A closer look at Power before Steam and the influence of power sources on location of industry.

The most important source of power was water. Mentioned in Lect. 1 that waterwheels introduced in Greece 65 B.C. with horizontal wheel. This Greek or Norse mill continued in use until quite recently, having spread all over Europe and the East. But recent research has shown that a much more efficient version of it developed in Spain in the early 1500's and is in use in Iran to this day - see below.

Vertical wheels were later, but still quite ancient. Vitruvius in the 1st century A.D. developed the undershot water wheel:-

Needs no head of water, but does need fast flow, and constant depth.
Very inefficinnt, but if wheel is large, considerable power developed.
(3 h.p. in some instances)

Example, 18 paddles, outside diam 1.85m,
46 r.p.m. See Hist. Tech. II, Fig. 545.

The overshot wheel developed in the 4th century A.D., but was never common in classical times.

Head of water obtained from dam, millpond aqueduct, etc.
Needs a well-directed and regulated water supply, but can use very sluggish streams.

The Romans built a vast power-mill at Arles in the earlier part of the 4th century A.D., using two parallel sets of 8 wheels in series, utilizing a total head of 18.6m. (i.e. about 60 ft.)

Thus

This mill could grind
enough corn to feed a
population of 80,000.

But the Romans did not use water mills extensively, and only for grinding corn anyway. Two probable reasons:

(a) Watermills depend on steady water supply, which is expensive to obtain.

(b) Ample supply of human labour available, due to acceptance of slavery.

Christianity was a powerful force in developing the use of natural power, since it preached the dignity of human life and helped to abolish the degradation of slavery.

N.B. The breast-wheel also developed for operating with small heads of water.

There were 5,624 water mills in England in 1086. Gradually water wheels were used for all sorts of industrial purposes. (This applied equally in Europe generally). Wherever power was needed, the work was set up by a stream and a waterwheel built. Typical were the hammer-forges and wheel-driven bellows:-

Waterwheels were used for pumping water out of mines, and indeed were so used long after steam came in. For example, Cornish mines in 19th century still used waterwheels where possible. A massive waterwheel installation was built at the Devon Great Consols Mine near Tavistock in 1850 and is worth describing. (It actually displaced steam on account of cost).

The Duchy of Cornwall gave permission to draw water from the R. Tamar for £250 p.a. - later rising to £460 p.a. A "great leat" was cut, 2 miles long, 18 ft. wide, to bring the water to a head of around 40 ft. Two other leats, totalling 6.5 miles, were also cut. The wheels driven were

(A) Two wheels 40ft x 12ft to pump out two mines,

Wheal Maria 2376 ft away and 400 ft higher
Wheal Josiah 2160 ft " " " " "

Power was transmitted by 3.5 inch thick flat rods on pulleys, weight being counterbalanced at wheel. Each wheel developed 140 h.p. At Wheal Maria 400 gal. of water per min was lifted from 480 ft depth; at Wheal Josiah, 270 gal/min from 690 ft.

(B) Wheel 35 ft x 45 ft driving foundry machinery.

(C) Wheel 39 ft x 10 ft (80 h.p.) pumped Agnes shaft, 184 fthms or 1104 ft deep.

(D) Wheel 30 ft x 16 ft forced 500 gal/min up cast iron pipes from Tamar to reservoir 1200 ft away at Wheal Josiah. Here it worked saw mills, hammer, lathes, foundry, etc. Counting the auxiliary wheels, there were 33 waterwheels. Some of the big wheels also used for haulage up shafts. (Ref. F. Booker, "Ind. Arch. of the Tamar Valley).

Another interesting matter is that in the days of Newcomen and the early Watt steam engines, steam was used to pump water to a head for driving a waterwheel! i.e. water was used to convert reciprocating motion to rotary motion. Sometimes the steam engine was used only in times of drought to pump the tail water back to the head.

Nowadays the main use of water power is to generate electricity. Modern water turbines are quite efficient. Modern turbines have outputs up to 50,000 h.p.

Now to return to the topic of horizontal wheels:-

A development of the Greek or Norse mill appears to have taken place in Spain around the early 1500's in which the efficiency may have reached 75%. There were basically two types:

(a) "molino de bomba" with sprial-bladed impact wheel.

(b) "molino de regolfo" with helical wheel with 5 or 6 blades operating tightly in an enclosed chamber. This is effectively an early form of the modern water-turbine. Effectively a reaction turbine.

L. Reti claimed both types would develop about 18 h.p. with the dimensions recorded.

H. E. Wulff says that the molino de bomba are still in use in Iran for corngrinding. He has studied their performance and agrees with 75% efficiency including gearing, but thinks power is only 9 h.p.

The principle of the reaction turbine was apparently first invented by Robert Barker around 1735 thus

although Turriano in Spain seems to have involved this effect in his "molino de regolfo" nearly 200 years earlier.

The first practical and powerful turbine consciously designed on the reaction principle was by Whitelaw in 1839. Was very cheap compared with conventional waterwheel. One example quoted was

Conventional	Whitelaw turbine
64ft diam	1/4 of space
100 h.p.	120 h.p.
£4500	£750

Another Whitelaw turbine in 1840 gave (on test) 62 h.p. with 83% effic!

Windmills.

Used mainly for corn-milling and pumping (for drainage). The usual design of windmill works well over a very narrow range of wind velocity. Characteristically a windmill of traditional design hardly operates below 12 m.p.h., develops full power (say 50 h.p.) at about 18 m.p.h., and has to be stopped at 27 m.p.h. to avoid damage. Sails might be 96 ft tip to tip, covered in canvas, later with shutters.

In English Fens, winds 12-16 m.p.h. occur 1778 hrs per year
winds 16-24 m.p.h. occur 450 hrs per year
N.B. approx 9000 hrs in a year altogether.

So availability of windmill power rather poor. Nevertheless, no. of windmills grew very large. See slide showing growth into mid-19th century in Kent.

Some modern work has been done on small wind-driven electricity-generating plants, using more efficient propeller-type "sails", and I think a good many are in use. But their contribution to power supply nowadays is quite negligible.

Location of Industry.

As now, industry has always had to locate itself in relation to

(a) Raw materials,
(b) Power,
(c) Transport.

But in earlier days, power (i.e. water power) was not transmissible over distances of more than a few hundred yards (exceptionally, leats up to 2 miles could carry water power a bit further) and was not transportable (i.e. petrol and coal are sources of power which are transportable). So if power was required, industry had to be located by streams.

Raw materials were important, e.g. in the iron industry, where ore, charcoal and flux (limestone) were required. Transport of the finished product was usually necessary unless the trade was entirely local, but this was not such a great difficulty (owing to lesser bulk) as transport of raw materials. Thus the iron industry grew up first in places like the Forest of Dean where ore, flux and trees occurred together and power. But timber for charcoal was often short.

Manufacturing (e.g. tools) often required power. Hence all the Birmingham blade and slitting mills etc. were by the streams. Our local streams get very low in Summer, and there was a lot of bother over power shortage then. One mill accused another of hoarding water, etc., interfering with water levels, etc.

References on Waterwheels.

1. R. J. Forbes, "Power", in "History of Technology", Vol 2, ed. Singer et al, pp 589-614, Oxford, 1956.

2. F. Booker, "Industrial Archaeology of the Tamar Valley", David and Charles, Newton Abbot, 1967.

3. L. Reti, "On horizontal waterwheels and smelter blowers in the writings of Leonardo da Vinci and Juanelo Turriano", Technology and Culture, 1965, p 428.

4. H. E. Wulff, "A postscript to Reti's notes on Juanelo Turriano's watermills", ibid, 7, 1966, p 398.

5. L. Reti, "On the efficiency of early horizontal waterwheels", ibid, 8, p 388.

6. P. N. Wilson, "The waterwheels of John Smeaton", Trans. Newcomen Soc., 30, 1960, pp 25-48.

7. A.Stowers, "Observations on the history of water power", ibid, p 239-256. (includes useful bibliography).

8. P. N. Wilson, "Early water turbines in the United Kingdom", Trans. Newcomen Soc., 31, 1961, pp 219-241.

9. J. Addison and R. Wailes, "Dorset Watermills", ibid, 35, 1964, pp 193-216.

10. P. N. Wilson, "Watermills with Horizontal Wheels", London, 1960.

11. A. Stowers, "Watermills c 1500-c1850", in "History of Technology", Vol. 3, ed. Singer et al, pp 199-213, Oxford, 1958.

12. R. A. Pelham, "Corn milling and the Industrial Revolution in England in the 18th Century", Univ. of Birmingham Historical Jl., 6, 1958, pp 161-175.

References on Power before Steam other than Water.

1. F. Atkinson, "The Horse as a source of rotary power", Trans. Newcomen Soc., 33, 1962, pp 31-55.

2. R. Wailes, "A note on windmills", in "History of Technology", Vol. 2, ed Singer et al, pp 623-628, Oxford, 1956. (This is an appendix to the main section on windmills in R. J. Forbes, ibid, pp 614-622).

3. R. L. Hills, "Machines, Mills and Uncountable Costly Necessities", Goose, Norwich, 1967, (espec. Ch. 3 discusses windmill performance in land drainage).

4. E. W. Golding, "The generation of electricity by wind power", Spon, London, 1955.

References on Location of Industry.

1. E. K. Berry, "The Borough of Droitwich and its Salt industry, Univ. of Birmingham Historical Jl., 6, 1957, pp 39-61.

2. R. A. Pelham, "The water-power crises in Birmingham in the 18th century", ibid, 9, 1963, pp 64-91.

3. "Birmingham and its Regional Setting: A Scientific Survey", Brit. Assoc. for Adv. of Science, 1950.