important people with close connections with Liverpool, and of Bernoulli, are given below. At the end of this section, the respective roles of Richard and George-1 in connecting to Ferguson and Hutchinson and in the development of the tables are discussed.[7]

William Hutchinson (1715–1801) was one of the most remarkable men in Liverpool's history. He rose from being a common sailor to become a privateer captain alongside Fortunatus Wright, the most famous of the Liverpool privateers. He was also at various times a shipowner, boatbuilder, commercial trader, inventor, author and philanthropist. His importance to the present study stems from his appointment as Dockmaster and Water Bailiff in 1759 and his decision to begin measuring the heights and times of high waters at the Old Dock gates in 1764. He continued with his measurements until August 1793, so providing the first extended time series of sea level measurements in the UK, which has proved invaluable to studies of ocean tides and climate change.[8] Hutchinson gave his first set of measurements (1764–67) to Richard and George-1 so that they could fine-tune their tables by comparison to real data.[9] These

[7] Readers not familiar with the terminology of ocean tides should read Pugh, *Tides, surges and mean sea-level.*

[8] Woodworth, 'High waters at Liverpool since 1768'.

[9] M. Reidy, 'The flux and reflux of science: The study of the tides and the organization of early Victorian science' (Ph.D. thesis, Univ. of Minnesota, 2000). Reidy suggests that Hutchinson may have received commission from the Holdens on sales of the tables. This suggestion seems to have been made first by Whewell, but is unsubstantiated so far as I know.

data are now lost and were lost even in the early nineteenth century (Annex 2). Hutchinson does not seem to have expressed regret at their loss (e.g. in his *Treatise*), perhaps because he knew that they were then still in the possession of the Holdens. He was clearly very proud that the tables were a product of his efforts and of the fact that it had become an offence carrying a £5 fine for a Mersey pilot to be without the tables and a watch.

Hutchinson was either a friend or close colleague of Richard Holden, as demonstrated by their names being linked in several ways. For example, they both took part in the 1764 observation of a solar eclipse (see below). A second example concerns Hutchinson's well-documented involvement since 1763 in the development of reflectors for lighthouses. The Liverpool Council minutes for 1 July 1772 ordered that 20 guineas be given to Mr. Holden (undoubtedly Richard) for 'his invention of the reflecting lights fixed up at the lighthouse for this port' which suggests that Holden had made improvements to Hutchinson's designs.[10] Both men were members of a Liverpool 'Ship Club', and there is a probable reference to Richard in 'The Address' of Hutchinson's *Treatise* in which he refers to discussions with 'a late mathematician friend of mine' on topics of ship design and management.[11] Their common interests may, therefore, have been wide-ranging.

James Ferguson was an astronomer, elected Fellow of the Royal Society in 1763.[12] He wrote several astronomical treatises, of which one contains an 'exercise' for the construction of a tidal clock and a partial autobiography, and had connections with a number of eighteenth century entrepreneurs.[13] Ferguson made part of his living by travelling around the country presenting lengthy series of

[10] E. C. Woods, 'Some history of the coastwise lights of Lancashire and Cheshire, Part 1', *THSLC*, 94 (1944), p. 84, refers to this person as 'William Holden' but on p. 100 as 'Mr. Holden'. Woodworth, 'A study of changes', quoted the former and wondered if he was related to Richard and George. However, from inspection of the original council records, it seems that Woods mis-read the handwriting of 'Mr.' for 'Wm.' There is no mention of a William Holden in *Gore's Liverpool Directories*.

[11] G. Williams, *History of the Liverpool privateers and letters of marque with an account of the Liverpool slave trade* (London, 1897).

[12] E. Henderson, *Extended memoir of James Ferguson, FRS* (Edinburgh, 1867).

[13] J. Ferguson, *Select mechanical exercises shewing how to construct clocks, orreries and sun dials on plain and easy principles,* (London, 1773); P. Fara, *Sympathetic attractions: Magnetic practices, beliefs, and symbolism in eighteenth century England* (Princeton, 1996).

lectures on scientific subjects.[14] He visited Liverpool on several occasions and usually stayed at Hutchinson's house. During one visit in March-April 1764, he gave a course of lectures at the Golden Lion Inn, Dale St., and observed a solar eclipse on 1 April. For accurate timing Ferguson had a meridian line drawn on the lead roof of Hutchinson's house with the aid of 'Mr Holden, master of a mathematical school' (i.e. Richard Holden). Hutchinson provided a good reflecting telescope for viewing the eclipse and Holden used his own instrument.

Ferguson gave Hutchinson a tidal clock which, from Hutchinson's description in the *Treatise*, was not accurate at Quarter Moons as is understandable.[15] Ferguson also almost certainly provided the initial encouragement for Hutchinson to begin his tidal measurements. Hutchinson wrote:

> For these reasons, and being requested by my friend Mr Ferguson the astronomer, who with great labour and pains furnished me with large schemes, tables, plans etc. relating to the tides in the year 1764, when I began, and have continued to make observations on the time and height of the tides flowing at the old dock gates.

Ferguson would have been up-to-date with developments in tidal theory such as those of Daniel Bernoulli (described below) and could have communicated them to Hutchinson and Holden. He was a lifelong friend of Colin Maclaurin, Professor of Geometry at Edinburgh University, whom he had first contacted on aspects of astronomy and who was one of the 1740 tidal 'prize essayists'. Ferguson, Maclaurin and the Liverpool maritime community were also linked through Murdoch Mackenzie. Ferguson and Mackenzie met in Edinburgh and were very close, Ferguson naming his third son after Mackenzie, and both being called protégés of Maclaurin.[16] Mackenzie was a native of the Orkneys and was a 'much travelled marine surveyor'. He had started his career in hydrography on Maclaurin's advice, and Maclaurin had recommended him for the

[14] Each series consisted of about 20 lectures. Participants were presumably invited to buy his books, such as *Astronomy explained*, advertised in *Williamson's Liverpool Advertiser* in April alongside the 1764 course.

[15] This interesting clock, which is described and illustrated by Henderson, is now lost but a near-copy of similar age is owned by a private collector in Liverpool. I am grateful to Mr John Griffiths of the Prescot Clock Museum for allowing me to see it.

[16] J. R. Millburn, *Wheelwright of the heavens: The life and work of James Ferguson FRS* (London, 1988).

task of surveying the Orkneys, where he made his own observations on the tides.[17] Mackenzie is thought to have been the person who introduced Ferguson to Hutchinson. His name appears in several documents in Liverpool, in particular in the Pilot Committee Letter Book at the Merseyside Maritime Museum, in which Mackenzie's advice to the committee on navigation and surveying matters can be found.

An indication of the extent to which Ferguson may have mixed in Liverpool society is given by an obituary following his death at the age of 66 in November 1776, written for the *London Annual Register* for that year by Dr Thomas Houlston of Liverpool, and reprinted the following year in the *London Magazine.* Houlston was a noted physician (MD from Leyden) and member of the staff of the Liverpool Infirmary, who worked with Hutchinson on methods of artificial respiration, primarily by attempting to revive people who had fallen into the docks.[18] He is not the first person one would have associated with Ferguson, given their different areas of interest, and it demonstrates that Ferguson was probably familiar with most people of interest in the town at that time.

Colin Maclaurin and Daniel Bernoulli, Professor of Anatomy and Botany at Basel, were two of the four recipients of the prize awarded in 1740 by the *Académie Royale des Sciences* in France for the best philosophical essay on the 'flood and ebb of the sea'.[19] (The other two, Antoine Cavalleri and Leonhard Euler, need not concern us). They are important to a discussion of the tide tables, as their efforts established the theoretical basis for the Holdens' work.

Maclaurin proved what Newton had assumed intuitively, that the shape of an otherwise spherical ocean in static equilibrium with the tidal force induced by a disturbing body (i.e. either the Moon or Sun) is a prolate spheroid (a shape like a rugby ball with one elongated axis of symmetry), the major axis of which points towards the body. Bernoulli's *Traité Sur le Flux et le Réflux de la Mer* in effect extended Maclaurin's essay, although at the time he was unaware of Maclaurin's contribution. His essay introduced the so-called Equilibrium Theory, which describes the temporal and spatial structure of

[17] M. Mackenzie, 'The state of the tides in Orkney', *Philosophical Transactions of the Royal Society*, 46 (1749), pp. 149–60.

[18] Hutchinson, *A treatise on practical seamanship*; T.H. Bickerton, *A medical history of Liverpool from the earliest days to the year 1920* (London, 1936).

[19] Cartwright, *Tides: A scientific history*.

the Equilibrium Tide due to the Moon and Sun in combination. In other words, Bernoulli combined the two individual prolate spheroids into one overall shape, and introduced the lunar and solar orbits and Earth rotation into the discussion, so that the time dependence of the Equilibrium Tide at any point on the Earth's surface could be parameterised. By this means, Bernoulli was able to construct a crude, generalised tide table for any port with predominantly semi-diurnal (twice daily) tides.

An important factor with respect to the Bernoulli method was the publication of the *Nautical Almanac* under the direction of the fifth Astronomer Royal Neville Maskelyne, who had his own interests in ocean tides. As is well-known, the *Nautical Almanac* was published primarily for the purpose of navigation at sea using the method of 'lunar distances'. However, the tables of lunar and solar parameters contained in the 1767 and subsequent editions were in an ideal form for application to Bernoulli's method, and, once the Holden technique had been established, the *Almanac* was the only source of information required for the ongoing computation of the tide prediction tables.[20]

It has been suggested that Bernoulli's essay was not available in English until 1830, and that the text of the essay was not widely available (e.g. it was not to be found at Oxford and Cambridge).[21] However, it is inconceivable that his ideas would not have been transmitted after 1740 to Maclaurin and his circle, as well as formally through the Royal Society. Either way, James Ferguson, with his interests in tides, would have been well aware of them by the 1760s, and could easily have provided advice to Richard Holden during his frequent visits to Liverpool.[22]

It is clear from knowledge of the individuals described above and of mid-eighteenth century Liverpool in general, that a number of

[20] Reidy suggests that other almanacs might have been used. However, the close timing of the first editions of the *Nautical Almanac* and the Holden tables, together with the evidence from George-3's correspondence (Annex 2), suggests that the *Nautical Almanac* was always used; see Reidy, 'The flux and reflux of science'.

[21] J. W. Lubbock, *Account of the Traite . . . of Daniel Bernoulli and treatise on the attraction of ellipsoids* (London, 1830); Reidy, 'The flux and reflux of science'.

[22] George-1's will suggests that he read extensively in French, leaving his collection of books in English and French (other than those related to the tide tables) to three of his daughters. Consequently, if Richard and George had interests in tides prior to meeting Ferguson, they might have acquired a copy of Bernoulli's essay in its original French, after its publication in various forms in the 1750s.

special factors came together at this time. The first factor, although a qualitative one, is the development of the town itself both culturally and commercially. For example, the Liverpool (later Lyceum) Library, 'the first gentlemen's subscription library in England', had been established in 1758 accompanying a growing general scientific and artistic interest. These cultural developments paralleled the needs of the expanding port, stimulating considerations of, for example, more efficient dock operations and good navigation through Liverpool Bay and the Mersey, of better ship design and safety at sea, and of care of widows and children of seafarers. Good tide tables were clearly one small piece in these developments.

These cultural and economic developments resulted in Liverpool being an important place to visit for peripatetic lecturers such as Ferguson, and his talks must have attracted a sizeable section of what might have been called the 'intelligent middle class' of the town. It is known that Ferguson stimulated Hutchinson's tidal observations. Consequently, it is likely that he suggested Richard's use of Hutchinson's measurements, providing scientific advice as appropriate. Richard would have been one of the mathematically best-qualified people in Liverpool to do the job, and someone to whom Hutchinson would have been happy to lend his tidal data set.

As to which of the brothers Richard and George-1 was the more important in this set of links, there are three points to make in Richard's favour. First, there is the statement on the cover page of the 1781 tables (but not the 1795 and later tables) that they are 'According to the Theory of the Late Mr. R. Holden' (Figure 1a). Second, there is an 1834 letter from George-3 to Whewell (Annex 2) which suggests that, so far as family recollections went, Richard had the greater scientific input. A third and more practical point is that Richard was based in Liverpool; there is no evidence that George-1 ever visited Liverpool or met Hutchinson or Ferguson.

While most of the linkage, and probably most of the scientific insight, was provided by Richard, it is clear that the work of computing the early tables was undertaken primarily, or even entirely, by George in the remote, pastoral and 'otherwise destitute' region of the Pennines far from Liverpool. For example, in the first volume of Hutchinson's journal of measurements one reads

The first sheets [i.e. the missing data for 1764–67] cut out to give Mr. Richard Holden . . . by which he found theory from natural causes to agree with the [tide tables], and his brother George Holden continues the author of our tide tables.

This assertion is supported by Figure 1a and George-3's 1834 letter. In addition, the earliest Preface to the tables that exists (from 1773, see Annex 3), which pre-dates Richard's death in 1775, is signed only by George, and gives credit to a Bryan Waller, with no mention of Richard.[23]

Once the tables were into production, the Holdens may not have had the opportunity for further links to tidal scientists (recall that Ferguson had died in 1776), and, even if such links had been possible, they may not have been desirable as by then the Holdens had their 'secrets' to keep. All three Georges deserve great credit for routinely producing the tables over considerable periods. From Figure 1a, we see that George-2 was helping his father with the tables as early as 1781, which means that by the time he died in 1820 he had been associated with the tables for almost half a century. George-3 provided a similar service in the nineteenth century. However, I have not discovered any change that either of them made to the original method, beyond George-3's trivial changes to the listings of the times of high water from apparent solar time to Liverpool Mean Time in 1837 and then to Greenwich Mean Time in 1851. For almost a century, the tables were published in the same format and using the same method.

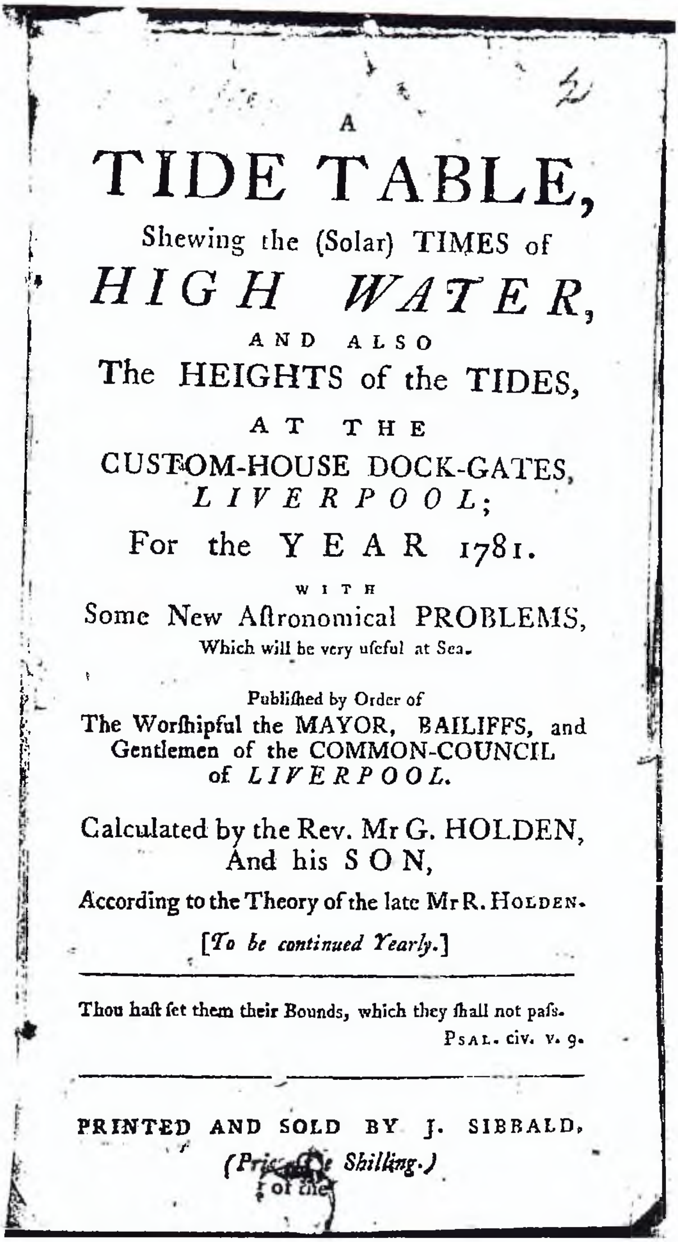
Consequently, two conclusions can be drawn: there was little or no fresh scientific insight after the first development of the tables around 1770; and it is unfortunate that the 'headmaster of the free grammar school at Horton' (George-2) receives more mention than his uncle and father.[24]

Publicly-accessible Liverpool tide predictions before 1770

Most of the methods used in England in early times to predict the times of high water were variations on a general rule, which was to assume that the high water at Full or New Moon occurs at a certain time of day at each place; on other days in the lunar cycle four-fifths

[23] *Gore's Liverpool Directories* for 1766–1774 contain several Wallers but no Bryan. It is possible that he was not of sufficient status to merit an entry. However, more likely he lived near George: Mr. John Wilson informs me that there was a Waller family at Thornton-in-Lonsdale. This possibility requires further research.

[24] For example, in Rossiter, 'The history of tidal predictions'.



A

TIDE TABLE,

Shewing the (Solar) TIMES of

HIGH WATER,

AND ALSO

The HEIGHTS of the TIDES,

AT THE

CUSTOM-HOUSE DOCK-GATES,

LIVERPOOL;

For the YEAR 1781.

WITH

Some New Aſtronomical PROBLEMS,

Which will be very uſeful at Sea.

Publiſhed by Order of

The Worſhipful the MAYOR, BAILIFFS, and Gentlemen of the COMMON-COUNCIL of *LIVERPOOL*.

Calculated by the Rev. Mr G. HOLDEN, And his SON,

According to the Theory of the late Mr R. Holden.

[*To be continued Yearly.*]

Thou haſt ſet them their Bounds, which they ſhall not paſs.

Psal. civ. v. 9.

PRINTED AND SOLD BY J. SIBBALD,

(*Price One Shilling.*)

FIGURE 1A *Cover page of the 1781 Holden tables, the earliest surviving set. British Library.*

JANUARY, 1781.

	D. H. M.		D. H. M.
Firſt Qr.	2 8 1 E.	Full Moon	10 8 51 M.
Laſt Qr.	17 1 40 M.	New Moon	24 11 58 M.

DAYS.		Morn.		Even.		Heights		Clock bef. Sun.
		H.	M.	H.	M	F.	I.	M.
Monday	1	3	3	3	24	13	0	4
Tueſday	2	3	47	4	11	12	4	5
Wedneſday	3	4	37	5	4	11	9	
Thurſday	4	5	34	6	6	11	8	
Friday	5	6	38	7	10	11	10	6
Saturday	6	7	44	8	13	12	6	
SUNDAY	7	8	41	9	7	13	5	7
Monday	8	9	31	9	55	14	5	
Tueſday	9	10	18	10	40	15	5	8
Wedneſday	10	11	2	11	24	16	5	
Thurſday	11	11	45	—	—	17	4	
Friday	12	0	7	0	28	18	0	9
Saturday	13	0	50	1	13	18	3	
SUNDAY	14	1	36	1	59	18	1	
Monday	15	2	22	2	46	17	6	10
Tueſday	16	3	11	3	37	16	8	
Wedneſday	17	4	4	4	34	15	6	
Thurſday	18	5	4	5	37	14	6	11
Friday	19	6	11	6	50	13	8	
Saturday	20	7	27	8	5	13	5	
SUNDAY	21	8	39	9	9	13	10	12
Monday	22	9	37	10	3	14	4	
Tueſday	23	10	28	10	50	14	11	
Wedneſday	24	11	10	11	29	15	6	
Thurſday	25	11	48	—	—	16	0	13
Friday	26	0	5	0	24	16	2	
Saturday	27	0	41	0	57	16	2	
SUNDAY	28	1	14	1	30	15	10	
Monday	29	1	46	2	3	15	4	
Tueſday	30	2	19	2	36	14	7	
Wedneſday	31	2	54	3	12	13	8	14

FIGURE 1B *Example page for January 1781 showing the two predicted times of high water each day, and one height for the period between 6am and 6pm (using apparent solar time and height above the Old Dock Sill). The print format of the tables was essentially the same for a century, times later being converted into mean time. British Library.*

REV. GEORGE HOLDEN, M.A.

To the Right Honourable the Lord Mayor, Recorder, Aldermen, & Members of the City Council, to the Chairman & Members of the Mersey Docks and Harbour Board, to Shipmasters, and to the Merchants & Tradesmen of Liverpool, this

Almanack and Tide Table

is respectfully inscribed by their most Obedient Servant,

Geo: Holden

FIGURE 1C *Portrait of George-3 which appeared in many 20th century editions of the Holden tables, beneath which the publishers inserted the signature of George-1 copied from earlier tables. Liverpool Record Office & Local Studies, H525.69 HOL.*

of an hour (48 minutes) was added for each day of the Moon's age (0–29 days).[25] The time of day of the high water at Full or New Moon was called the 'Establishment' and sailors would have owned tables of Establishment for the ports that they visited. Something like this rule would have been what Hutchinson referred to as the 'common method' in the quotation given above.[26]

An advantage of the simplicity (or crudeness) of this rule is that it could be engineered into the form of a tidal clock (in effect, an early analogue computer) in which parallel clock mechanisms with periods of 12 and 12.4 hours replicated the solar and lunar components of the tide, indicating the time of the next high water on the clock face. Such devices inevitably worked reasonably at spring tides and less well at neaps. Several examples of tidal clocks which were visible to the public (e.g. on church steeples) can still be found.[27] However, so far as I know, no such public clock was constructed in Liverpool. The tidal clock provided by Ferguson to Hutchinson in 1764 was one of a number of smaller, domestic clocks which he designed.[28]

In order to acquire a feel for the quality of publicly-accessible tide prediction tables available in Liverpool before the Holdens, I looked at one year of predicted high waters printed in *Williamson's Liverpool Advertiser* between June 1756 and June 1757.[29] These values were published each Friday for the ensuing week, containing times of high waters only and not heights, and were unattributed. I expected to find a crude description of high water times, based on something like the 'common rule', but I was surprised to find them so useless (no other word will do). Any user would have made major errors sooner or later if he had relied on them, and presumably no knowledgeable ship's captain would have used them at all.

The tables consisted of two columns (morning and evening times) for each day, with never a 'no tide'. With the average time between high waters being 12.4 hours, there should be one or two mornings

[25] Cartwright, *Tides: A scientific history.*

[26] Reidy in 'The flux and reflux of science' describes a more complicated form of the 'common method' which applied at the end of the eighteenth century and which was available within publications such as J. W. Norie's *Practical Navigation.*

[27] Cartwright, *Tides: A scientific history.*

[28] Millburn, *Wheelwright of the heavens.*

[29] These studies of the earlier period are not affected by the '11 day jump' which accompanied the adoption of the modern (Gregorian) calendar a few years earlier in September 1752.

and evenings each month with no high water. However, a time was always listed for each day in each column. Closer inspection showed that the interval between consecutive high waters was almost always 12.4 hours, with no variations of +/- 0.2 hours as would be expected from the Moon's orbit. Occasionally, another interval of about 12 hours was used (seemingly at random), while in the case of the 'no tides' the interval would be taken at face value as 0.4 hours. Finally, considering the predicted times *in toto,* it seems that they lined up approximately with times of the passage of the Moon overhead, with no consideration of the 'Establishment' or 'phase lag' of the tide relative to the Moon's timing.

The fact that Liverpool's newspapers published such poor tide tables, grossly inferior to those computable by even the 'common method' and to those available at London a century before, is astonishing, and explains why the work of the Holdens would have been so well-received a few years later by the community of port users, including experienced mariners such as Hutchinson. The first Holden set appeared in the *Liverpool General Advertiser* on 6 July 1770. However, even these new Holden predictions were restricted to just the times of high waters, without information on heights, in spite of the fact that the Holdens clearly thought it important to know both quantities (Annex 3). A reader would have had to purchase the tables separately if he had wanted the heights as well (e.g. Figure 1b). This situation persisted until 7 February 1791 when heights (one value per day for the daytime tides only) were included in the *Advertiser* for the first time.

The Holden tide table method

The eminent philosopher of science Rev. William Whewell (1794–1866) wrote:

> Liverpool, London and other places had their tide tables constructed by undivulged methods, which methods, in some instances at least, were handed down from father to son for several generations as a family possession, and the publication of new tables, accompanied by a statement as to the mode of calculation, was resented as an infringement of the rights of property. The mode in which these secret methods were invented was that which we have pointed out: the analysis of a considerable series of observations. Probably the best example of this was afforded by the Liverpool tide-tables. These were deduced by a clergyman named

Holden, from observations made at that port by a harbour-master by the name of Hutchinson, who was led, by a love of such pursuits, to observe the tide for above twenty years, day and night. Holden's tables, founded on four years of these observations were remarkably accurate.[30]

Whewell worked closely with John Lubbock during the nineteenth century on an improved understanding of ocean tides and on the development of improved tidal predictions for British ports. He was clearly impressed by the accuracy of the Holden method and tried several times to encourage George-3 to divulge its details, although Holden stressed that he was unwilling to do so on account of the income they brought.

There were two main approaches to the construction of tide prediction tables during the eighteenth and nineteenth centuries.[31] The first required the use of considerable amounts of tidal information (i.e. high water heights and times), together with data sets of lunar age and meridian passage times and lunar and solar parallax and declination. If a long period of data were available (in principle a lunar 'nodal cycle' of 18.6 years would be ideal), tidal heights and times could be studied in terms of the variation of each parameter separately, with findings combined into an overall description of the dependence of the tide upon each component of the parameter set.

This approach was essentially the same from the work of Jacques Cassini in the early eighteenth century through to that of John Lubbock in the mid-nineteenth century, and formed the basis of practical tidal prediction even into the twentieth century in the Admiralty Tide Tables.[32] From the above quotation, one can conclude that Whewell actually believed that the Holdens also worked this way, thanks to their access to the several years of Hutchinson's observations. However, if he had read carefully the Preface to the tables (Annex 3), it would have been clear that George Holden did not think a great deal of Cassini's method, which would anyway have required data-processing resources beyond the means of a rural curate.

A second approach become evident after 1740 with the publication of the form of the Equilibrium Tide by Bernoulli. The two

[30] W. Whewell, *History of the inductive sciences from the earliest to the present time* (London, 1837).

[31] Cartwright, *Tides: A scientific history.*

[32] Rossiter, 'The history of tidal predictions'; Cartwright, *Tides: A scientific history.*

prolate spheroids of the Equilibrium Tide can be described (somewhat crudely) as the theoretical tides which would occur in the ocean, due to the gravitational forces of the Moon and Sun, if the Earth was covered uniformly by an ocean which responded instantly to changing forces (i.e. was inertia-free and not constrained by the dynamics of moving large amounts of water around the ocean basins). Newton provided much of the insight based on considerations of an idealised Moon or Sun: Bernoulli deduced the combined Equilibrium Tide that would result from knowing the orbits of the real Moon and Sun, such as were provided later to good accuracy by the *Nautical Almanac*. It turns out that the *spatial* variation of the tide in the real ocean is far more complicated than that of the Equilibrium Tide, because of the ocean dynamics, but Bernoulli found that its *temporal* variation at any location with predominantly semi-diurnal tides (which includes most of the European Atlantic coastline) can be parameterised in terms of the Equilibrium Tide to a good approximation with a small number of adjustments. He was able to compute a generalised tide table for such locations, and, in so doing, is credited with being the first to blend Newtonian theory with real data to produce practical tables.

In order to apply the method to a particular port, knowledge of two parameters is needed, which in this case would have been readily obtainable from an inspection of the four years of Hutchinson's data. The first is an estimate of the 'solar-lunar potential ratio' which in the theoretical Equilibrium Tide has a value of 0.46, although it has a much lower value of approximately 0.33 around UK coasts.[33] The second is a measure of the 'Age of the Tide', which is the time by which spring tides lag the New or Full Moon, and which is typically 1–2 days around the UK (43 hours at Liverpool).

The second approach has the great advantage of computational simplicity, which Richard and George-1 would have had no difficulty with. Therefore, one might have known that the Bernoulli method's analytic formulation in terms of lunar and solar parameters would have had greater appeal to the Holdens.[34] Even if the first approach might be ultimately more accurate than the second, as

[33] Doodson & Warburg, *Admiralty manual of tides.*

[34] This suggestion has also been made recently by Reidy in 'The flux and reflux of science' although without a quantitative study. Reidy also suggests that most other tide table makers of this period must have worked in a similar way.

demonstrated by Lubbock's later work, the second would prove almost as good for everyday use.

In George-3's letter to Whewell in 1833, there is an important clue that the Bernoulli method was used (Annex 2). However, in order to verify this suspicion, the predicted heights and times from the 1795 Holden tables were transferred into computer files. The tables contain only one high water height prediction per day for the tide between 6 am and 6 pm (Figure 1b). Holden claimed that 'this will always be sufficient, as the night tides are known accurately enough from them, being something lower in the months January, February, March, April, November, and December, and higher in all the other months'.[35] Two high water times are shown for each day, separated into morning and evening and given in terms of local apparent solar time ('sun dial time'). The 1795 tables were chosen as they were the earliest set available to me in Liverpool libraries. Files of lunar age, declination and parallax, each predicted for noon each day, together with the predicted time of the lunar passage of the Greenwich meridian, were constructed from the *Nautical Almanac* for that year. Finally, a small computer program based on Bernoulli's method was written to predict the heights and times of high water for the year to be compared to those obtained from the Holden tables.

From some trials with the program it appears that the Holdens employed a solar-lunar potential ratio of around 0.36.[36] They accounted for lunar parallax and declination exactly as described by Bernoulli, but took no account of solar parallax or declination; and, most importantly, they accounted for the Age of the Tide not only by adjusting the time of Mean High Water with respect to the time of lunar passage of the meridian (i.e. what is accounted for by the phase lag of the M_2 constituent in modern harmonic analysis), but also by lagging the Bernoulli-predicted heights and times (relative to lunar passage) by four tides.

35 In modern terms, this is a consequence of the 'diurnal tidal inequality' which much exercised nineteenth century tidalists and, in particular, of the K_1 harmonic constituent which has a Greenwich phase lag at Liverpool of approximately 200° and an amplitude of about 11 cm.

36 This figure assumes that they used a value for mean lunar parallax close to 3422.5 arcseconds. This is a modern value for the Moon; if they used a slightly different value, then their determined potential ratio would have to be scaled by the cube of the ratio of the mean parallaxes. Such an assumption has no effect on the tidal predictions themselves.

The predicted high water times obtained by this small program are virtually identical to those of the Holden tables. The root-mean-square (rms) difference between them is only 1.5 minutes, of which a large part can be explained by the times in the tables being given to the nearest minute.

Once one can predict the time of high water, it is straightforward to insert that value into Bernoulli's equations to obtain the height of the combined lunar-solar high tide. This height then has to be scaled by a constant of proportionality which converts the Bernoulli value into the actual levels as observed at the port (i.e. a type of 'admittance'). In the present exercise, the constant that the Holdens used can be determined most easily by means of linear regression of the Bernoulli values with those of the Holden tables; Holden himself would have performed some kind of comparison of the Bernoulli values to the high waters of the Hutchinson data set.

A further, somewhat *ad hoc* complication is that the Holdens apparently applied an additional 17 cm (or a corresponding number of inches) offset during summer and autumn (days 130–313), to reflect in a rough-and-ready way the fact that the daytime tides are on average lower than nighttime tides in summer (and vice versa in winter), as described above. (There is also a possibility that, if Holden had inspected Hutchinson's data in detail, he would have realised that high waters are generally higher during the winter than the summer, owing to the seasonal cycle of mean sea level). If one then undertakes a slightly more complicated derivation of the overall constant of proportionality, but allowing for the offset, one obtains a time series of predicted daytime high water levels virtually identical to those of the tables (Figure 2). The rms difference between them is 3.3 cm, part of which can be explained by the Holden heights being given to the nearest inch. Subsequently, the tables for 1781, 1809 and 1865 were studied in a similar way as for 1795, with the conclusion that the method used by the Holdens was essentially the same throughout (although of course without checking all of the tables I cannot exclude the possibility that one of the Georges may have been tempted to tinker with the method occasionally).

The close numerical agreement of the results of the calculations using Bernoulli's method to the values published in the Holden tables provides convincing (if not absolute) proof of the Holden method. Once it had been developed by Richard and George-1, the

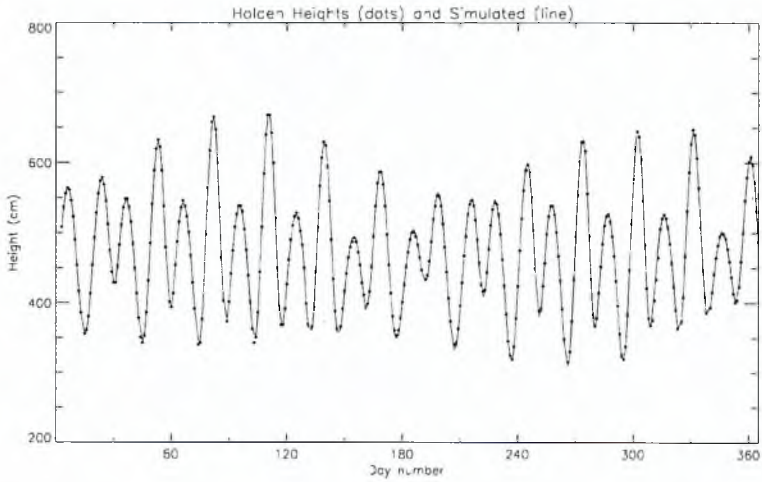


Figure 2 *Heights of daytime high waters for 1795 from the Holden tables (dots) and as computed by the author using the Bernoulli method (line).*

high water predictions for further years would have been readily computable as soon as the *Nautical Almanacs* for those years became available. Consequently, it is not surprising that, even in George-3's time, the technique was still proving to be a welcome source of income for comparatively little effort. It is strange, given the predominantly semi-diurnal character of the tides around most of the UK coast, and the potential for the generic application of the method to other locations, as long as a small amount of observational data were available to determine the necessary few parameters, that none of the Holdens sought to extend their profitable activity elsewhere.[37]

Even though the Holden method appears to be no longer a secret, a question remains as to its accuracy. From the earliest surviving Preface to the tables (from 1773, which was included in the Hutchinson *Treatise* and is reproduced in this paper as Annex 3), it can be seen that Holden claimed his high water predictions to be accurate to seven inches (a number suspiciously close to the

[37] The Preface to the 1795 tables shows that George-2 did have access to a few months of data from Bristol. For many years, tide tables for English ports, including Bristol, were based on applying small corrections to either the London or Liverpool tables.

seasonal offset described above) and five minutes.[38] In order to test this claim, the Holden predictions for 1795 were compared to those obtained using modern techniques of the Proudman Oceanographic Laboratory. Such comparisons are necessarily complicated, and anyone interested in the technical details is invited to consult the author. However, one can say that, if allowance is made for the fact that the predictions represent the main semi-diurnal characteristics of the tide only, and cannot accommodate diurnal terms properly and long period and shallow water terms at all, then the claims to accuracy (or perhaps 'precision' would be a better term) were justified. If no allowance is made for the simplicity of the method, and especially for a systematic shift of approximately 8 minutes in the predicted times of high water if shallow water terms are ignored, then it seems that the claims to accuracy in heights and times were optimistic and could be increased realistically by about 50%.[39]

It is worth noting at this point that, if accuracy is being considered, then the Holden tables were by the mid-nineteenth century not necessarily the best available in Liverpool, although long familiarity by port workers and town council had established more trust in them than in competitors. Other tables were available at an early stage from Elliot (1798–1807), continued by Wolfenden (1808 onwards), although they were almost certainly no better than Holden's. However, from the middle of the nineteenth century the Holden tables had a major competitor in 'Smith's Liverpool Commercial Almanack and Tide Table. Calculated by Alex Brown, A.M.' based on the use of the Hutchinson data by John Lubbock and colleagues at the Royal Society.[40] The main advantages of these tables were the proper consideration of the 'diurnal inequality' instead of the *ad hoc* Holden treatment, and the prediction of low water heights and times as well as high waters. It has been suggested that one reason for Lubbock's support for the development of Smith's tables was to force the hand of George-3 to divulge his

[38] The earliest surviving complete set of tables, including Preface, is from 1781 and is held at the British Library (Figures 1a,b). Weekly listings of high water times for earlier years can be found in preserved copies of the various *Liverpool Advertisers*.

[39] The tables do not always state which datum the predicted high water levels are to be referred to. However, Old Dock Sill datum, as used at Liverpool for many years, would have been assumed by any user.

[40] Rossiter, *The history of tidal predictions*.

methods.[41] If that was the intention, then Lubbock was unsuccessful. The Holden product was able to eventually see off the competition, partly by continuing to stress its close links to the town authorities (see Figure 1a,c)

The Holden tide tables after 1865

The main purpose of this report was to investigate the period up to George-3's death in 1865. However, some comments should also be made on the fate of the tables after this date. First, the tables always appeared, even up to the last edition in 1974, as if they had been computed by George-3. In many editions, a copy of his portrait was included, underneath which was a signature which the reader would have assumed was George-3's, but which was actually George-1's, as can be verified by comparison to a signature in the 1781 edition (Figure 1c).

In 1867 the format of the tables (now published by C. W. Townshend & Son, Castle Street, Liverpool) changed from a listing of two times and one height of high water each day to two times and two heights. This was an attempt by the publishers to accommodate properly the 'diurnal inequality' which Lubbock and others had investigated many years before. In order to test the quality of this development, the heights and times of high waters from the 1872 tables were entered into computer files. A comparison of these values to modern predictions showed that diurnal inequality was accounted for to a reasonable approximation for most of the year (i.e. with an approximately correct amplitude and phase lag). However, I have failed to discover who was responsible for these improvements; as mentioned above, any casual reader of the tables would have understood George-3 to have still been the author.

One possibility is that the owners of the tables simply acquired published tidal predictions from the Hydrographic Department of the Admiralty which was then, and remains, the main source of tidal predictions in the UK. The Admiralty had produced predictions for UK ports routinely since 1833, although not at first for Liverpool. These were the forerunners of the Admiralty Tide Tables (ATT) which adopted that now familiar name in the Admiralty's 1918/19 publication. However, inspection of the archives of the Hydrographic Office (as it is now styled) showed this suggestion to be

[41] Reidy, *The flux and reflux of science.*

incorrect, the values published by the Admiralty and in the Holden tables being similar, of course, but sufficiently different to indicate different methods of computation. Therefore, the authorship of the tables for the latter part of the nineteenth century remains a mystery.

In the 1876 edition, the word 'copyright' appeared on the front cover together with a statement on an inside page that any infringement of copyright would be proceeded against. This is probably the reason for the suggestion that 'the method was copyrighted in 1867' (*sic*).[42] Copyright would apply only to the printed tables; so far as I know, the method was never patented.

By the 1900s the tables had passed into the ownership of the Liverpool Printing & Stationery Company, with published tidal predictions still similar to, but different in detail from, those of the Admiralty. However, in 1915 the Holden tables contained values identical to those in the ATT, with the latter computed by the 'harmonic method' and credited to the tide prediction machine of Mr E. Roberts.[43] Consequently, it seems that the publishers simply copied tidal predictions from the ATT without acknowledgement, perhaps owing to the difficulties of wartime. Holden and ATT values remained identical until 1924, when the Holden publishers acquired harmonic method values computed by the University of Liverpool Tidal Institute (the predecessor of the Proudman Oceanographic Laboratory at Bidston Observatory). Bidston Observatory remained the supplier of tidal information to the Holden tables until their last edition.

Throughout the nineteenth century the published tables had expanded into an almanac containing everything a Liverpool port and river user could need in addition to the tide tables themselves. By 1915 the almanac contained around 300 pages. The additions included calendars of coming events, shipping line and river traffic information, astronomical data, mathematical conversion tables, information on sizes and sill depths of docks, tidal stream data for pilots, climatological meteorological data, UK geographical information, maps of Liverpool Bay and the Mersey and advertisements. In addition, simple tide tables for seven other UK ports and Brest had been added (computed one assumes by the Admiralty).

The size and the specialised nature of these publications were undoubtedly major factors in their demise, coupled with the major

[42] Rossiter, *The history of tidal predictions.*
[43] Cartwright, *Tides: A scientific history.*

changes in the port itself in the latter part of the twentieth century. One milestone occurred in 1946, when paper was in short supply after the war, and a change of ownership at James Laver printers resulted in that company deciding to produce their own much simpler and cheaper set of tide tables. This product (also with tidal predictions supplied by Bidston Observatory) gradually took over the Liverpool tide table market and survives to this day. The Holden version passed into the ownership of McCorquodale & Company in 1968 but with dwindling sales. The last edition of the Holden tables (the 205th) appeared in 1974.[44]

Conclusion

This report described two detective stories. One took the form of an investigation into the exact method by which the Holden tables were computed, and was necessarily somewhat technical in nature. After more than 230 years have passed, it was satisfying to lay bare the 'Holden secrets' at last. The other story was concerned with determining how ideas could be transmitted from Europe to the north of England, and to people who can in no sense be considered members of the British scientific élite. In some histories of tidal science, the Holdens do not receive a mention at all, because they did not themselves further knowledge in the field (and after all they attempted to keep what they knew secret). However, one can argue that, in terms of benefit to society in general, their contribution was at least as important as those of their scientific contemporaries. The 'doldrums of UK tidal science' had strong gusts of fresh air from Liverpool in the work of Hutchinson and the Holdens.

Acknowledgments

Drs David Cartwright, FRS, and Michael Reidy gave valuable advice on aspects of this paper. My thanks go to the Local Record Offices at Liverpool, Chester, Preston and Northallerton and to the Borthwick Institute of Historical Research at York University. I also thank Ms Mary Creaser, Archivist Bradford Diocese; Mr & Mrs Ron Dagnall of Rainford; Rev. John Dalby, Vicar of Clapham & Austwick; Mr Garry

[44] No edition later than this date has been found. Bidston Observatory did not keep adequate records of the companies to which it provided tidal predictions and McCorquodale printers no longer exists.

Gannicliffe of Laver Publishing; Mr Paul Hughes of Liverpool John Moores University; Dr Adrian Jarvis, Director of the Liverpool Centre for Port & Maritime History; Mrs Eileen Kermode of Maghull; Commander John Page of the UK Hydrographic Office; and Mr John Wilson of Tatham.

ANNEX 1: SHORT BIOGRAPHICAL DETAILS OF EACH HOLDEN[45]

Francis Holden

The family history starts with the marriage of Francis Holden, from Champion near Slaidburn in Lancashire (but at that time in Yorkshire), and Hanna Prockter, of Clapham in Yorkshire at Thorton-in-Lonsdale on 17 September 1716. Champion is a section of hill-farming land to the north of Easington Fell. The parish records show that Richard was their first child, baptised on 9 March 1718.[46] In the record, Francis is said to be from Swallowscars, which is a farm at the west end of the Champion area. Mary was the second child (1719), after which the family moved to Kettlesbeck Farm near Eldroth in the parish of Clapham and Austwick. The Clapham parish records list the baptisms of a steady stream of children: Elizabeth (1721), George (baptised 12 May 1723) and nine others up to 1740. Francis was buried on 15 December 1741 at Thornton-in-Lonsdale. No record of a will has been found.

Richard Holden

As Francis's eldest son, Richard might have been expected to inherit the farm and stay in Yorkshire. However, nothing is known of him between his birth and appearance in Liverpool in the 1750s well into middle age. A search of the records of all the then Scottish and English universities showed no evidence for someone of his name having attended. The earliest reference to him in Liverpool can be found in his will. That refers to an indenture made on 20 January 1756 with Jonathan Gouldson, a feltmaker from Chester. If marriage

[45] A more detailed version of this annex is available as Proudman Oceanographic Laboratory Report No. 58.

[46] Modern style of dates has been used throughout. Parish records occasionally give the date of birth as well as baptism, but not in this case.

to Gouldson's only daughter Esther took place, Richard agreed to leave one third of his estate to her in his will. Marriage must have followed soon afterwards, although the place and time have not been found, for the records of St. George's parish in central Liverpool refer to the baptism of Richard's daughter Hannah on 8 February 1757. So far as I know, Hannah was Richard's only child. In both the indenture and in the parish records, he is referred to as a 'brazier' (brass worker), while in the parish records he is shown to be living in Castle Street.

The circumstances in which the Castle Street establishment turned into a school are unknown, although this must have occurred before 1764 when Richard helped in the observations of a solar eclipse (see above). Thereafter, *Gore's Liverpool Directories* for 1766–73 all contain an entry for his school in Castle Street. The earliest Liverpool newspapers date from the 1750s (if one ignores the *Liverpool Courant* in 1712) and might have provided information on the founding of the school if it had been advertised in this period, as it was later. However, no mention of the school at this time has been found. In December 1773, *Williamson's Liverpool Advertiser* carried a long announcement that the school would be moving the following May to Rainford outside Liverpool, to a house which is now the Golden Lion Inn. In December 1774, the Rainford Academy advertised its opening for the new year on 9 January. This turned out to be the day Richard died. He was buried in the graveyard of the Old Chapel at Rainford, which has since been replaced by All Saint's church. An old photograph of the grave survives, but the grave itself has been covered by the grass of the new churchyard.

George-1

In common with Richard, nothing is known of George's early life until his marriage to Jane Brooks (or Brookes) of Bentham on 20 September 1755. Bentham is a small town in north-west Yorkshire on the Lancashire border, and George had been appointed as Usher (under-master) of Bentham Grammar School at some point before this date.[47] Jane was said to be the daughter of Marmaduke and Alice Brooks of High Bentham, with Marmaduke 'a man of good position'.

[47] R. E. Huddleston, J. R. Wilson & J. S. Warbrick, *The history of Bentham Grammar School, 1726–1976*, (Bentham, 1976).

George relinquished his position at Bentham in 1758 to take up an appointment as curate of the chapel at Pilling near Fleetwood in Lancashire. The Chester diocese records show that he was ordained deacon on 2 July 1758 (giving no details of a university degree as would have been normal if he had one) and licensed to the chapel at Pilling the next day. Holden had a sun-dial mounted over the south-west door with the inscription 'Thus eternity approacheth. G.Holden 1766' which can still be seen in good condition. After nine years at Pilling, he returned to the Bentham area to live at the Green at Tatham, taking the perpetual curacy of the Fell chapel on 11 May 1767.[48] He was to hold this position for the rest of his life, being joined by George-2 as assistant curate at some point before 1783. Tatham parish was described as 'wholly agricultural and pastoral, a great part of it being wild fell and mossland. Of trade, manufactures and commerce, it is destitute'.[49] Tatham Fells chapel is about three miles from the Green and five miles from Tatham itself, and was rebuilt in the nineteenth century. It contains a board from the old chapel showing the Lord's Prayer and Creed and George's name. A description of George at this time exists

> Local tradition says that [Holden] was a little hump-backed man, with one arm shorter than the other . . .One Sunday, having nearly completed . . .his walk from his house to the chapel, he suddenly discovered that, in one of his tide calculations, he had left out a cipher; back he at once turned and . . .there was no preaching at Tatham Fell that day. Holden was also somewhat of a religious controversialist . . .he was called into the Punch Bowl Inn to argue with the Roman Catholic priest, who, getting the worst of the discussion, lost his temper, and on Holden's saying that "God made man upright at first," he thundered out in reply, "then who the devil made the hump-backed ones?"[50]

George and Jane's family included sons Francis (1756, died same year) and George baptised 29 December 1757 (i.e. George-2), and daughters Hannah, Elizabeth, Jane, Catherine and Alice. He was buried at St. John the Baptist, Low Bentham on 21 May 1793, where

[48] A 'curate' was usually understood as being an assistant of the incumbent of a parish. A 'perpetual curate' was the incumbent of a chapel or church of a district forming part of a parish; in effect they ranked as vicars.

[49] E. Baines, *The history of the County Palatine and Duchy of Lancaster* (London, 1868).

[50] H. Fishwick, 'The history of the parish of Garstang in the county of Lancaster', Chetham Society, 104 (1878).

a plaque was erected to his memory which still exists. His grave is unmarked. In his will he left to George-2 'my three book cases with all my Latin and Greek books, my mathematical books, either printed or in manuscript, my Hadley's quadrant sector and scales, and all the books and instruments useful in navigation, and . . . all my books, papers, and instruments used in calculating the Liverpool Tide Table, upon condition that he will give to my daughter Alice Holden all the profits of the Tide Tables for the two first years after my decease'. George-2 acquired an estate called Birch Hill situated in Easington Dale Head near Slaidburn, and his grandson (George-3) inherited a silver watch.

George is claimed to have received a 'government grant' for his work,[51] which might be a reference to a grant from Liverpool town council (George-3 certainly received such a grant). Those funds, together with profits from the sale of the tables, must have constituted a major fraction of his income, as the curacy of a small chapel such as Tatham Fells could not have provided much. The family, however, were clearly 'middle class'. His son (George-2) attended Glasgow University while his nephew, Francis Holden (son of brother Procter), attended both Glasgow and Cambridge Universities.

George-2

George-2 apparently had a similar physique to his father, with one arm shorter than the other, and their personal histories were similar in some respects. The records of the Borthwick Institute of York University show that on 21 August 1783 George Holden, clerk, was licensed to the Free Grammar School at Horton-in-Ribblesdale in Yorkshire. He had married Ann Procter of that parish on 14 September 1782. The similarity of the unusual surnames of Ann and of George's grandmother (Hanna Prockter) cannot be a coincidence; George's sister Hannah also married a Procter (Christopher) from Skipton and they had a son, George Holden Procter, who received £5 in George-1's will. It seems that the Holden and Procter families were thoroughly entangled.

The Roll of Graduates of Glasgow University shows that George graduated with a LL.D. (Doctor of Law) in 1778. This was very unusual, as only fifty law degrees were conferred by the University

[51] Fishwick, 'History of the parish of Garstang'.

before 1800. The Borthwick Institute records show that on 21 May 1798 George was instituted as perpetual curate of Horton in York diocese 'on his own petition asserting that he was patron thereof in full right'. Previously, he had been appointed as deacon in Chester diocese in 1780 and priest on 26 May 1782. In 1793, he had succeeded his father to the perpetual curacy of Tatham Fells, which he continued to hold until his death on 31 December 1820, continuing to live at Horton. George was 'a man of high classical and mathematical attainments' who 'educated a greater number of clergymen for the Establishment than most men in a similar situation'.[52] His and his wife's grave can be found in Horton churchyard, as can a marble memorial inside the church.

George-3

George-3 was born in Horton-in-Ribblesdale soon after his parents' marriage and baptised on 12 June 1783. He took an MA from Glasgow University in 1805 having matriculated in 1798. The Borthwick Institute records show that George Holden MA, clerk, was ordained deacon at Carlisle (in Chester diocese) on 14 September 1807 and ordained priest in York diocese on 14 August 1808. On 20 September 1807 he was licensed to the curacy of Brafferton near Thirsk on the nomination of the vicar, but the records do not indicate when he resigned that position. In 1811 he was appointed as perpetual curate at the Ancient Chapel of Maghull near Liverpool where he remained until he died on 19 March 1865. From June 1821 to June 1825, he also held the perpetual curacy at Horton-in-Ribblesdale made vacant by the death of his father.

Holden oversaw many changes to the thirteenth-century Ancient Chapel of Maghull and built a rectory, both of which still exist alongside the late-nineteenth century St. Andrew's church.[53] In between his clerical duties (and for at least a part of his office he had the use of assistant curates), he was a Justice of the Peace. He never married. His grave can be found a few yards east of the Chapel. Figure 1c shows a portrait which appeared in early twentieth century Holden tables, and which is almost certainly the painting by Jones of Chester presented by grateful parishioners and friends.

[52] Anon, 'Obituary of George Holden', *Gentleman's Magazine* (1821), pt. xci, p. 189.

[53] B. S. Healy, *The ancient Maghull chapel, a brief history* (Maghull, 1993).

George 'always walked in the old paths, believing what was true once remained so for all time'.[54] He was known nationally as a writer on Biblical matters and wrote over fifteen theological works. He was moderately wealthy, and one assumes that part of this wealth came from inherited property and writing, in addition to the income from the curacy of the Chapel and from the tide tables. His will extended to five pages with many bequests to servants, cousins and friends, including the disposal of the family properties at Horton-in-Ribblesdale and Birch Hill, and the reversion of the patronage of the parish church at Horton to the Bishop of Ripon. The largest item concerned the bequest of all his printed books and manuscripts towards the formation of a library for the benefit of the clergy of the diocese of Ripon, in which diocese he had been born. He also left a sum of £3,300, the income from which was to be used for the custody and augmentation of the library. That library eventually passed from Ripon Cathedral to form the present-day Holden Library, which is a component of the Brotherton Library at Leeds University. Neither the will nor the library contain references to the tide tables.

ANNEX 2: PARTS OF TWO LETTERS FROM GEORGE-3 AT MAGHULL TO WILLIAM WHEWELL AT TRINITY COLLEGE, CAMBRIDGE[55]

27 September 1833

I beg to return you my sincere thanks for your truly valuable treatise on the Tides; and I assure you that, so far from having any objection to communicate to you my method of calculating the Liverpool T. Table, I shall be most happy to shew you the whole; but it is impossible to do it in the compass of a letter, or of many letters. All that I can do at the present is to say that the calculations depend entirely upon the moon's meridian passage, her parallax and declination. By the help of the Nautical Almanac, and certain

[54] Anon, 'Obituary of George Holden', *Gentleman's Magazine* (1865), pt. i, pp. 657–59; Dictionary of National Biography (London, 1885).

[55] These part-letters are reproduced by kind permission of the Master and Fellows of Trinity College, Cambridge.

tables formed by my grandfather, the first calculator of the Liverpool T. Table, these powers are ascertained in a way so simple and easy as to be little more than a mechanical exercise.

Tho' I shall be glad, whenever opportunity occurs, to submit all the Tables & Rules to your inspection, I confess I do not wish to make them public. The corporation of Lpool give me 50 guins. for the tide Table, and I make about as much more, so that it nearly equals my Curacy of Maghull. I cannot therefore willingly consent to give immediate publicity to the mode of calculating it, which would probably lead to the loss of half my income. Such sacrifices indeed ought to be made could they in any way contribute to the interests of science; but these interests cannot, I conceive, be affected in this instance, as my method is in strict accordance with, or rather founded on the received theory of the Tides.

19 April 1834

I have read your enclosure, and do not perceive any thing in the slightest degree objectionable, I mean anything to which I can personally object. Whatever is submitted to the public is fairly open to public examination and criticism; and any observations which may come from a scholar and a man of science will be made in such a way as ought not, in reason, to give offence to a brother aspirant to literature.

The observations of Mr. Hutchinson, to which you allude, are probably lost, as I have never met with them among my papers, of which I have a great number relating to the T. Tables. But I will look them over again, and if I find Mr. Hutchinson's observations, I will immediately transmit them to you.

The gentleman who originally framed the Rules by which I continue to calculate the Lpool T. Tables, was my Grandfather, Curate of Tatham-Fell's Chapel in this Diocese. But his brother, I believe, had the chief share in the formation of the theory upon which the Rules are founded.

In my former letter I stated my feelings and sentiments on this subject without reserve. I own that I cannot divest myself of some apprehensions which I trust may be excused when it is considered that I am so dependant upon the T. Tables for my pecuniary resources. Nevertheless every man should rejoice at the progress of science; and if I can in any way contribute to it by shewing you my Rules etc, I shall be most happy to do so; and, should you visit this part of the country, I shall be glad if you will favour me by such accommodations as the Glebe House at Maghull affords.

ANNEX 3: PREFACE TO THE 1773 HOLDEN TABLES, COPIED FROM HUTCHINSON'S *TREATISE*[56]

A perfect theory of the tides, and an accurate method of calculating them, has been greatly wanted in every age since navigation was first practised; and, though industriously sought after, has hitherto baffled the researches of the most learned. And as their theory has hitherto remained defective, so their methods of calculation, founded thereupon, have succeeded no better; for, (as I am now furnished with about three thousand observations made upon the tides at *Liverpool*, and three hundred and sixty at *Bristol*, with which I can compare my own, and all other methods of calculation) I think I may venture to assert, that all the methods given us in books of navigation, and all the tide tables inserted in our almanacks, are very frequently subject to the error of an hour, and many times of much more; except that of *Monsieur de la Caille*,[57] which yet is often liable to an error of forty minutes, as any person will find who takes the trouble of making a sufficient number of observations.

Indeed no person can expect that it should be otherwise, who considers that *Monsieur de la Caille*'s, and all other methods (except that of *Monsieur Cassini*, which in truth is no better) depend entirely upon the moon's age, or her difference from the sun; without regarding the different distances of either the sun or moon from the earth, their declinations, the latitudes of places, or any thing else that affects the tides.[58]

[56] By kind permission of the Syndics of Cambridge University Library.

[57] Nicolas Louis de La Caille (1713–62) was one of many leading French geodesists concerned with the length of a degree of the meridian. He also mapped the southern stars from the Cape of Good Hope. Holden must have seen his method (a crude use of high water times at full and new moons with interpolation in time for other lunar ages) in one of the later editions of *Elements of navigation* by John Robertson (1754) which copied tables from an early edition of *Nouveau traité de navigation* by P. Bouguer, which was strongly edited by de La Caille. (D. Cartwright, personal communication).

[58] This is something of a misrepresentation: Holden's method (as we understand it to have been) did not consider solar parallax and declination or latitudes of places either.

Thus deficient are all former methods in computing only the times of high waters; as for the heights, the calculation thereof has never before been attempted by any one, that I know of; though they are, as I apprehend, equally necessary; for of what advantage can it be to the seaman, to know when the tide will be at the highest, if there will not be, at that time, depth of water sufficient for his purpose? Indeed it would be of no more service to know that there would be depth enough of water, unless he knew at the same time, when to expect it. But to know what height the tide will rise to, and at what time, must contribute greatly to his security: and is not absolutely requisite, that a tide table should inform him of both these?

If any person shall think proper to compare this table with his own observations, he ought always to set his watch right immediately before, by some good sun dial; for these calculations are made according to solar time.

And if the watch be thus truly regulated, I doubt not but that they will be found to correspond very nearly with the observations, as this table is composed with the same care and exactness as the last, I having had the assistance of Mr. *Bryan Waller* through the whole work.

Indeed it cannot rationally be expected that any method of computation can perfectly agree with the tides, because they are subject to various alterations from the wind. Yet notwithstanding all the irregularities caused thereby, the heights given in the last tide table, have agreed with the observations (upon an average) within seven inches; and the times within five minutes.

Geo. Holden