THE MIDLAND WIND AND WATER MILLS GROUP

(affiliated to the Society for the Protection of Ancient Buildings)

This Journal is published by the Midland Wind and Water Mills Group, which is concerned with the study of the history and technology of mills, and, in principle, with their preservation and restoration. Its area is the region loosely defined as the Midlands, especially the central counties of Staffordshire, Worcestershire and Warwickshire.

The Group, which functions as an autonomous society, holds monthly meetings, with talks and discussions, during the winter, and arranges several tours to mills during the spring and summer. Members periodically receive a Newsletter and the Journal, and can purchase other publications at preferential prices.

For further particulars, please contact:

Mrs. M. Tucker,
26, Twatling Road,
Barnt Green,
Birmingham. B45 8HT

Wind and Water Mills

The Occasional Journal of the Midland Wind and Water Mills Group

affiliated to the Society for the Protection of Ancient Buildings

Number 9

Wind and Water Mills, although the journal of the Midland Windand Water Mills Group and therefore naturally concerned with the mills of the Midlands, is not intended to be narrowly parochial.Interesting and important articles relating to mill matters in other parts of Britain and the world will be included whenever available. In general, articles by members will have priority, but submissions by others will be willingly considered.

A.B.

Cover illustration, Blakesley tower mill, 1899, by F.C. Gill.

Midland Wind and Water Mills Group Publications

The following publications are available from:
Mr. B. Job, "Meadowside", Clayton Road, Newcastle-under-Lyme, Staffordshire. ST5 3ET

Staffordshire Windmills

by Barry Job, 76 pages, 35 photographs plus line drawings and sketches.
£1.75 (inc. postage).

Wind and Water Mills No. 3

Published June 1982. 48 pages, 15 drawings and maps.
Contents: Watermills of the River Salwarpe and its Tributaries. Part 2.
A History of Norton Lindsey Windmill, Warwickshire.
Drawings of Norton Lindsey Windmill
Notes on the Structure and Machinery of Norton Lindsey Windmill.
Millstone Making in France: When Epernon Produced Millstones.
French Millstones.
Everton Windmill, Nottinghamshire.
£1.00 (inc. postage)

Wind and Water Mills No. 4

Published July 1983. 64 pages, 41 drawings and maps.
Contents: Nineteenth-century Millers at Turn Mill and Elmbridge Mill,Worcestershire.
Watermills and Water-powered Works on the River Stour. Part 1.
Bedfordshire Windmills.
The Horizontal Mills of Hazara.
The Development of the Water Turbine.
Jesse Shirley's Etruscan Bone and Flint Mill, Etruria,Stoke on Trent.
£1.00 (inc. postage)

continued inside rear cover

Wind and Water Mills

The Occasional Journal of the Midland Wind and Water Mills Group

Number 9

1989

contents

THE VANISHING WINDMILL. Page 2.
(Reprinted from "The Northampton County Magazine", 1928.)
by F.C.GILL.

MEMORIES OF WALK MILL, ECCLESHALL. Page 11.
by CHARLES HOWELL.

TIDAL POWER: FROM TIDE MILL TO SEVERN BARRAGE. Page 15.
by GORDON TUCKER.

TWO SOUTH AFRICAN WINDMILLS. Page 38.
by NIALL ROBERTS.

A TIDE WHEEL AT TINTERN? Page 45.
by STAN COATES.

ISSN 0260-504X

HON. EDITOR

A. BONSON. 14, Falmouth Road,
Congleton,
Cheshire . CW12 3BH .

THE VANISHING WINDMILL

By F. C. Gill

To those who love the countryside the fast vanishing windmill is a picturesque and fascinating subject. When we remember the paintings of the windmill by Rembrandt, Turner, Constable, Cotman, Cox and many other distinguished artists, we can realise that in the eyes of the artist the windmill is a glorious thing.

The origin of the windmill is a matter very largely of speculation. They are not mentioned in Domesday nor is there any certain reference to them either in England or on the Continent in the eleventh century. A French document is known giving permission to a convent to erect watermills and windmills. The earliest known English windmill is mentioned about 1190. It was at Haberdon, in Suffolk. Pipewell Abbey, in Northamptonshire, was situated in a wood, which in the course of 180 years was entirely destroyed, in part because "in the whole neighbourhood there was no house, watermill or windmill built for which timber was not taken from the wood." So says Dugdale, who quotes "windmill" from a Pipewell document apparently of the twelfth century.

In the course of time windmills became numerous in most parts of this country where they seemed early to grow more popular than in Europe. Fifty years ago they were prominent objects in the landscape up and down Northamptonshire. This brief account is illustrated with a few drawings that I have made of windmills in the last thirty years (*i.e. 1898-1928*). Nearly all of these are now no more.

In Northamptonshire there were, roughly speaking, only two types of windmills. The first kind are known as Post Mills. In these mills the whole two or three storied structure can be moved, by one man, round about a central tree trunk or post. To give extra accommodation to the miller it became practice about seventy years ago to construct a cone-shaped structure enclosing the base of the post, its cross beams and spurs. Sometimes, perhaps generally, the enclosure was upright with a cone shaped roof. In the Long Buckby instance the masonry was a truncated cone.

Tower and Smock Mills are towers with revolving tops, usually actuated automatically by rear "fantails" at right angles to the sails. These small auxiliary sails were invented about 1750. Smock mills are so called because the octagonal tower is constructed of wooden boarding, and bears some resemblance to a smock. This type of mill did not exist in Northamptonshire, but is to be found in Southern England and East Anglia.

The mill at Bozeat, the photograph (see Plate 1) of which was taken in October (*1927?*), is the last Post Mill standing in this county. It is about three quarters of a mile south west of the church and a hundred yards from Olney Road. It is supported by a great post 2ft 8ins square, resting on four great cross beams measuring 10ft from the centre. These cross beams rest on solid brick piers. From the ends of the cross beams

spring cross trees, or spurs, 7ft in length. The height of the mill is about 35ft. The entrance is approached by 18 steps. The tail tree (by which the sails are adjusted to the wind) is 35ft in length.

These sails are 25ft long. Two of them are constructed to carry cloths, and two are slatted, the slats being adjusted by a lever in the mill. The stocks or "whips" upon which the sails are built are of Norwegian pine. The whole structure was originally of oak and was built in the year 1761.

It may interest readers to state that the amount of wheat ground with a steady wind was about six, and with a strong wind nine bushels an hour.

The premises adjoining the mill at Bozeat are in the occupation of Mr Little, to whom I am indebted for the above information.

It was not uncommon with windmills to work all night and Sundays too when the wind was favourable. The writer has a friend whose grandfather worked, to his great dislike, on a Sunday, in the old Post Mill at Staverton, long since gone.

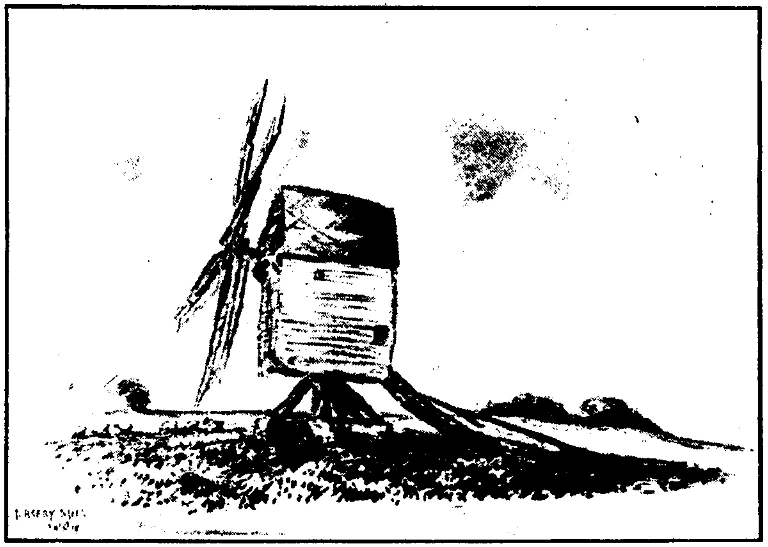

Figure 1. Naseby post mill,1918.

The mill at Naseby was very similar to Bozeat. It stood in the centre of a field, about a mile from the village, on the left side of the road leading to Thornby. It was demolished soon after the war (*first world war*), nearly ten years ago; from its timbers were made several nice pieces of "antique" oak furniture by one of our local craftsmen.

Byfield Mill,(see Plate 2), which was a noted landmark on that side of the county, the property of Mr. John H. Bromley, "fell to rest" on December 12th, 1912. The oldest initials on the post were D.L. 1820.

Figure 2. Yelvertoft post mill,1898.

Yelvertoft Mill contained two pairs of stones. It stood half a mile from the village in a small circular enclosure on the left hand side of the bridle road to Hillmorton. It was the property of the late Mr William Bray, and was pulled down in 1899.

As a specimen of our Tower Mills I give a drawing of Blakesley Mill.(see Plate 3) It was built by Francis Welch in 1832, at a period when many of the Post Mills were replaced by mills of this type. When the drawing was taken, in 1899, the platform from which the cloths were adjusted to the sails was still standing. It is now entirely dismantled and reduced 20ft in height. It is used as a builder's store. There was a like mill at Braunston, now derelict, and also used as a store.

Fifty years or more ago, there stood at the back of Market Street, Northampton, on the eastern side and within sight of Kettering Road, a Tower Mill. The writer recollects meeting in June, 1888, one, John Martin, who learned milling in this mill in 1845. He migrated to Grand Rapids, U.S.A., and became a most successful man in business.

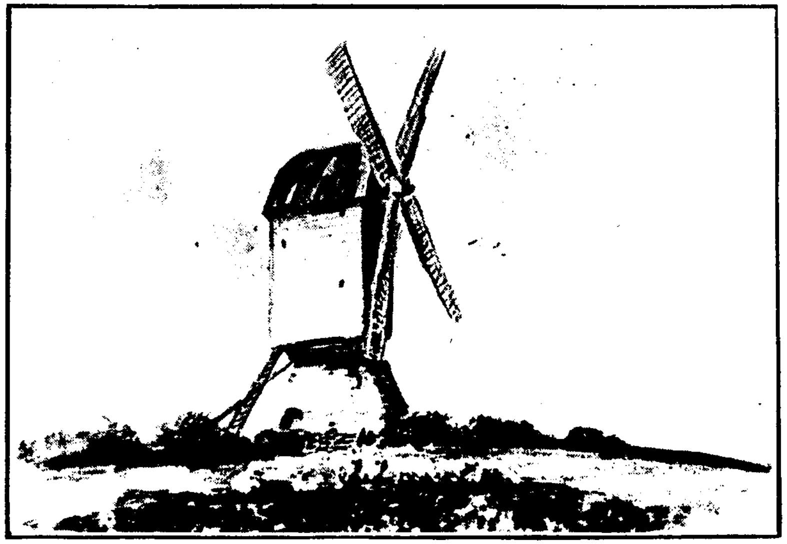

Figure 3. Long Buckby post mill.

Long Buckby with a cone-shaped structure, stood about a mile due east of the church, on high land. It was a landmark the whole county round. It belonged to a Mr. A. M. Allen and was felled on January 2nd, 1914.

Badby and Scaldwell Mills, (see Plate 4), were similar to those described, and were demolished previous to the Great War.

It would be possible to compile a long list of windmills formerly existing but it would resolve itself into a catalogue. There were, for instance, two at Brixworth, one north and one south of the village. There were two at Bozeat where one, mentioned above, remains. There was one at Holcot, near the lane to Walgrave. Bridges mentions a windmill at Whiston, but there is no knowledge now of so much as its site. There was one at Stoke Bruerne on the way to Stoke Plain. Of the mill formerly at Moreton Pinkney there is a drawing in the Dryden Collection at Northampton Museum. In Northamptonshire Notes and Queries Major C. A. Markham has given drawings and descriptions of several destroyed mills.

The output of a Tower Mill was about double that of a Post Mill.

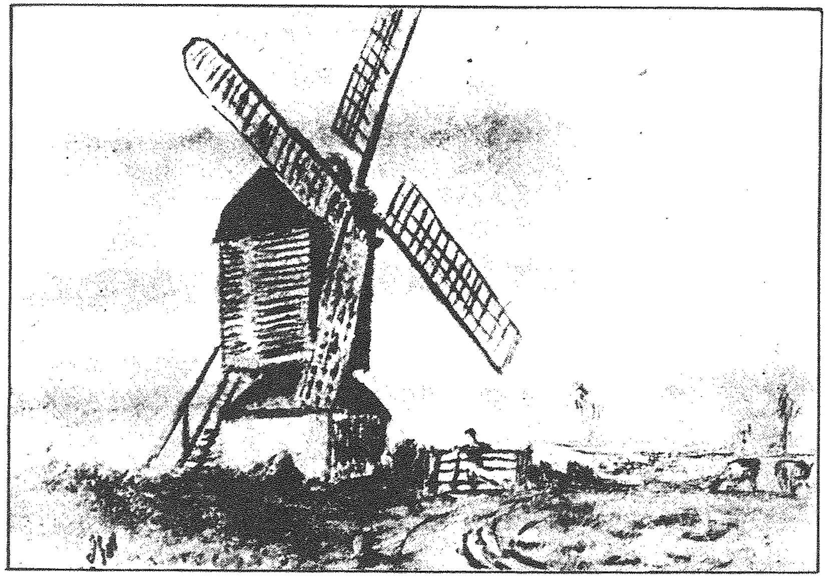

Figure 4. Badby post mill, 1900.

It is not often that the wind overpowered a mill but at Yelden, in Beds, during the night in the grip of a great gale in October, 1877, the sails broke loose and by friction set fire to the mill, which was burnt to the ground. During the great gale in March, 1895, at Fenny Compton in Warwickshire, the Post Mill collapsed, being uprooted. The catastrophe was witnessed by people of the village below, but it was some minutes before the clouds of flour dispersed and revealed to them what had happened.

In conclusion, these useful and picturesque achievements of our forefathers were an institution, a need of humanity. But now the day of the old-fashioned windmill is over. Its career of service has been long and honourable and for all its failure to compete with modernity, the world will be the poorer for its passing.

Editor's Note.

This article is a reprint of that which first appeared in "The Northampton County Magazine" in 1928. I am indebted to Mr. Michael Lowndes for bringing it to my attention. Any additions to the original text are in italics and occur only to clarify dates.

Plate 1. Bozeat post mill, October 1927.

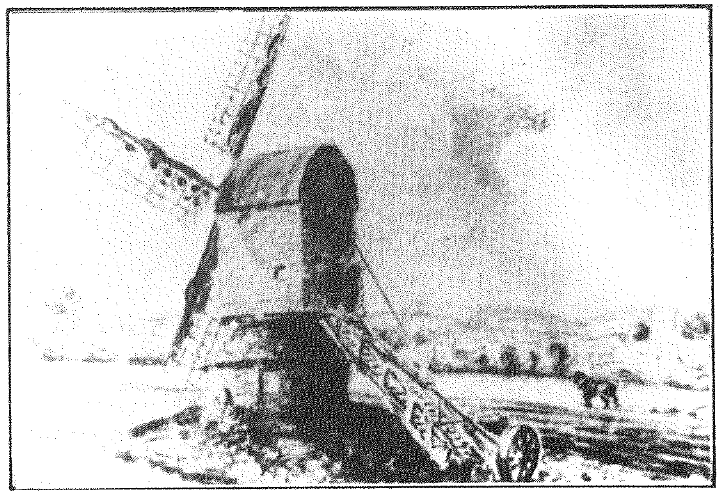

Plate 2. Drawing of Byfield post mill, 1899.

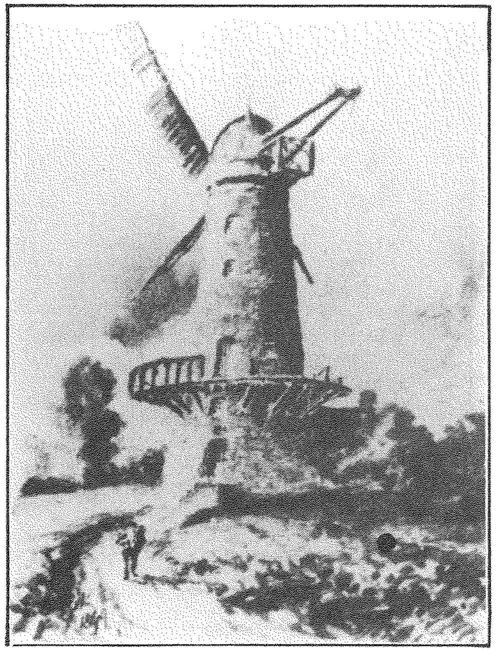

Plate 3. Drawing of Blakesley tower mill, 1899.

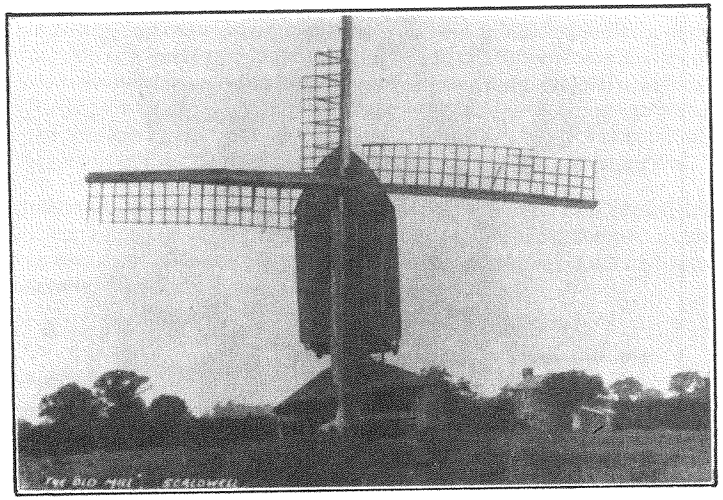

Plate 4. Postcard view of "The old mill", Scaldwell.

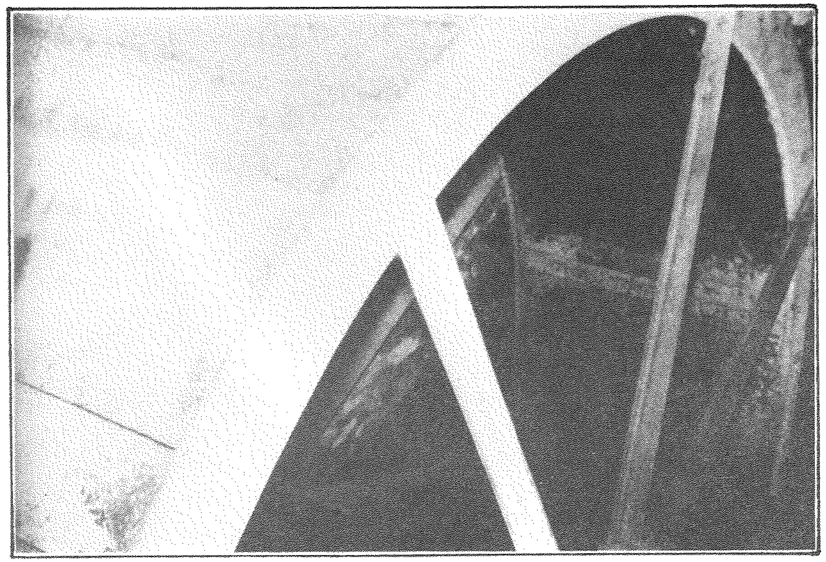

Plate 5. The waterwheel at Walk mill, 1968. (see pages 11-14)

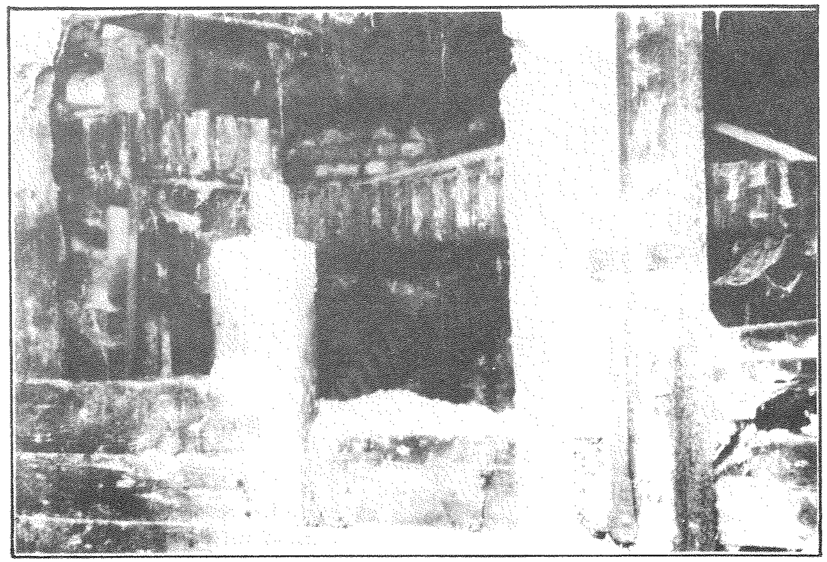

Plate 6. The main gearing, Walk mill, 1968.

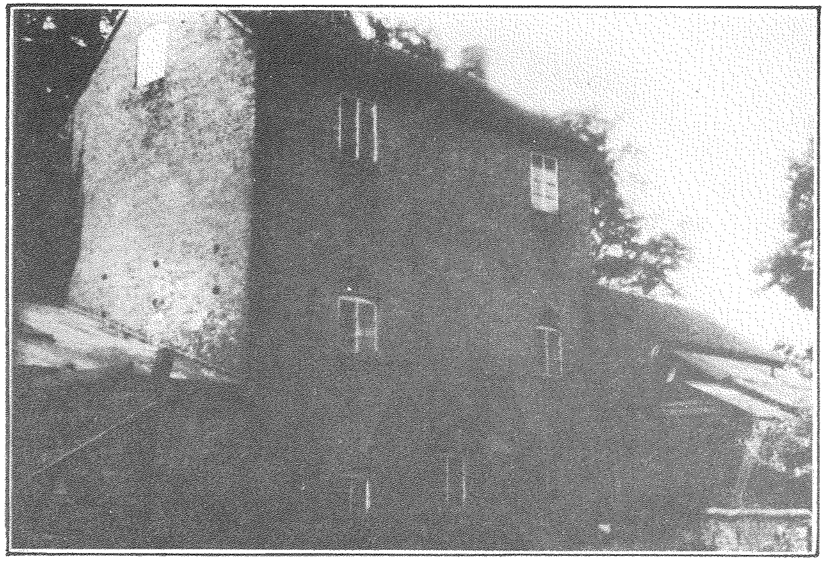

Plate 7. Walk mill in 1968.

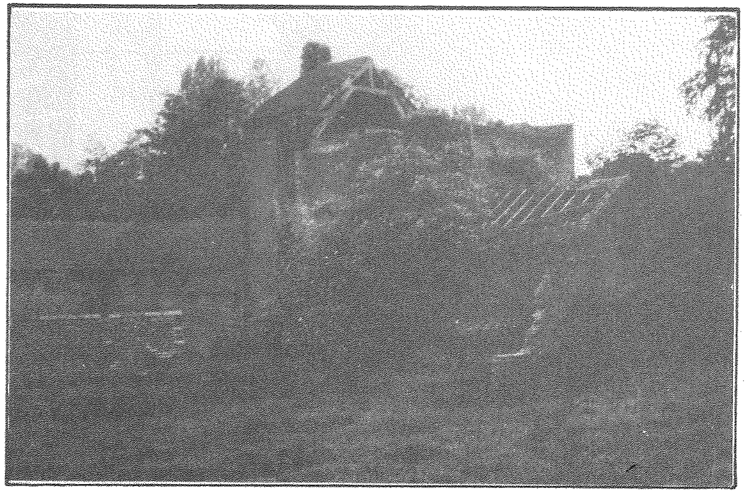

Plate 8. Walk mill in 1988, showing the damage sustained in the last 20 years.

MEMORIES OF WALK MILL, ECCLESHALL.

by Charles Howell

The following notes regarding the mill at Walk Mill are written from my memories, conversations with local people in the Eccleshall districts, and recollections of the mill during the many years I knew the property, also working the mill with my father and brothers for a considerable time. The dimensions of the machinery and other details, whilst fairly close, may not be strictly accurate.

The mill is the second on the course of the River Sowe, it is situated about three miles north-west of Eccleshall, Grid Reference SJ 792298. The name of the hamlet of Walk Mill suggests that at one time the mill was used for fulling, or "walking" of cloth; possibly this operation could have been carried on in conjunction with the corn and flour mill. Without doubt it is a very ancient milling site, the present brick building is said to have been built in 1797. The older part of the building around the basement of the water wheel housing and the adjoining Malt House, is obviously of quite an early date, parts of which could date back to Saxon times. The Domesday Survey which was compiled between the years 1080 - 1086 records two water mills in the Eccleshall Parish, possibly the mill at Walk Mill was one of these sites.

My first personal recollections of visiting Walk Mill was in 1933 when, at the age of seven, I went with my father to dress a pair of millstones for Mr. T. Bratton, the then miller who had run the mill for many years. Mr Bratton took over the tenancy of the mill from his father-in-law, Mr Thomas Pitt, who had run the mill since the late nineteenth century. My father, William Howell, was a well known local miller and millwright, and carried out millstone dressing and mill repairs at a number of mills in the Midland counties of England. One of the memories of that first visit to Walk Mill was that lying on the top floor were two bags of dried acorns, which I had never seen in a mill before,and in fact, after visits to hundreds of mills, I have never seen since. I was told that in the old days acorns were collected by cottagers, allowed to dry, and then taken to the local mill to be ground into pig food.

Mr Bratton was one of the last millers in the district to use a horse and traditional mill cart to carry out deliveries and collections to and from, local farms. I well remember the horse and cart at work. This method of transport was changed at the mill about 1937, when a new Fordson lorry was put into service.

Most of the present older machinery in the mill appears to have been installed in the early nineteenth century, or possibly when the mill was rebuilt in 1797. The high-breast, or backshot water wheel, is approximately 18 feet in diameter by 5 feet wide with 56 closed buckets. There are two sets of eight cast-iron arms and wheel hubs, or "bosses". The sole is of sheet iron, as also are the outside plates of the buckets, which are bolted through wooden bucket bottoms to the sole. The water wheel shaft is round, about 20 inches in diameter, and of hollow cast-iron cylindrical construction. It is approximately 15 feet in length. The pit wheel is of cast-iron, quite large, about 11 feet in diameter and was cast in halves. The wallower is cast iron; this is a replacement. The original wallower was badly cracked and a new wallower, cast in halves, lay in the basement of the mill as long as I could remember. In about 1950 the old wallower broke; my brothers, Harry and George, fitted in the replacement wallower which had the name of the iron founders "RODENHURST - MARKET DRAYTON" printed in the cast-iron. This replacement wallower ran well and was trouble free. The great spur wheel is also cast- iron, about 10 feet in diameter and cast in halves. The stone nuts, (pinions) which are mounted on the millstone driving spindles, are cast-iron mortise gears with wooden teeth. The stone nuts were taken in and out of gear by means of iron racks wound up and down by iron handles on a thread.

The bridge-trees and bridge posts were all of wooden construction until about 1948 when, because of extensive rot in the wood, my brother Harry fitted a pair of cast-iron bridge posts, complete with a cast-iron bridge tree under one of the pairs of stones. This cast-iron millstone equipment came out of the former steam driven flour mill in Telegraph Street, Stafford. The crown wheel is all iron, and at one time drove three small line shafts by cast-iron mortise pinions with wooden teeth to power the ancillary machinery. It would seem that the flour dresser, powered from one of these line shafts, had been a wire machine, judging from the various spout holes in the floor. This machine had gone before my first visit to the mill. The original sack hoist was of wooden construction with slack-belt drive activated by a beam and catch. This was badly worn and would not work properly. My brother Harry and myself fitted a modern, iron friction hoist in about 1947; this was driven from one of the line shafts from the crown wheel and worked very well. further drive from the crown wheel line shafts would have been to a smutter/wheat cleaning machine. This was gone before I first visited the mill, so I do not have any idea how this machine operated.

The upright shaft is of great interest. It is of oak, is round and bears evidence of being turned up on a lathe. Where the spur wheel is mounted there is a square section about two and a half feet square. In the upright shaft there is quite a large crack, or split in the wood which starts just above the spur wheel and terminates just below the crown wheel. However, this split in the wood did not seem to have any adverse effect on the running of the mill, the upright shaft working perfectly well during the 40 years or so that I saw the mill at work.

There were originally four pairs of millstones. In my memory there were three pairs of French Burr millstones in working position, all around 50 inches in diameter. I would think that the fourth pair had probably been Derbyshire Peak for grinding barley meal, and possibly for oat hulling in preparation for grinding oatmeal. Today, there are two pairs of French millstones in working position.

Water was the only power used at the mill until about 1956 when my brother Harry fitted in a Bamford diesel engine of 14 H.P. to drive a further line shaft which powered a 30 inch vertical millstone grinder with composition stones. Also, from this line shaft there were drives to an oat roller, a Bamford steel plate grist mill, a vertical feed mixer of one and a half tons capacity, and an oil cake breaker. In about 1963 a large double

roller mill manufactured by Robinsons' of Rochdale was installed to meet the demand for rolled barley, which was then very popular for cattle feed. In the last working days of the mill, diesel tractors were also used for power.

I do not remember any flour being produced at the mill; in my lifetime only grain grinding was done and the processing of feeds for farm animals and poultry, plus the distribution of ready mixed feeds from the large national compounders to farmer customers.

As long as I have known the mill it has been owned by the Sugnall Estate. When Mr Bratton retired in 1944, my father took over the tenancy. My brother Harry became tenant in 1954, and when Harry died in 1973, my brother Edmund took over the tenancy and continued until he retired in 1980.

About the end of 1975 a tremendous gale blew a large beech tree, reputed to weigh more than 15 tons, from a neighbouring property right across the mill building. This did a lot of damage to the mill building and brought milling operations to an end. However, my brother Edmund continued to do a small distribution business from the adjoining Malt House which is attached to the mill, until his retirement.

For hundreds of years many millers were also maltsters, and at Walk Mill the Malt House still survives with the drying kiln. The Malt House building is approximately 55 feet long by 15 feet wide. At the end of the building nearest to the water wheel the large steeping , or sprouting, tanks are still in position. These are of cast iron and it appears that they received the necessary water by pipe from the water wheel penstock, or pentrough.

The kiln which dried the sprouted barley has a floor of perforated tiles, each tile is about 14 inches square, the total floor area of the kiln being about 14 feet square. Below the floor is the kiln fire place with its hopper shaped flue which distributed the heat equally across the kiln floor, so that the heat would pass through the tile perforations so as to dry the malt, or damp grain. The kiln was last used around 1950 when we dried some damp wheat for a farmer. I well remember attending to the coke fire and turning the grain over by shovel on the kiln floor, a good job on a cold day.

Above the main door to the Malt House is a beautifully carved stone lintel with the date 1830, which is probably a date when some of the brickwork was renewed, since the basement of the building is obviously very much older. Today, much of the brickwork of the Malt House and kiln is in a rather poor state, but it is still capable of being successfully repaired providing that not too much more time elapses before some action is taken.

The mill malt house complex at Walk Mill is a rare survival, and I hope that everything will be done to ensure that the necessary repairs are carried out on the buildings to save them before it is too late. The Walk Mill site depicts an important rural industry which was carried on for many centuries, the milling of flour, grinding of grain, the production of malt, which included the drying and grinding, and the general processing of grain for animal feeds.

There was an attempt to repair the mill building around 1977 but bad luck plagued this project. As I understand it, a government sponsored organisation to provide work for unemployed young people, known as Manpower, started to rebuild the mill. However, one night a gang of thieves came to the mill and stole all the scaffolding which brought this worthy project to an end. The mill is now in a ruinous condition, but there is a renewed interest by a heritage group to completely repair the mill and restore it to working condition. I hope that all interested groups and the local council will help in every way possible to restore this important mill and the adjoining Malt House complex.

To my knowledge, there is at least one other complete water- powered mill malt house complex in Staffordshire. This is at Coley Mill, right on the Staffs/Salop border, just east of Newport, Salop. At present Coley Mill is in reasonably good condition, but now appears to being very neglected.

Editor's Note.

Mr. Charles Howell left his native Staffordshire nearly 20 years ago, in 1969, to become the miller/millwright at Upper Mills, Phillipsburg Manor, North Tarrytown, New York, U.S.A.

Plates 1,2,&3 are printed with the kind permission of Mr. John Bedington and Plate 4 is from the editor's collection.

TIDAL POWER:
FROM TIDEMILL TO SEVERN BARRAGE

By Gordon Tucker

1. Introduction

Tidal power has been used on a small scale for centuries to drive waterwheels for corn-mills, and there were some electricity- generating tidemills in the last two decades of the nineteenth century. The impression of colossal power in the tides, as witnessed in the flow of large estuaries, has led to much thinking about the possibility of exploiting this power for the generation of electricity on a large scale. Nowhere has this thinking been more evident than in relation to the Severn Estuary, where the funnelling and resonance effects make the tidal rise and fall among the highest in the world (e.g. on the Cardiff-Weston line the mean range on spring tides is about 11m or 36ft). The trouble is that while the energy or power of the tides can be to some extent visualized, it is hard to visualize the energy actually generated by a country's electricity system or drawn from it by the consumers. It comes, therefore, somewhat as a surprise to learn that the total annual energy which could be extracted from **all the world's** tides would not be likely to be more than twice the present total annual energy demand on the British electricity network, [1] which is of the order of 200 terawatt-hours (TWh or 10^{12} watt-hours), perhaps more easily understood as 200 billion units. The prospect of **British** tides supplying a dominant part of Britain's energy needs is therefore small. Nevertheless, tidal power is inexhaustible and pollution- free and therefore not without its attractions. This paper traces the changes in thinking over the years, especially in relation to the Severn Estuary.

To set against the two advantages just mentioned, tidal power has the formidable disadvantage that the power is not continuously available; the tide ebbs and flows, so that there are four zeros of flow, or two peaks of height (or "head"), in every period of just over one day. Moreover, the time of the peaks varies from day to day. By no direct system can electricity be generated when it is most required, so that tidal power can be used, in all except a few limited special applications, only in conjunction with energy storage. In most of the small unambitious tidal- electricity systems proposed or tried in the last two decades of the nineteenth century, the storage was electrical storage in secondary batteries. In more ambitious systems a retiming of water flow was proposed by the use of multiple basins, but these involved a large loss of available power. In the Severn Estuary proposals of the 1920s and 1930s, pumped storage was involved, in which electricity generated from tidal power when it was not required was used to pump water from the estuary to a reservoir at a height of nearly two hundred metres, from which it could be used to generate another supply of electricity when the demand for it arose. However, once the national electricity grid became available in the 1930s, there was more possibility of absorbing power into the system by shutting down some thermal stations when it was available, and storage became less important. Now, in the 1980s, the grid has its own pumped-storage facilities, and any proposed tidal-power contribution has to be viewed merely as part of a very large and complex system. Thus the simplest tidal system is now generally the most attractive.

So far only technical and operational aspects have been discussed. There are two others which are critical too: economic and political.

It has always been hard to show a very marked economic advantage for tidal power. There is, of course, no fuel cost, and the life of the plant is likely to be long. But against this is the fact that the capital cost of the huge barrage involved is enormous and the time of construction is very long - say ten or fifteen years. Capital charges ensure that the electricity generated is not appreciably different in cost from that generated at thermal or nuclear power stations.

In the political field, however, these very disadvantages of high capital cost and long construction time can become great advantages, for they represent the creation of a large number of long-term jobs. It is not coincidence, therefore, that it is in periods of high unemployment (1920s, 30s, late 40s, late 70s and 80s) that so much is heard of the Severn Barrage proposal, and that there is relative silence in the prosperous 1950s and 60s. Another political attraction of tidal power is that there is no fuel supply that can be withheld during industrial disputes, nor can inflation seriously affect the cost of generation once the system is built. The possibly damaging effect of the system on the physical environment, however, could have adverse political repercussions; environmental considerations need to be handled with great sensitivity

2. Outline of history of tidal power proposals and practice.

2.1. Tide-mills.

The use of the tide for operating corn mills is many centuries old - certainly over seven centuries. The basic concept of the mill was no different from that of any other watermill; water flowed from a higher level to a lower level via a waterwheel, which thereby drove the machinery of the mill. The distinguishing feature of the tide-mill was that the water at the higher level was accumulated in a pond behind an embankment by the flow of the rising tide into the pond, through a sluice which closed when the pond was full and the tide started to fall. The waterwheel could be driven as soon as the tide had fallen sufficiently to clear the blades or paddles of the wheel. If enough water had been ponded in relation to the desired rate of work, work could be continued until the tide was rising again.

The tide not only goes through an approximately daily (25 hour) double cycle of high and low water, but also through an approximately fortnightly cycle of variation of the tidal range (minimum at "neaps", maximum at "springs"). There are other, less important, cycles too. So the amount of work that can be done by a tide-mill varies from day to day.

The ordinary waterwheel has more disadvantages in relation to a tide-mill than to ordinary water mills. As the wheel has a fixed axis, the tail-race level must be fixed just below it, yet the tide level may have fallen well below this; thus part of the head is wasted. The use of reaction turbines with a draught tube would avoid this loss.[2]

The period of work could be (but rarely was) extended by the use of two basins: one a high-level pond as before, the other a low- level basin emptying out through a sluice or sluices at low tide. The waterwheel operates in a channel connecting the two basins.

The number of tide-mills in Britain was once quite large, counted in hundreds, as shown by the researches of Professor Walter Minchinton and his colleagues.[3] Now none are left in commercial work, but at least three have been restored to working order, at Woodbridge (Suffolk), Eling (Hampshire) and Carew (Pembrokeshire).

At least one case of the use of the tide for generating electricity for the lighting of a house is documented. In 1894 it was reported that[4] that a house on the Cheshire coast was electrically lit from a 4 horse-power tidal plant. Batteries would have been necessary to obtain the light when required, the tidal power providing the charging current.

Just as ordinary water mills were rarely built on main rivers but rather on smaller side-streams in order to minimise the difficulty and cost of the engineering work, so tide-mills were usually built on small tidal creeks rather than on estuaries. An example which is now fairly well-known through restoration is the tide-mill at Carew, situated on a quite remote reach of the Cleddau estuary.

2.2. Early tidal proposals for electricity generation.

(a) In relation to the Severn Estuary.

First of all, it is worth mentioning that a proposal for a barrage across the Severn Estuary was made in 1846.[5] This was to be made at the Aust Passage, and was to carry road and railway links. Naturally, at that date there was no question of electricity generation, nor was there any suggestion of power being derived in any other way.

The public supply of electricity began in 1881, and it therefore shows considerable initiative on the part of Bristol councillors that in November of that year they seriously discussed a proposal to dam the River Avon in order to use the tidal power (not just the ordinary river flow) to generate electricity to enable them to replace the gas lights in Bristol by electric lamps. Councillor Smith had consulted Sir Charles Bright (of telegraph fame), and Professor Silvanus P. Thompson had done some calculations. He estimated that the 4274 gas lamps in the city were using 40×10^{12} ft.lb. of energy per year, but that only one-twentieth of this would be needed to give the same light by electric lamps; i.e. 750,000 kWh (or units) or what we would now call 0.75 GWh (Gigawatt-hour). A dam at Totterdown, above Bristol, was estimated to be able to produce a tidal energy of 2.5 GWh (in modern terms) per year, and at the mouth of the Avon perhaps 20 GWh.[6] At this early stage in the history of electricity supply there was clearly no need to think of harnessing the Severn Estuary itself; its tributary estuary, the Avon, would be more than adequate.

A committee appointed by the Council to consider this matter reported at the beginning of January 1882.[7] They were "of the opinion that it is within the range of practicability to convey to Bristol ..... power obtained by the action of the tides, but are unable, without the aid of professional advice, to report how this may best be done...." and asked for £100 to enable them to get such advice. After much discussion this was agreed. The curious and disappointing thing is that no more was heard of the matter; the minute books and the press are silent. Latimer (1893) merely says that "the investigation led to no practical results",[8] and Wells (1909) says the same.[9] Probably the matter became completely overshadowed by the discussions about converting the river into docks.

(b) A few examples elsewhere.

Power from the tides remained a theme of interest during the next 40 years, as the following examples show.

Poole Harbour, 1881. The surveyor proposed the electric lighting of the town of Poole by the use of tidal power from Poole Harbour, a large almost enclosed tidal inlet.[10]

Bombay, India, 1886. Tidal power proposal being seriously discussed by local journals; battery storage system.[11]

Sullivan Harbour, Maine, U.S.A.. Large tidal lagoon filled through a narrow gorge; to be used for generating electricity to light the town.[12]

River Seine, France, 1890. Two two-basin tidal power systems proposed producing thousands of horse-power.[13]

Barrage across Irish Sea, Kintyre to Northern Ireland, 1894. An ambitious project with a power station at each end.[14]

Santa Cruz, Pacific Coast, 1895. The electricity to light the town and drive the street-cars. Claimed to be actually in progress and near completion, but no more heard of it.[15]

Cuxhafen, then Husum, Germany, 1908-12. Two-basin scheme of about 5000 horse-power apparently received Government sanction; purpose to supply a large part of Schleswig-Holstein.[16]

Bay of Fundy, New Brunswick, Canada, 1919. Scheme to utilise the world's highest tidal range.[17]

2.3. Electricity-generating proposals for the Severn Estuary,1920-present time.

Apart from one or two rather tentative proposals before 1918,[18] the first serious proposals for a large-scale electricity- generating Severn Barrage scheme appear to have arisen immediately after World War 1 from a number of sources, important among which was the Great Western Railway, which was primarily concerned with getting a better transport link across the estuary, and saw the barrage as a possibly economically-attractive way of doing this. The first intimation appears to have come from an article in *The Times* on 26 November 1920, but it was on 29 November that a further article attributed the scheme to Mr J. F. Pannell, an employee of the G.W.R.. Apparently separately, however, the Water Power Resources Committee of the Board of Trade had been giving preliminary consideration to a Severn Barrage, and issued its report on 1st December 1920.[19] This was basically a list of possibilities and problems, but had a favourable tone. There was no electricity grid at this time, and it is interesting that it was thought "very likely that the whole of the energy could, in due course, be absorbed locally. The application of a portion of the energy to railway traction in the dense traffic districts of the South Wales coalfields ... is indicated." Storage was envisaged as a possibility but "means for making economical use of intermittent supplies of energy must not be ignored." Nevertheless, high-level pumped-storage was an integral part of the system described in *The Times* on 26 November 1920, and in the account in *The Electrician* on 3 December 1920 (p.659). The barrage was to be roughly on the line of the Severn Tunnel.

There was much discussion of the scheme in Parliament over the next few years, a major attraction of it for M.P.s being the relief of unemployment. Indeed, it was frequently in debates on unemployment that the matter of the Barrage was raised.

During the dozen years after the 1920 report, there was much consideration of the Barrage scheme by official committees and consultants, and the most important results were the reports of Professor A. H. Gibson of Manchester, published in May 1929 and October 1932,[20] concerning the hydraulic problems, and of the Severn Barrage Committee of the Economic Advisory Council, published in 1933,[21] concerning the scheme as a whole. Articles in the technical press also explained and discussed the project.[22] The scheme was much the same as in 1920, with high- level pumped storage. It is described in Appendix 1.

Table 1 has been prepared to present a summary of the main features of the principal Severn Barrage schemes from 1920 to the present, and details will not be discussed at this stage.

There was further discussion, but World War 2 interrupted it for a while; then in 1943 a new Panel was appointed by the Minister of Fuel and Power, and this reported in 1945.[23, 24] The barrage itself was to be much the same as in the previous proposals, but there were two important differences: a fundamental one, that there was to be no pumped-storage of any kind, because the development of the national grid had made it possible to envisage absorbing the scheme into the national network, so that it no longer required a localised system; and a more arbitrary one, that there was to be no associated transport system for road or rail.

Again, nothing more was done, and there seemed to be a lull in the subject during the period of growth of affluence. It was the work of university engineers (Dr T. L. Shaw at Bristol, Professor E. M. Wilson at Salford) that brought it out again around 1970. Recently it has been to some extent the environmental movement that has "raised its profile", and very serious proposals are now put forward. They will be discussed in later sections.

2.4. Electricity-generating proposals (and actualities) using tidal power in estuaries other than the Severn, 1920-present time.

In Britain, a very comprehensive survey of tidal power potentialities was made in 1923 by Davey,(25) whose book had over 260 pages, with maps, and discussed 63 possible locations in Britain. By modern standards these were not all ambitious schemes in terms of capacity, but the output power, if all were realised, would have been about 2000 MW continuous. The advantage of a distributed scheme like this, with stations from the south coast of England to the north of Scotland, was that tidal peaks would be distributed over the whole day, and that assuming a full electricity grid system, there would be no need for storage. The scheme was, of course, far before its time, and made demands on capital investment which no private or public body could meet in a foreseeable period.

More recently, suggestions for barrages in the Solway Firth, in Morecambe Bay, and at Strangford and Carlingford Loughs in Northern Ireland, have been put forward,(26) but with comparatively little support.

Probably the world's only modern operational tidal power scheme is that on the Rance Estuary in France. This was commissioned in 1966.(27) By modern concepts, it is quite a small plant; the maximum generating capacity is only 240 MW, and the total net energy supplied in a year is only the order of 0.5 TWh (or 500 million units). But it has many pioneering features of operation. The turbo-generators are fully reversible; not only can the turbines respond to water flow in either direction (i.e. to either inflowing or outflowing tide), but they can also work as pumps when the generators are supplied with electricity from the grid and used as motors. This gives great flexibility of the times during which generation takes place, and can increase efficiency by enabling overfilling or overemptying to take place. As an example, suppose generation takes place on outflow. The inner basin would normally be filled on the flood, the sluices closed, and then when the tide has ebbed enough to give a head, the basin will be slowly emptied through the turbines. Now suppose that towards the end of the flood tide, electricity has been drawn from the grid to drive the turbines as pumps and overfill the inner basin by say 0.5m. Only enough electricity will have been needed to lift the water 0.5m. But when this extra water is used to drive the turbines, it works with a head of several metres, and thus generates much more energy than that taken for pumping. Overfilling of this kind is a feature now of most tidal power proposals.

Date of proposal	Approx. position of barrage	Maximum generating capacity (MW) (note1)	Max. energy supplied in average year (TWh) (note2)	Average generating capacity (MW) (note3)	Capital cost £M	Cost per KWh	Pumped-storage high level	Pumped-storage low level	Rail/road crossing
1920	Severn Tunnel	650	1.36	160	30	0.62d	yes	no	yes
1933	Severn Tunnel	778	1.60	184	50	0.23d	yes	no	yes
1945	Severn Tunnel	800	2.36	270	40	0.20d	no	no	no
1970	Lavernock-Brean Down (Cardiff-Weston)	3500	1.19	140 (note4)	1000	?	no	yes	?
1974	Aberthaw-Watchet	8500	25.00	2900	2500+	?	no	2-basin scheme	no
1981	Lavernock-Brean Down	7200	12.90	1470	5660	3.10p	no	no	no
1986	Lavernock-Brean Down	7200	14.40	1640	5543	3.00p	no	no	?
1986	2Km below Severn Tunnel ("English Stones")(note5)	972	2.80	320	1150	2.90p	no	no	probably

Note 1. This is the maximum capacity of the installed equipment.
Note 2. Assumes that all energy that can be supplied is taken. There is a small yearly variation of maximum tidal energy available.
Note 3. This is the quantity in previous column divided by the number of hours in a year.
Note 4. This scheme is conceived primarily as a pumped-storage facility for the National Grid and only secondarily as a means of feeding additional energy into the system; hence the small quantities in this column and the preceding one.
Note 5. This is the less-favoured of the two 1986 schemes.

TABLE 1. Summary of the Severn Barrage electricity-generating proposals.

The 24 turbo-generators, each of 10 MW, are of the 'bulb' type, in which each complete machine set operates in a tube in the dam, and the turbines are of propeller type. Although in Severn Barrage proposals the machines are much larger, they are now always of this type. Overfilling of the inner basin for ebb generation is accepted as a standard feature of most of these proposals.

A Russian pilot plant to demonstrate a new method of construction was commissioned in 1968,[28] at Kislayaguba on the Barents Sea. Instead of the cofferdamming method used at La Rance, this scheme used prefabricated caissons, each containing sections of the power station, towed to the site and sunk onto a prepared bed. The method was so successful that it has been proposed for all recent Severn Barrage schemes.

New ideas being considered for other areas, such as the Bay of Fundy, include the direct production of compressed gas instead of electricity from the tidal power, the storage of this gas in underground caverns (e.g. former salt deposits), and its use to generate electricity as and when required.

3. Severn Barrage proposals of the 1980s.

Interest in the Severn Barrage continued throughout the 1970s, and the proposals described in Appendixes 2 and 3 were followed by others, described in Department of Energy papers[29,30] and elsewhere. In 1978 the Secretary of State for Energy set up a committee under the chairmanship of Sir Hermann Bondi to assess the feasibility of a Severn Barrage. The findings of this committee were published in 1981.[31] They were generally favourable, but even after the expenditure of £2.3M on the study, they felt that there were too many areas of doubt and ignorance for a decision to be made. So they recommended that a much larger study should be undertaken at a cost of about £20M. This was agreed, and a consortium of six interested firms was set up with the name "The Severn Tidal Power Group" with funds at least partly provided by the Department of Energy. The group's studies were published in 1986.[32] Although they had to leave room for a Government decision regarding the placing of an Enabling Bill before Parliament, they were firmly of the opinion that the "building of an energy generating barrage on the recommended Cardiff Weston alignment would be of great value and a permanent asset to the country." The government's response was the funding to the extent of £1.42M of a £4.26M study of outstanding problems to be undertaken in equal parts by the Government, the CEGB, and the Severn Tidal Power Group, and to be managed by the latter. The plan was outlined in a consultation document[33] published in February 1987. That is how the matter stands at the time of writing.

The barrage proposals referred to above are described briefly in the following sections.

3.1. Energy Paper 46 (1981).

Regarding the location of a barrage, this paper pointed out that the range of tide decreased as one went further out in the estuary, so that, although a longer barrage further out would, by enclosing a disproportionately larger volume of water, manage to generate more energy that one closer in, the cost per unit of energy would be greater. A balance has therefore to be struck where a worthwhile amount of energy is generated at a cost per unit not significantly above the minimum. In this report the recommended location for a barrage was the line from Lavernock Point to Brean Down, enclosing the two small islands of Flatholm and Steepholm, as shown in Figure 1, and there indicated as "First Stage". This would have 160 turbine-generators, each 9m diameter and of 45 MW generating capacity, giving the total generating capacity of 7200 MW shown in Table 1. The estimated total energy output in an average year would be just under 13 TWh, i.e. 13 billion units, at a cost of just over 3p per unit, which is less than the cost per unit from a thermal station but higher than that from a nuclear station. Thus the economic attractiveness of tidal power depends on the proportion of nuclear capacity in the national system. With the low proportion at present in Britain, tidal power has a potential economic advantage.

Ebb generation, without pumping to increase the flood level, and with no pumped-storage system in the estuary to permit re-timing of the supply, was the plan. This avoided the use of reversible pump-turbines, which are less efficient than straight turbines. But a possible second-stage development was suggested, as shown in Figure1, with a long embankment and then sluices and turbines, reaching to Minehead; this would operate in the flood-generation mode and thus provide electricity over an additional period. However, the cost per unit was a good deal higher, and the building of this second stage could be foreseen only if the general power scene in the country changed considerably.

Ebb generation is more effective than flood generation because the area of the basin is greater at high-tide level than at low- tide level, and the basin therefore empties more slowly than it fills up.

The document also discusses the possibility of a barrage right across the estuary from Minehead to west of Aberthaw, i.e. even further out than that proposed by the CEGB in 1973-4 (see Appendix 3), but this was shown to have no economic attraction.

In case it is not obvious, it is perhaps worth mentioning that in all Severn Barrage schemes, provision has had to be made for shipping to and from the various ports in and connected to the estuary within the barrage, notably Sharpness and Gloucester in all schemes; and Avonmouth and Bristol, and Newport and Cardiff, in more recent schemes. This is done by inserting locks in the barrage at the most suitable place for shipping, i.e. in the deep-water channel. The locks in the 1981 scheme are clearly marked in Figure.1.

3.2. Severn Tidal Power Group (1986).

This very detailed study followed the suggestions of *Energy Paper 46* by considering a barrage on the Lavernock-Brean Down line (always referred to as the Cardiff Weston line), but also considered a less ambitious barrage scheme on a line about 2Km below the Severn Tunnel (the "English Stones" line) put forward by one of the firms in the consortium. As a result of the more detailed studies it was concluded that it would be worthwhile to use the turbines as pumps to overfill the basin at the flood, and Fig.2 shows a graph of the water heights against time for a typical cycle. It was also thought that the adoption of 160 turbines of 9m diameter and 45MW capacity, as recommended in *Energy Paper 46*, was too much of a step in the dark; instead 192 turbines of 8.2m diameter and 37.5MW capacity were chosen for the Cardiff Weston scheme. The costs are shown in Table 1, and it will be seen that for the longer barrage, the total energy produced is greater and the cost per unit lower than in the 1981 scheme, mainly because of the use of overfilling of the basin, especially at periods of low tidal range. The financial performance of the shorter barrage is good, but it is not very ambitious and has too many unknown factors relating to the movement of sediments. The Cardiff Weston scheme is recommended for adoption. The consortium considered that it would be difficult to finance it entirely by private risk capital and that there should be Government assistance.

The contribution to employment would be considerable: 280,000 man-years of direct and 140,000 man-years of indirect employment, followed by over 25,000 permanent jobs, direct and indirect.

3.3. Firm Power Contribution and national significance of tidal power.

In the reports which form the basis of this Section 3 of the paper, a term "Firm Power Contribution" is used which has important implications. It is defined as the installed capacity (in MW) of a thermal or nuclear generating station which would have to be provided to meet the same demand with the same margins in the system that the tidal station could meet. Obviously this is very different from the peak output from the tidal station, and is equally obviously related to the storage capacity of the national network, and to the temporal pattern of demand. But for the Cardiff Weston scheme, the Firm Power Contribution is given as 1,100MW. This is not very different from the generating capacity of a modern nuclear station; the Heysham station under construction is rated at 1,320MW. So if we had the Severn Barrage, we could manage with one less nuclear station or perhaps one less coal-fired station. In view of the popular emotional antipathy to nuclear stations and the proven environmentally-lethal acid rain from coal-fired stations, this would be a very welcome thing. It is difficult to see why we still await a decision.

In Table 1 there is a column "Average Generating Capacity", which is a term coined by the present author. It is useful in being more obviously calculable than "Firm Power Contribution", and in giving some sort of picture of the size of the scheme in comparison with ordinary stations.

A statement from *Energy Paper 46* on the subject of storage is worth quoting without comment:-

"Storage is a property of the overall electricity supply system and the amount of storage must be chosen in the context of the overall system, not by having regard to one particular type of generating plant. The need for extra storage is thus decided by examining various possible ways in which the electricity supply system might develop with and without tidal power.

Analysis shows that except in the case of systems with a high proportion of nuclear power, **the introduction of tidal power would not lead to the need for more storage. Tidal power may be injected directly into the system displacing the operation of other plant."**

3.4. Constructional Methods.

The basic system of construction of the barrage is to use plain embankment made of dredged estuarial material lined with stone for those portions which are in mean depth of less than 15m and which have no operational function, and to use prefabricated caissons of reinforced concrete in deeper water and to carry the sluices and the turbine-generator units. The length of the section containing the turbines is 3.6Km and this has to be in deep water; thus the alignment of the barrage is to a large extent dictated by this. Because of this factor, the STPG concluded that the alignment shown in Figure1 should be changed to make the turbine section run more nearly west-east, and the barrage would therefore leave the island of Steepholm outside the basin.

The caissons would be built on a special site at the side of the estuary, and the machinery would be fitted into them before they were towed into position and sunk on to a prepared bed.

While a decision on the exact landfall of the two ends of the barrage was deferred, yet a preference was expressed for points slightly to seaward of Lavernock Point and Brean Down.

Locks to enable shipping to pass through the barrage have to be provided, and since these require to be in deep water, they have to be in the deep channel near the Welsh side which is not used by the turbines. There is some uncertainty as to the size of lock to be provided, but provision for ships of 150,000dwt is discussed, with dredged channels of minimum depth of 11m. Rather than build the locks in caissons, it is preferred to cut them through artificial sand islands.

3.5. Environmental Factors.

Even a casual thought shows that the presence of a barrage scheme alters the environment greatly, although it proves very difficult to estimate the effects with any sort of precision. Within the basin enclosed by the barrage the cycle of variation of water level is grossly changed, with a twice-daily upper level (assuming overpumping

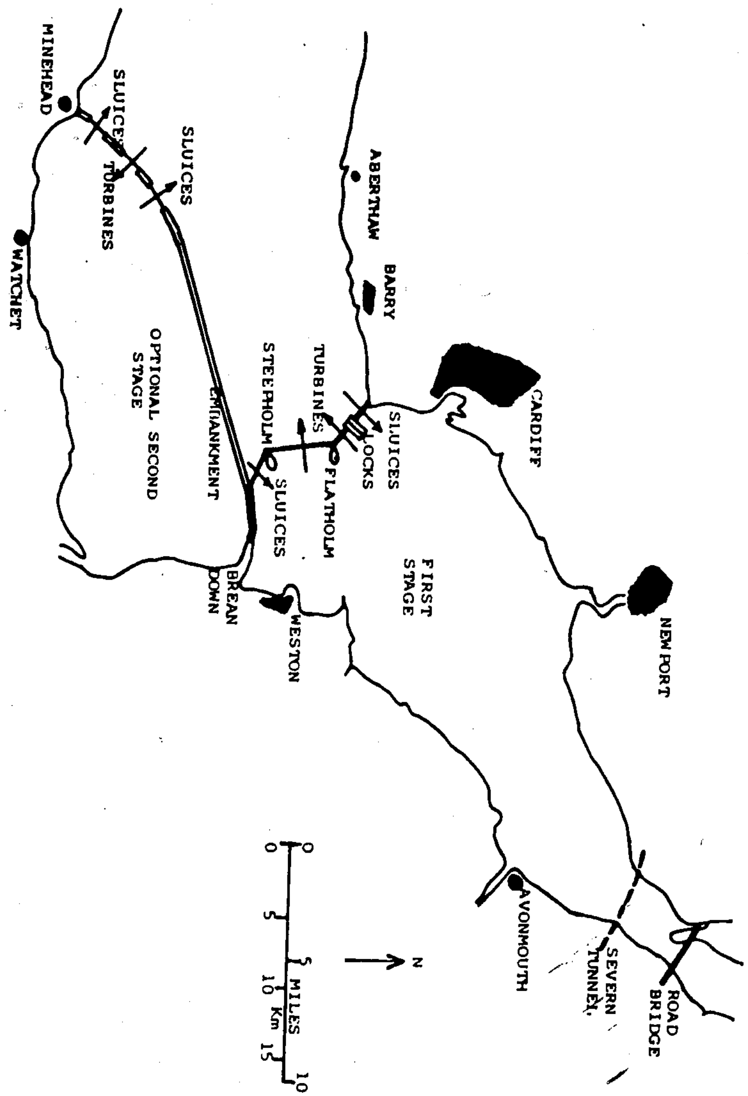

Figure 1. The Severn Barrage proposals of 1981.

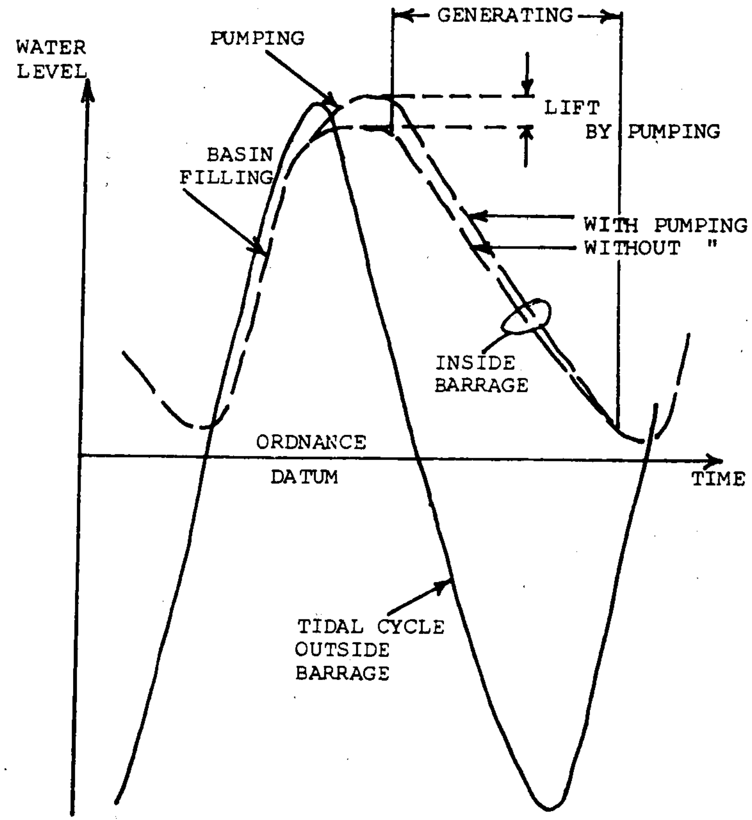

Figure 2. Water levels at the Barrage with and without pumping. (1986 scheme)

as described) roughly equal to that of spring tides, and a lower level slightly above normal meantide level. This would affect birds and plants.

The barrage obviously affects the movements of sediments. Much less mud and sand would be kept in suspension within the basin than at present. This matter is much more serious for the shorter English Stones barrage, where it is estimated that half the storage capacity could be lost in between 10 and 100 years by increased sedimentation. Salinity, and water quality generally, could be affected by the barrage. The reduced turbidity would lead to greater biological activity. The different water levels would probably adversely affect drainage and increase effluent concentration. Fish could be damaged in passing through sluices and turbines.

Some of the environmental effects are likely to be harmful, but some are likely to be beneficial.[34] And we must remember the point already made that the barrage scheme would require one less nuclear or coal-fired station to be built.

The environment would also be affected by a decision to make a road across the barrage. The network of connecting roads which would have to be built, while providing welcome employment, would absorb much land and be detrimental to the landscape, and lead to some pollution of the atmosphere by noise and fumes.

APPENDIX 1.

Description of the Inter-War proposals with High-Level Pumped Storage.

As stated in section 2.3, there was continuous consideration of the Severn Barrage proposal between the original statements in 1920 and the Report of the Severn Barrage Committee in 1933; during this time the scheme varied only in points of detail as various parts of it were worked out by consulting engineers and other experts. Therefore what we shall do here is give a summary of the scheme as described in 1933.

The site of the barrage is shown in Figures 3 & 4. Navigation would be continued and suitable locks and piers, etc, would be provided. Road and rail transport would be provided partly along the line of the barrage. The electrical energy output from the barrage itself, assuming 67 of the 72 turbines were working, would be

4.68GWh on each spring tide

3.19GWh on each mean tide

1.3 GWh on each neap tide.

Over the average year, the total potential output from the generators would be 2252GWh or 2.25TWh. It was estimated that the cost of this would be about 0.18d per KWh. It was, however, also recommended that a high-level pumped-storage scheme should be provided to enable the energy to be supplied to the grid at controllable times and at controllable rates. This would have a pipe-line between the River Wye at Tintern and the high-level reservoir at Trellech Grange (see Figure 5). Some of the energy generated at the barrage would be used to pump water up to the reservoir, and the water from the reservoir would be used to generate electricity by machines at Tintern when the demand arose. The reservoir would have a top water level of 500ft. above Ordnance Datum, and at this level an area of about 750 acres. It was estimated that the energy stored between 500ft. and 450ft. would be about 20.5 x 10^6hp-hours, and between 450ft. and 400ft. about 6.5 x 10^6hp-hours. The total energy stored between 500ft. and 400ft. would be about 27 x 10^6hp-hours, or in electrical terms, about 20GWh. As this was more than four times the energy generated at the barrage even on a spring tide, there was clearly no need to worry about the reservoir filling and emptying on every tide; the daily variation in level would be relatively small, but there would be variation more nearly approaching the full amount over fortnightly and longer periods. As the water was from the estuary, it would be salt, or at any rate brackish, and there would therefore be an environmental problem different from that of ordinary hydro-electric systems. There would also be an environmental problem at Tintern; the pumping and discharging of so much water would affect the salmon fishery and alter the silt deposition.

The use of pumped storage evidently increased the cost of electricity supplied to the grid, and also reduced the overall amount of energy because of losses in the additional processes involved. It was estimated that in one year about 700GWh would

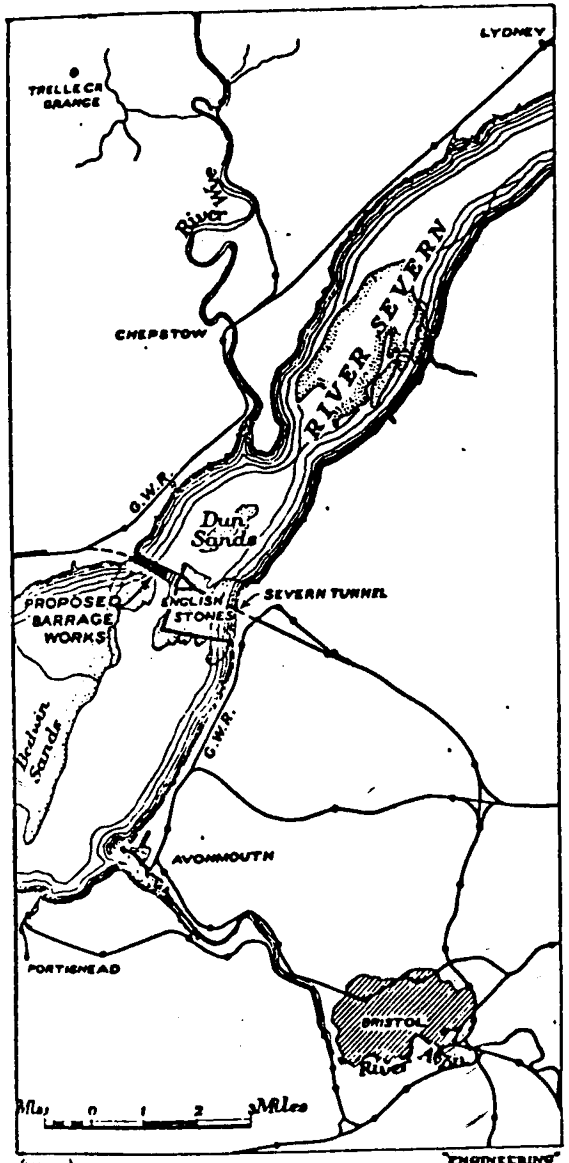

Figure 3. Map of the Severn Barrage Scheme , 1933. (*Engineering,* 7th April 1933)

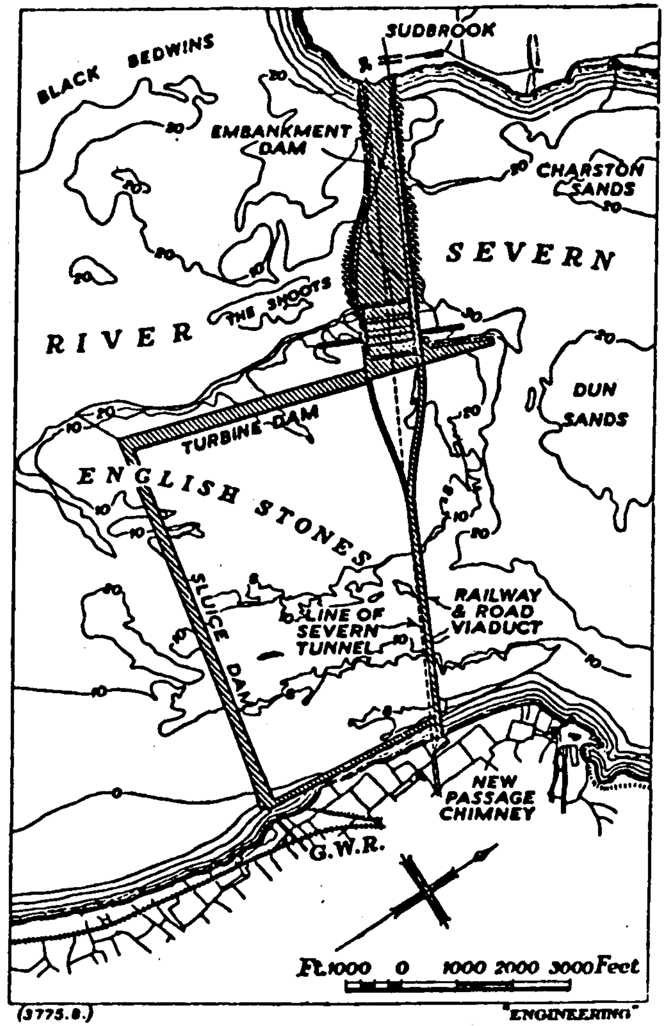

Figure 4. Map of the Severn Barrage Scheme, 1933. (*Engineering,* 7th April, 1933)

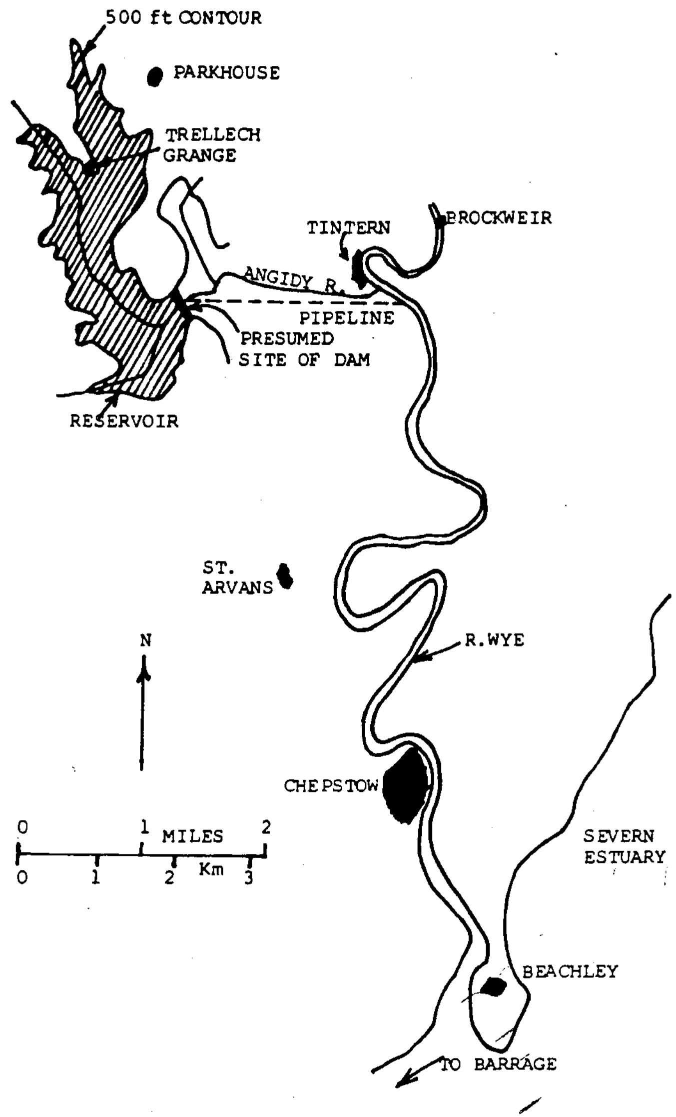

Figure 5. Proposed pumped storage scheme, 1933.

be supplied direct to the grid from the barrage, and about 900 from the pumped storage system, making about 1600GWh/year in all instead of the 2250GWh/year available from the barrage. The cost per KWh would be increased by 0.23d, but this was still only about two-thirds of the cost from the most efficient coal-fired generating stations of that period.

The total cost of the scheme was estimated as:-

Barrage and power station	£25,457,574
Reservoir and storage station	£11,468,901
Extra transmission lines	£1,500,000
Road, railway and harbour	£12,000,000
Making a total cost of about	£50M.

The time of construction would be about 15 years, and the labour force (direct and indirect) would rise to a peak of nearly 28,000 in the 13th year, with an average over the 15 years of about 12,000.

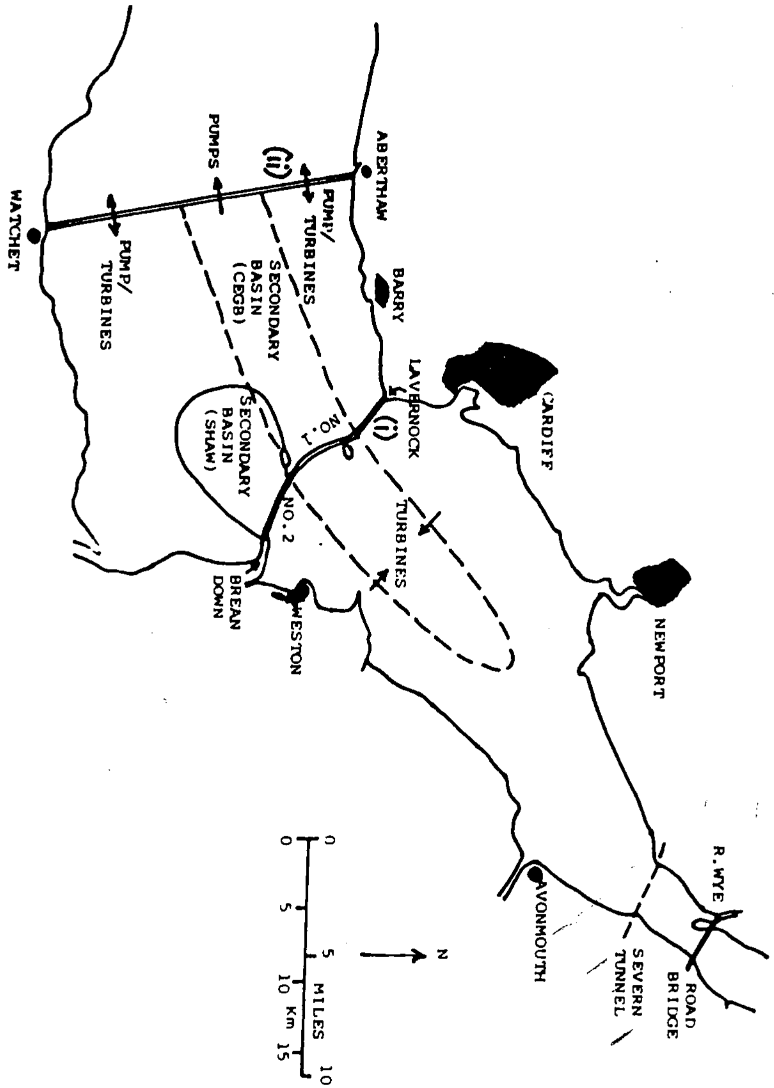

Figure 6. The Severn Estuary showing (i) Shaw's scheme of 1970. (ii) CEGB scheme of 1973-4.

APPENDIX 2.

Description of the Low-Level Pumped-Storage Proposal of 1970.

The proposal by Dr T L Shaw[35] was for a main barrage (see Fig. 6i) between Lavernock Point and Brean Down, incorporating the island of Flat Holm but passing just north of Steep Holm; the length was about 8 miles. A roughly-oval secondary basin was to be formed by a dam making a wide sweep southwards through Steep Holm and round to Brean Down, with a length of about 13 miles, enclosing an area of about 17.5 sq. miles with a mean depth below OD of about 60ft. The main shipping channel lies to the north of this basin. The capacity of the secondary basin is about 60% of that of the main basin. Reversible turbines (i.e. turbines which can operate in either direction of water flow and can also be driven as pumps) are fitted in the barrage in two sets, one (No.1) between the main basin (or upper estuary) and the sea, and the other (No.2) between the main and secondary basins. There is no connection between the secondary basin and the sea.

Cheap night power from the grid would be used to ensure that the main basin is full (i.e. a few feet above high-tide level) and the secondary basin is empty at the start of each day.

Generation during the day would take place in machines No.1 when the tide is sufficiently low (e.g. for a period of about 5 hours, not necessarily in one stretch), and in machines No.2 for the remainder of the period. Then at night, electricity from the grid would be used to drive both machines No.1 and No.2 as pumps to refill the main basin and empty the secondary basin.

The environmental effect of raising the upper level of the main basin by a small amount would not be expected to be large, nor would serious land drainage difficulties be expected. The effect of the low-level secondary basin should be nil, as it is entirely isolated from the land.

In a programme like this, the output power could be 3500MW over 24 hours, i.e. the energy generated would be 42GWh; but the energy absorbed at night would be 38.75GWh, so that the net daily output would only be 3.25GWh. Clearly the scheme is intended primarily as a pumped-storage facility for the grid, but with a net generating capacity. In this concept it differs from all the other schemes considered.

APPENDIX 3.

Description of the CEGB Continuous-generation Scheme of 1973-4.

This scheme,(36) like Dr Shaw's of 1970, used a secondary basin which was preferably isolated from land. As shown in Figure 6ii, the main barrage was to be further down the estuary, approximately between Aberthaw in South Wales and Watchet in England, and the secondary basin was to be inside the main enclosed basin (or upper estuary). Another important difference was that the scheme was conceived primarily for generation and not as a pumped- storage facility. The secondary basin was therefore not intended to have its minimum water level much below low-tide level, and filling of the high basin and emptying of the secondary basin could in principle be by gravity through sluices at appropriate states of the tide, although pumping would probably be used. With suitable proportioning of the basin sizes and with suitable operating programmes, it was estimated that with turbines of 6000MW capacity between high and low basins, and 2500MW capacity between high basin and the sea, a continuous (though not constant) output could be maintained throughout the year, providing about 25 TWh of energy to the grid. Operation on the basis of generation only during a limited day-time period appeared not to improve the performance.

The capital cost was estimated at £2500M-plus.

References

1. E. M. Wilson, "Energy from the sea - tidal power",*Underwater J.*, August 1973, pp 175-186, see especially p.175.

2. Technical aspects of tide-mill design are well discussed by D. H. Jones, "An analysis of tide mill operation", *Trans. 6th. TIMS Symposium,* 1985, pp.123-136.

3. W. E. Minchinton and J. Perkins, "Tidemills of Devon and Cornwall", *Exeter Papers in Industrial Archaeology*, Exeter, 1971;

W. E. Minchinton, "Tidemills of England and Wales", *Trans. 4th TIMS Symposium*, 1977, pp.339-353; and many other papers and books.

4. *Electrical Engineer,* **13,** 1894, pp.33.

5. "Embankment across the Severn", *Pembrokeshire Herald,* 27th March 1846, quoting from *Herepath's J.*

6. Report of Town Council Meeting, *Western Daily Press,* 10th November 1881.

7. *Ibid,* 3 January 1882.

8. J. Latimer, "Annals of Bristol in the 19th century", 1893, p.513.

9. C. Wells, "History of the Port of Bristol", 1909, p.225.

10. *The Electrician,* **7,** 22nd October 1881, p.353.

11. *Ibid,* **18,** 31st December 1886, p.161.

12. *Electrical Engineer,* **2,** 20th July 1888, p.46.

13. P. Decoeur, "Continuous utilization of tidal power", *Le Genie Civil,* **17,** 1890, p.130; abstract in *Proc. Inst. Civil Engrs.*, **102,** 1890, p.337.

14. *Electrical Engineer,* **13,** 9th Febuary 1894, pp.160-1.

15. *Ibid*, **16,** 20 December 1895, p.697.

16. *Electrical Times*, **33,** 21st May 1908, p.505; **41,** 2nd May 1912, p.462, **42,** 19th September 1912, p.268.

17. *Ibid*, **56,** 11th December 1919, pp.462-3.

18. L. B. Bernshtein, "Tidal Energy for Electric Power Plants", (Translated from Russian), Jerusalem, 1965, p.259.

19. Third Interim Report (Tidal Power) of the Water Power Resources Committee, board of Trade, HMSO, London, 1920.

20. Republished together as "Construction and Operation of a Tidal Model of the Severn Estuary", HMSO, 1933.

21. Report of the Severn Barrage Committee, HMSO, 19th January 1933, reprinted 1945.

22. Articles in *Engineering*, **135**, 17th March 1933, pp. 307-8; 7th April, pp. 394-6; 2nd June, 1933, pp.599-600.

23. Report on the Severn Barrage Scheme, by Panel appointed by Minister of Fuel and Power, HMSO, 1945.

24. Editorial, "The Severn Barrage", *Engineering*, **159**, 2nd March 1945, pp.171-2.

25. N. Davey, "Studies in Tidal Power", Constable, London, 1923.

26. E. M. Wilson, "A feasibility study of tidal power from Loughs Strangford and Carlingford with pumped storage at Rostrevor", *Proc. Inst. Civil Engrs.*, **32**, 1965, pp.1-29.

27. "La Rance Tidal Power Scheme", special number of *Revue francais de l'Energie*, No.183, September-October, 1966. Also illustrated booklet, "The Tidal Power Stations of the Rance", Ref.A/20, issued by the French Embassy in London, 1967.

28. Full account given by E. M. Wilson in reference1.

29. "Tidal Power Barrages in the Severn Estuary", *Energy Paper No.23*, Dept of Energy, HMSO, May 1977.

30. "Severn Barrage Seminar, 7th September 1977: Report of Proceedings; Written Contributions", *Energy Paper No.27*, Dept. of Energy, HMSO, 1978.

31. "Tidal Power from the Severn Estuary", *Energy Paper No.46*, Dept. of Energy, HMSO, 1981.

Vol.1: Report to the Secretary of State for Energy. (111pp)

Vol.2: Analysis, studies, reports and evaluations. (459pp)

32. "Tidal Power from the Severn", Thomas Telford Ltd., London, 1986.

Vol.1: Report. (97pp)

Vol.2A: Engineering and economic studies, Cardiff Weston scheme. (Approx. 300pp)

Vol.2B: Engineering and economic studies, English Stones scheme. (Approx. 250pp)

33. "Severn Barrage Development Project; Description of studies to be undertaken during 1987/8: *Consultation Document No.1*", Severn Tidal Power Group, Febuary,1987. (Discussed, with diagrams, in *The Times*, 17 Febuary 1987.)

34. "A Severn Barrage", text of an exhibition, Woodspring Museum, Weston-super-Mare, 1981. Available from the Museum, price 65p.

35. T. L. Shaw and G. R. Thorpe, "Integration of pumped-storage with tidal power", *J. Power Division of Proc. American Soc. of Civil Engrs.*, **97**, January 1971, pp.159-180.

36. J. D. Denton et al., "The potential of natural energy sources', *CEGB Research*, No.2, May 1975, pp.28-40, espec. pp.36-39.

TWO SOUTH AFRICAN WINDMILLS
by Niall Roberts

This article describes two windmills seen during a visit to South Africa in 1985. Both windmills are in the Cape Town area (see Figure 1).One of these had been fully restored, with machinery. The other was restored structurally and had sails but, it was understood, had no machinery below the windshaft. A preserved sail-less tower was also seen from a distance.

Mostert's Windmill (Mowbray,Cape Town)

This is a three storey whitewashed stone tower mill (believed to have been built in 1796) with a thatched cap and four common anticlockwise sails (see Plate 9). One of Cape Town's many modern expressways passes beside it. Although the cap is essentially conical, it has such marked "dormers", for the protruding windshaft at the front and to admit light (and provide an opening for the external brake-lever) at the rear, that it could almost be described as having a pitched roof. Winding is by a double-braced tailpole with a capstan winch at its lower end and a circle of anchor posts set in the ground around the base of the tower. (see Plate 10). Walton[1] points out that this is the only recorded example in the Cape of a tailpole winch and he suggests that this may have been added when the mill was restored by the Dutch millwright, C. Bremer, in 1936. The cap runs on a dead curb. The sailbars are morticed directly through the wooden stocks which pass through the ornamented poll end (see Plate 11). Walton draws attention to the fact that the sails on this Mill, later copied to some extent on Durbanville Mill, were at the time he wrote his book the only complete set of sails in South Africa and that they do not necessarily reproduce exactly the original sails at this or other mills in the Cape. The Mostert sails were designed by Bremer for the 1936 restoration. Another feature of the restored mill which, Walton suggests, may have been introduced during restoration is the rather elaborate date board with the inscription:

Mosterts Meule

AD - Welgelegen - 1796

According to Walton, there is no evidence of such boards being used on any South African mills. The flanged collar around the neck of the windshaft to protect the neckbearing from rain also looks like a modern feature.

The internal machinery is understood to be original, but the metal staves and associated metal hoops in the lantern wallower would seem to be the result of

modernisation at some stage. The stout clasp-arm brakewheel with wooden teeth is almost wholly surrounded by an equally stout brake shoe in two parts. The brake-lever carries a weight box filled with stones and rests on a fixed iron brake-hook by means of an iron bar let into the side of a recess in the lever, unlike the cam-shaped swinging brake hooks we are accustomed to in this country. An iron extension to the end of the brake lever is itself suspended by a chain from a secondary brake control lever pivoted from the roof of the cap, and from the outer end of the control lever, which projects through the dormer window in the rear of the cap, hangs the brake chain (see Plate10). A square iron quant is let into a longitudinal slot at the lower end of the wooden upright shaft. The slot is closed by a fitted piece of timber secured by three iron clamps. There is only one pair of stones.

The present varnished stone furniture appears to date only from the 1936 restoration (see Plates 12-13), and the cruckstring is arranged unusually and, at present, not entirely correctly. Instead of rising upwards from an anchorage point at the end of the feed shoe, over the notched bar across the horse and then downwards to a twist peg, the cruckstring is anchored to a swivel-block secured at the top of the tun, then passes down to an eye-hole in an extension to the shoe, then upwards through a hole in the "willow-spring" and finally over a small pulley on the edge of the opposite side of the tun and down through a hole in the floor to a twist peg near the meal spout. The oddity is that the cruckstring passes **through the willow** so the willow serves merely as a support for the string and, as currently "strung", the willow does not serve to hold the shoe end against the quant. Walton's book (page 163) does, however, show the correct arrangement with the willow "strung" to the end of the shoe quite independently of the cruckstring. There is no sign of a bell alarm.

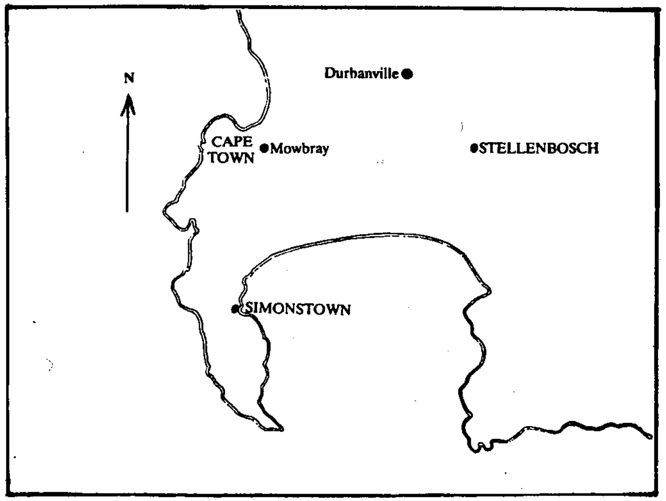

Figure 1. Map of Cape Town showing the mills visited.

Tentering is by means of a suspension iron (the lighter bar) between one end of the bridge tree and the mid-point of a brayer on the stone floor, with the fulcrum of the brayer at one end and with the brayer's other end suspended by a short chain from the end of a lighter-staff (see Plates 13-14). The opposite end of the lighter-staff is held in position by a loop of rope, one end of which is knotted beneath the stone floor and the other end of which passes through a second hole in the stone floor and has what looks like a cannon ball as a weight for securing the rope around a suitable part of the hursting near the meal spout (At the time of my visit, the rope was needlessly long for this purpose and the weight rested on the floor). There is what looks like a flangeless belt pulley on the stone spindle, and Walton suggests (page 164) that this may have been for a belt drive to a governor. This seems unlikely, given the relative primitiveness of the present method of tentering, but perhaps in the 1936 restoration the mill was "put back" to an earlier tentering arrangement rather than restored to its last known working condition. If that is what happened, maybe the tailpole winch ought not to be there! (Personally I would not be dogmatic about the "last working condition" principle but I would favour historical consistency. Unfortunately there was no "Guidebook" available which might have clarified these matters.)

Durbanville Windmill

This mill is situated in the centre of a small new housing estate about 20 Km North-East of Cape Town not far off the N1 Highway and has been restored only during the past few years. According to a plaque on the mill wall, the mill was built about 1801. As a well-deserved tribute to Mr. Walton's keen interest in, and extensive knowledge of, South African mills of all types, the road in which the mill now stands bears Mr. Walton's name. Walton's book shows a photograph of the base of the tower as it was before restoration and he records that the roofed stump of the tower was used to house a horse mill (page 146). The rebuilt tower has a very marked batter (see Plate15). Like Mostert's, upon which, according to Mr. Walton, the restoration was based, the cap is thatched but, unlike Mostert's Mill, the tailpole has only single bracing and carries no winch at its lower end. The pole-end lacks the carved decoration of Mostert's and there is no date board. Another difference from Mostert's Mill is the scarf jointing of the stocks secured by three iron clamps (see Plate 16), so that there is in effect a wooden "cross" consisting of the stock "stubs" set into the wooden pole end. In Plate 16, the diagonal line of the scarf joint has been "touched-up" as this did not show up as clearly as expected in the original photograph. The joint does not have "locking wedges" at its central point, and relies on bolts and clamps to hold it secure. (At Mostert's Mill, the stocks are each a single piece of timber without joints). It was not possible to see the interior of this mill and it is not known if it has any machinery, but this seems unlikely as the restoration appears to have been carried out to provide an attractive "centre piece" for the small estate of dwellings around the mill.

References.

1. Walton, J. "Watermills, Windmills and Horse Mills of South Africa",C. Struik, Cape Town,1974.

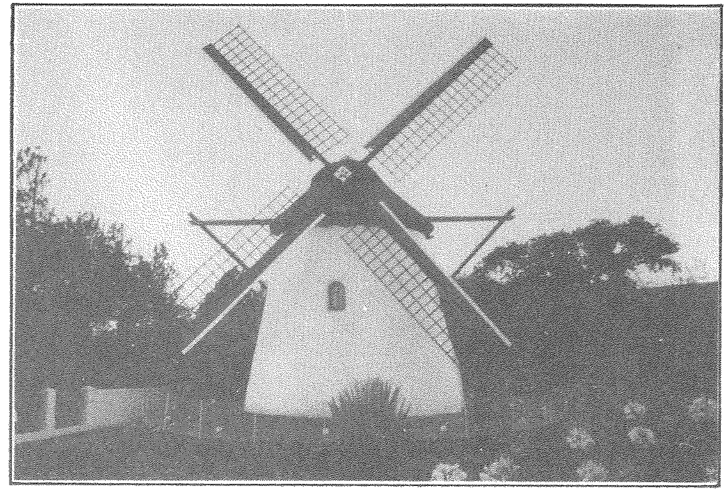

Plate 9. Mostert's mill,front view.

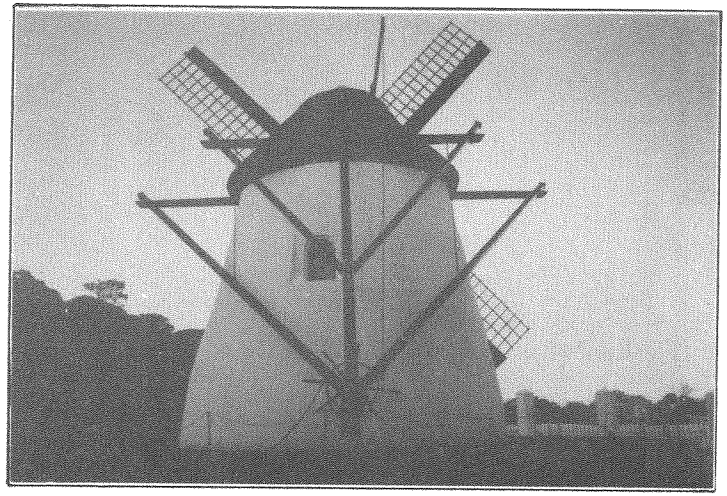

Plate 10. Mostert's mill, rear view.

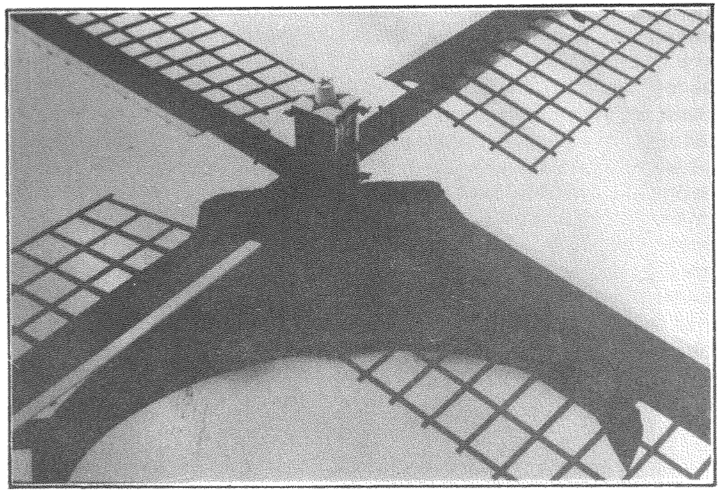

Plate 11. The poll end and cap, Mostert's mill.

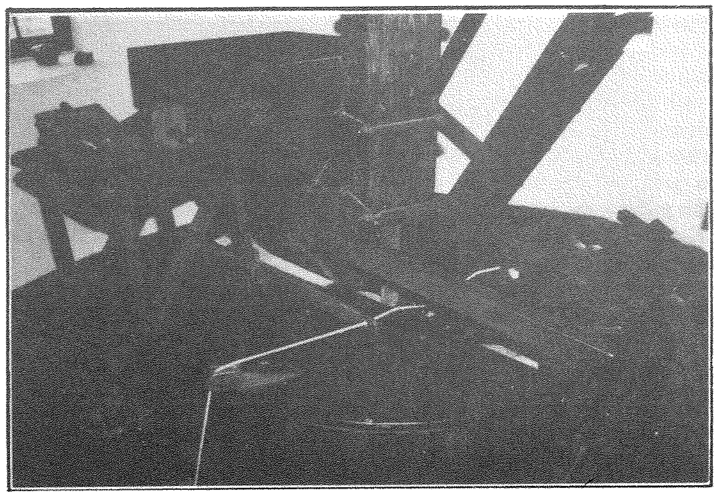

Plate 12. The stone furniture, Moster's mill.

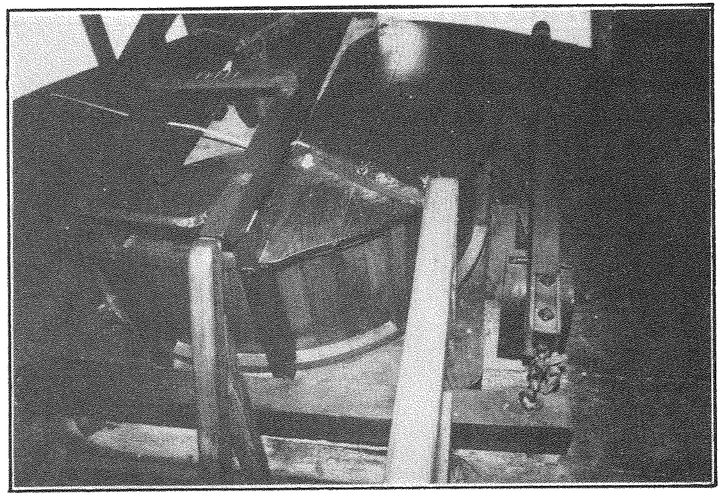

Plate 13. Tentering showing prayer and lighter staff, Mostert's mill.

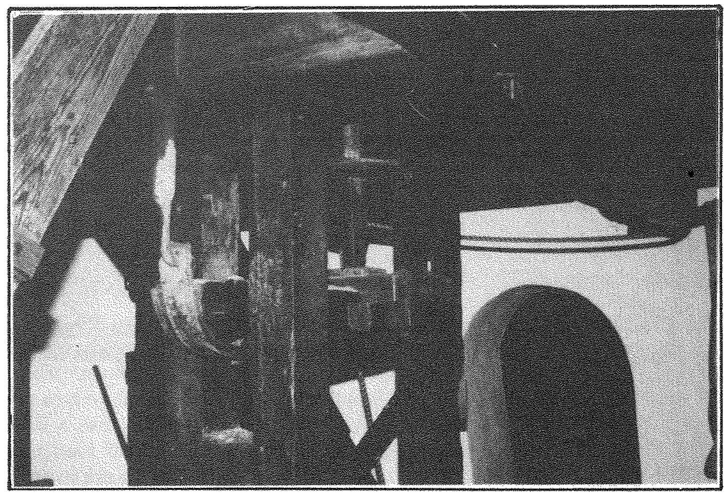

Plate 14. The bidge tree, suspension iron, and tentering rope, Mostert's mill.

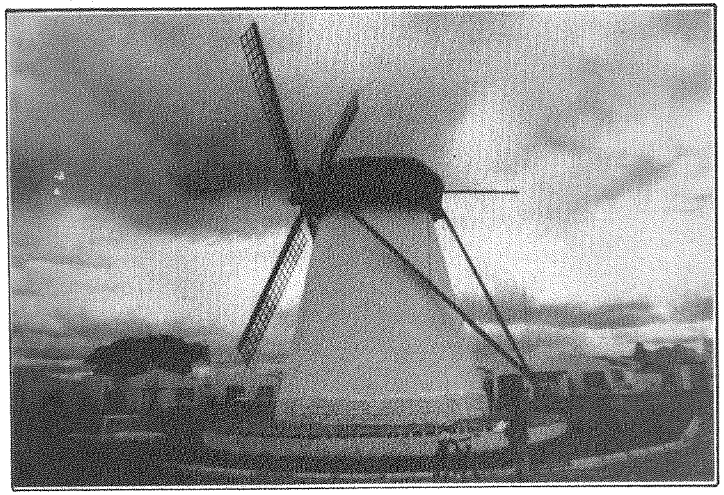

Plate 15. Durbanville mill.

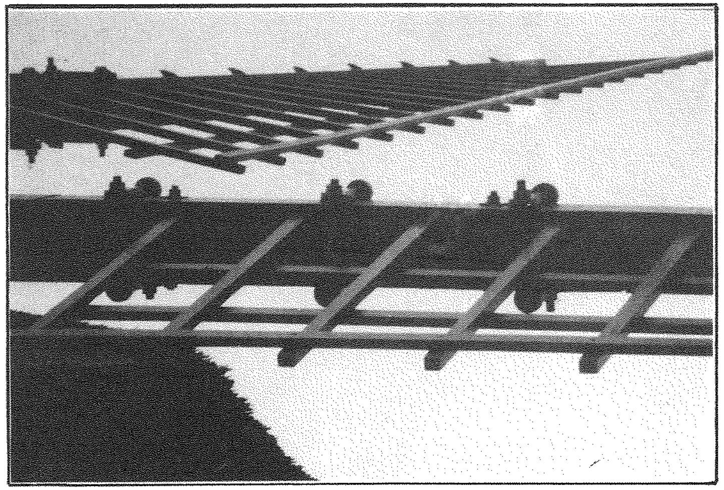

Plate 16. The stocks showing the scarf joint, Durbanville mill.

A TIDE WHEEL AT TINTERN?

by Stan Coates

Around the middle of the 16th century it was the policy of the government to "free the realm from dependence on foreign sources for vital commodities" and in the winter and spring of 1565-66 a survey of various rivers in the kingdom was made to investigate sites for the use of water power. At that time the woollen industry was dependent on imports of foreign wire for wool cards, a simple hand brush with wire teeth used for straightening the fibres of wool and laying them parallel to each other for making into thread. Iron and steel wire was also in great demand for the manufacture of fish hooks, small chains, pins, etc., and imported wire was found to be superior to the British product.

A suitable site was found at Tintern, near Chepstow, a major port for the area, which lies at the confluence of the Rivers Severn and Wye in South Wales. Several skilled men were brought from the continent to "introduce into the realm the science and faculty of drawing and forging of iron and steel into wire by waterworks, a thing altogether foreign until that time"(1) and a works was established in 1566 on the little Angidy River which flows into the River Wye near Tintern Abbey (see Figure 1.). This was the first water-powered wire making industry in Britain and subsequently became a very large and important source of wire which was in more or less continuous production for over 300 years. There were a dozen or so separate sites along one and a half miles of the river and the location of most of these is well known. A schedule of 1821 lists a total of twenty water-wheels in use by the industry.(2)

The River Wye, being navigable played a very important role in the transport of materials for the works but it is tidal with a rise and fall of some 22ft where the Angidy River joins it. At this point there was a small floating dock with a gate which impounded the Angidy River to facilitate loading and unloading the boats.

The area round this dock has recently been developed by the owner as a visitor centre and during building work in the vicinity of the dock walls the wooden axle and cast-iron nave of a very large water wheel has been uncovered. Unfortunately most of the wheel and its pit is buried under later buildings and rubble and much tidal mud lies over what might otherwise be visible. What can be seen, however, presents a very puzzling picture relative to its water supply arrangements.

There is no possibility of excavating the site and so the width and diameter of the wheel must remain a mystery, but from the sheer size of the approximately six foot diameter casting forming the nave and the two inch thick section of the webs, it must have been exceptionally powerful. Its location, however, means that the wheel must have been back flooded by the rising tide of the Wye for a number of hours each day. The owner of the site estimates that the tide rises above axle level on about ten days of each month. A wider, smaller diameter wheel would, of course, give a longer period of operation before being flooded but, paradoxically, the twelve inch wide pockets in the

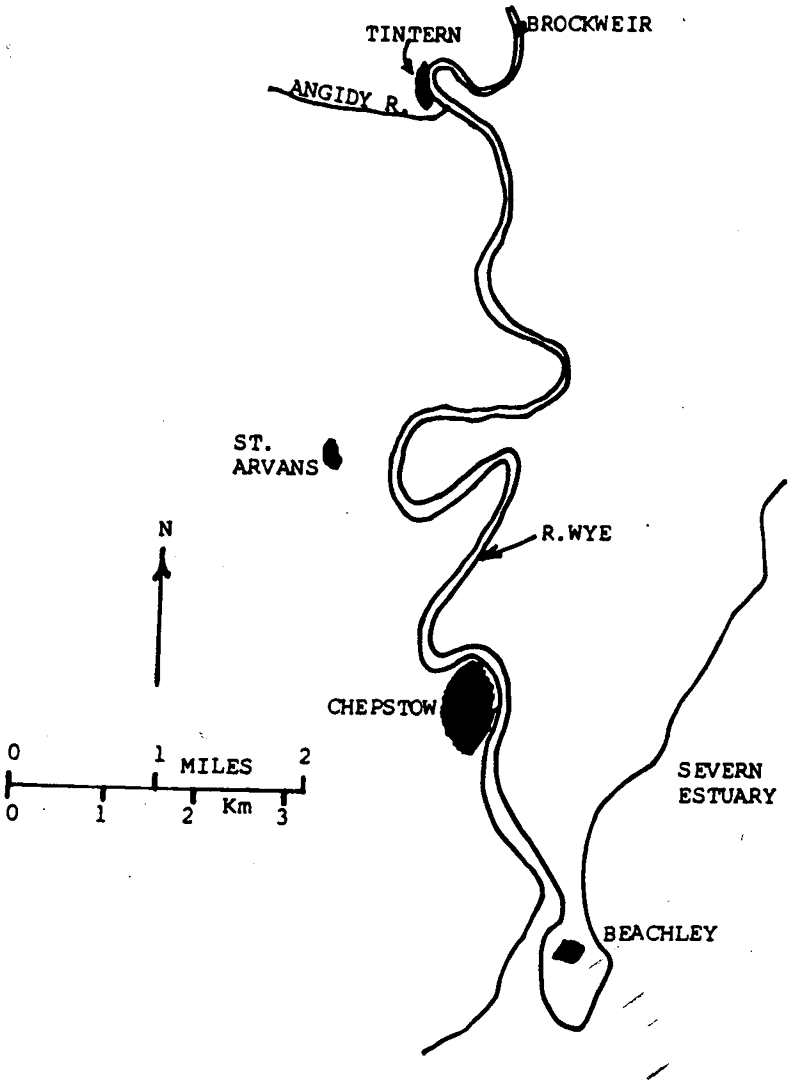

Figure 1. Map of the River Wye showing the location of the Angidy River.

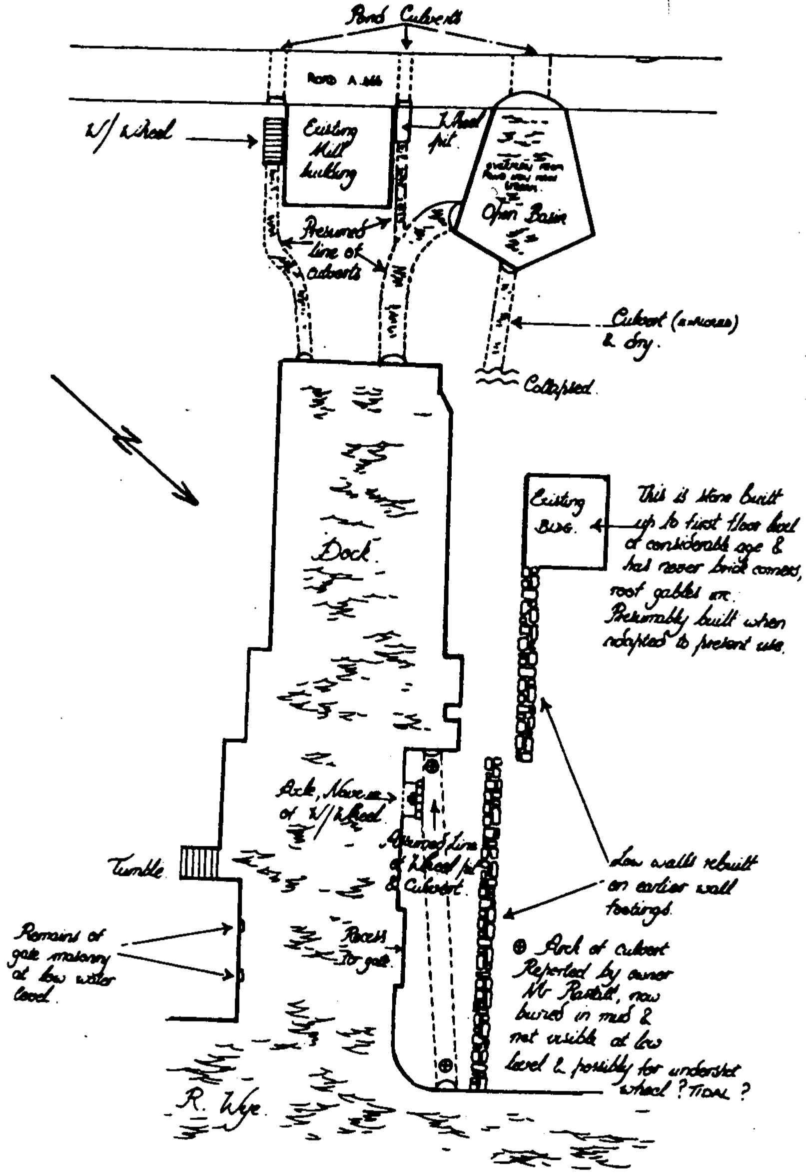

Figure 2. The Floating Dock at Tintern, SO 002530.

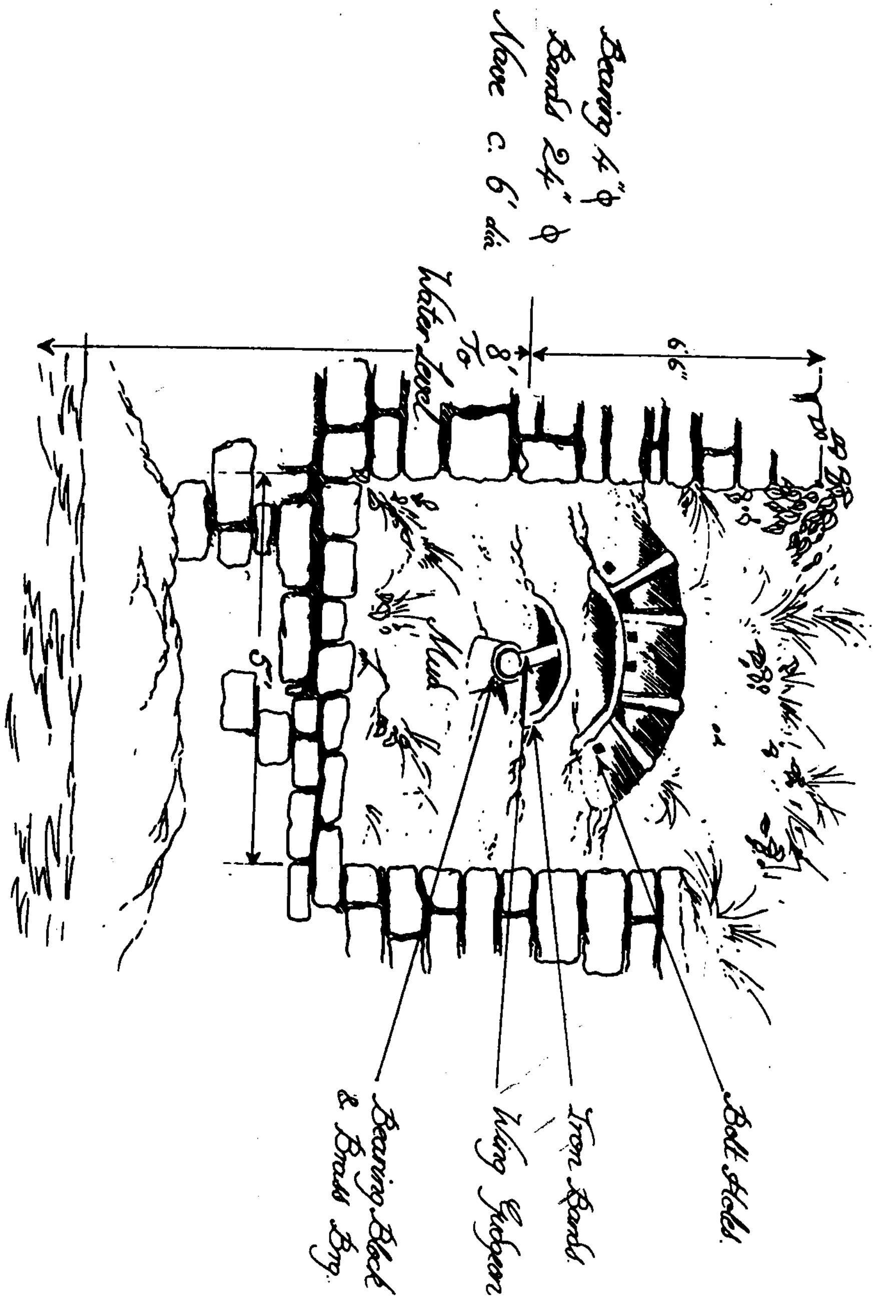

Figure 3. The remains of the water wheel in the north side of the dock wall at Tintern, SO 002530, 3rd July 1987.

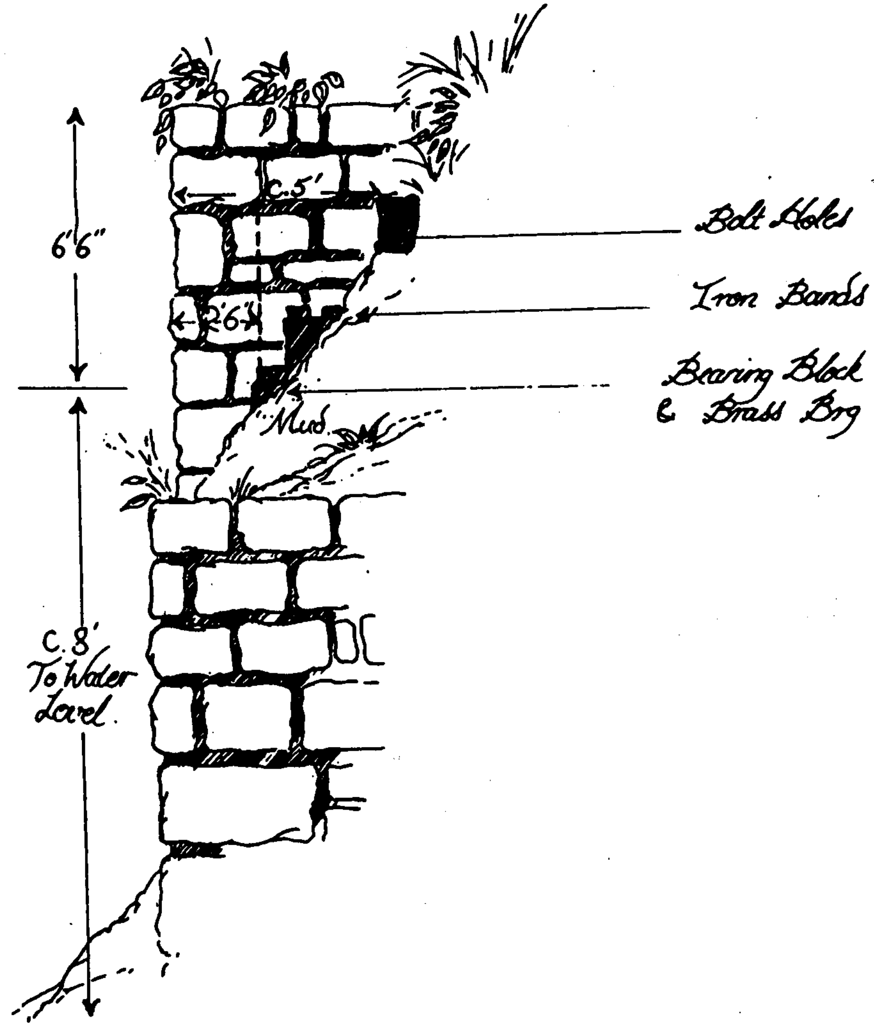

Figure 4. Vertical section through the waterwheel remains.

nave indicate very heavy wooden arms for the wheel which would seem to make a large diameter more likely.

A more fundamental question, however, is whether the wheel took its power from the tidal rise and or fall of the Wye, a tide wheel, or the little Angidy River, or perhaps from both. Additionally, what process would have justified such large capital expenditure on a machine which could have operated for so few hours each day.

Reference to the sketch plan of the dock (see Figure 2.) will show the several possible water arrangements for the wheel although the culverts to and from the wheel pit are no longer visible. The most likely method of operation would seem to be to use the dock as a reservoir by allowing it to fill with the gate open on the rising tide and impounding the water at high tide by closing the gate. Then, at low tide the water could be released through the wheel before the rising tide again flooded it. The other method could be to close the gate with the dock empty and allow the rising tide through the wheel in the reverse direction, or alternatively the wheel could have been arranged to turn in either direction. If the wheel was reversible then a rolling mill for which there is some inconclusive evidence, would seem to be the most likely reversible machine not requiring continuous operation but great power.

It is possible that the Angidy River itself would only have performed a topping up of the reservoir of water in the dock but at times of high flow could have significantly increased the running time of the wheel. Whatever system was used, however, the work of loading and unloading boats in the dock would have been severely disrupted when the wheel was in use.

So far it has not been possible to date either the dock or the wheel with accuracy and so the exact relationship between the work of the two must remain uncertain. but if the wheel was a tide wheel then no other example is known in the area. If it drove iron working machinery, as it most probably did, then this is a very unusual application of tidal power

References.

1. W. Rees, "Industry before the Industrial Revolution", Cardiff, 1968.

2. H. W. Paar & D. G. Tucker, "The old wireworks & ironworks of the Angidy Valley, Gwent". *J. Hist. Met. Soc.*, **9**,1975.

Publications: (continued)

Wind and Water Mills No.5.

Published July 1984. 48 pages, 17 drawings and maps.
Contents: Fladbury Mill, Worcestershire.
Watermills and water-powered Works on the River Stour. Part 2.
The Temple Farm Wheel, Temple Balsall.
The Dressing of Millstones: English Practice.
The Making and Dressing of French-Burr Stones.
The "Norse" Watermills of Shetland.
Windmills in Mallorca.
Watermill Research and Development in Nepal.
£1.00 (inc. postage)

Wind and Water Mills No. 6

Published July 1985. 64 pages, 8 photographs, 13 drawings and maps.
Contents: The Water Supply to Keele Hall, Staffordshire.
The "Moulin de Billion", Morbihan, Brittany.
Watermills and Water-powered Works on the River Stour. Parts 3 & 4.
Hurcott Paper Mill.
The Rise and Fall of the Fulling Socks.
Boulter at Wheatley Windmill (drawing).
£1.00 (inc. postage)

Wind and Water Mills No. 7

Published 1986. 52 pages, 9 photographs, 10 drawings and maps.
Contents: Mills and Milling in Medieval England.
Watermills and Water-powered Works on the River Stour.Part 5.
Mills on the Upper Arrow Valley, Herefordshire.
The Machinery of Blackford Mill, Henley-in-Arden.
Wheatley Windmill.
£1.00 (inc. postage)

Wind and Water Mills No.8.

Published May 1988. 44 pages,14 photographs, 6 drawings and maps.
Contents: Crag Works.
Some South African Watermills.
A Fourteenth Century Millstone Transaction.
Birkdale Old Mill.
From Mill to Megawatt.
£1.65 (inc. postage)