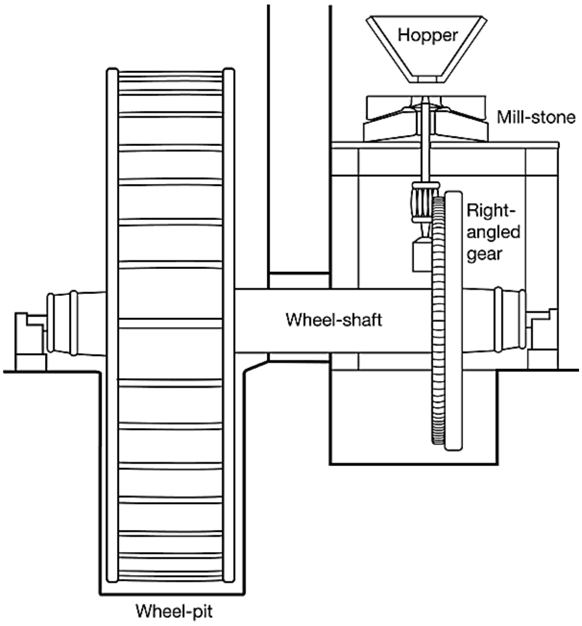
A1. Overview of Fife & Clackmannanshire Watermills

1. Introductory Remarks



My purpose here is to provide additional information about artefacts which once proliferated along each of the rivers dealt with here, but now survive if at all, largely as ruins, home conversions in riverside settings, or occasionally as working museums. It is fairly certain that the Romans brought watermills to England, and they spread throughout the medieval period all over Britain and Ireland, (there were thousands in total), in the hands of monasteries, landowners and burghs. Although medieval innovators had realised that a waterwheel could provide the power to carry out other tasks, the great majority were used for flour production, until much later. There were medieval watermills across Fife and Clackmannan, but as in Scotland generally, their major role in industry extended from the 2nd half of the 18th century well into the 19th century, and some continued to operate until midway through the 20th century. Medieval watermills sometimes employed horizontal wheels immersed in a flowing stream, but by early modern times vertical wheels, as shown in the simple diagram of a corn mill above, were ubiquitous; water rotates the waterwheel on the left, the drive system changes the rotation axis from horizontal to vertical, and increases the speed of rotation, and the top mill-stone moves over the fixed lower stone to grind corn.

As might be expected, after 1750 in an era of revolutionary improvement of many facets of life, mill wrights and their employers looked to enhance mill technology. Some of the greatest engineers of the day dabbled in the field, including Thomas Telford and John Rennie the elder, but the major advances in knowledge and capability were made by William Fairbairn, Andrew Meikle, and initially, by the Yorkshire engineer, John Smeaton. The latter made mill design a science, and in particular used small scale models to compare the efficiencies of different schemes for delivering water to the wheel. He showed that the so-called undershot design, in which wheel blades, attached to the rim, dipped into water flowing in a lade when at the 6 o'clock position and were pushed forward by the flow momentum of the stream, were only 20% efficient in utilising energy from the water. Breast-shot, and over-shot designs where the water was directed into buckets at a high point on the wheel, (respectively at the '9 o'clock' and '12 o'clock' points on the circumference) and emptied as the buckets reached a low point, did much better with 75% efficiencies possible. Of course, choice of design was not as simple as that, because the latter types depended on water being drawn off into a lade at a level significantly above the downstream return point into a river or stream. Weirs downstream of the entrance to the lade would help to increase this driving head, but only by a metre or so, whereas at least 5m was required. Of the others named, Meikle, born in East Linton, amongst many incremental developments, made water-powered threshing machines viable, while Fairbairn's contributions related to the details of design, robust construction, and understanding of causes of failure; he can be given credit for maximising the capabilities, and probably prolonged the life of the technology.

I shall delve a little further into the technical aspects of water mills. The power available is fairly easily calculated, as E X 9.81 X M X H, the product of the efficiency, E, the gravitational constant, 9.81 metres per (second)^2 in standard metric units, the mass flow rate of water over the wheel in kilograms per second, M, and the height dropped by the water between the point where it enters and leaves the wheel (the head) in metres, H; the latter dimension is effectively the diameter of the wheel for an overshot wheel, and slightly greater than the radius for breast-shot designs. (The calculation is more complex for undershot mills which depend on the transfer of momentum from the flowing water to blades on the waterwheel, though conversion to an equivalent head allows comparisons of efficiency to be made between the different delivery schemes). Considering an imaginary over-shot mill on the River Eden near Kemback where the mean river flow is 53000 gallons per minute which equates to c4000kg/s, so if the mill was permitted to ‘borrow’ 10% of that water by way of a lade, say 400kg/s; then with a waterwheel, 4m in diameter, and an efficiency of 0.7%, the power generated by the mill would be 11kw, (14.9 hp). This may seem small compared with car engines generating c100kw, and a modern jet engine, c50000 kw, but on the other hand the best a horse can do over an extended period is 0.5kw, while a very fit man on a treadmill would struggle to reach 0.1kw over any significant time period; the latter were the comparisons which mattered to mill-builders in earlier centuries.

Another key parameter is the speed of rotation, and the optimum value for maximum efficiency of an over-shot or breast-shot wheel has been found to be given by an empirical formula, 21 ÷ (wheel diameter)$^{\frac{1}{2}}$, so would be 10.5 RPM for the imaginary mill discussed above. The formula makes assumptions about a number of factors including the smoothness of the delivery of water, into the wheel containers, with splashing and air entrapment minimised, the subject of much successful experimentation by William Fairbairn. Almost invariably, the operations carried out by a mill, require rotation speeds higher than reasonable for the water wheel itself, and the gap is bridged by gearing incorporated in the drive train. So, in a corn mill, the movable grinding stone might rotate at 200 RPM, up to 20 times faster than the waterwheel, and governors will often be fitted to limit speed variability, but a price is paid in reduced efficiency, and thus power available, which in turn might limit the sizes of the stones and the through-put rate of corn. Hopefully, these paragraphs convey the fact that mill design was not straight-forward, and the improvements made by the likes of Smeaton, and Fairbairn, made a great difference, especially when more complex operations associated with textile manufacture had to be carried out. It should also be added that some of the improvements to the drive train were just as important when a steam engine replaced a waterwheel.

One more aspect which had to be got right was the water delivery system, about which Shaw’s magisterial volume ‘Watermills in Scotland’ perhaps has less to say, than might have been expected. On the medium-sized rivers which mainly concern this document, the system normally comprised a weir, a sluice gate and a lade or leat which conveyed water to the wheel, and past it, returning it to the river from the wheel pit through a tail race. Typically, a weir might be up to a metre high, and water would back up behind it in a pool of that depth. A mill lade, fed normally through a sluice gate, upstream of the weir, tracked the river downstream, sometimes carrying water to one mill, sometimes to a series of mills, and sometimes extending for less than a hundred metres, sometimes more than a kilometre. Typically a lade might be c1m wide like that to be seen containing a water wheel displayed at Bonnington in Edinburgh, rarely much more, and only slightly wider than the wheel to minimise the waste of power-delivering water. The height at which it arrived at the mill, in comparison with the surface of the river, there or downstream, was the main determinant of whether the mill could be over-shot, or breast-shot design; undershot waterwheels were unusual on Scottish rivers. On slow lowland reaches, over-shot mills could usually be ruled out, but even where waterfalls, downstream of a weir on faster-flowing rivers, meant that the entry and exit of a lade were at levels, metres apart, a route had to be found which allowed the water to retain most of that head difference until it reached the mill, if an over-shot or even breast-shot design was to be a viable option. The lade downstream of the mill was sometimes lengthened to reach a point where the river bed had fallen further than at the mill, so allowing water to be discharged at a level lower than that of the river alongside, and increasing the available head. Traces of many mill lades survive, not always the channels themselves, but bridges and hedgerows which define their line of travel; in such cases observations on the ground and study of maps can allow conclusions to be drawn about the configuration of a long-gone mill.

Of course, watermills were not only sited on rivers that can be described as medium-sized; there were a many near the sources and on tributaries of those looked at here, and on many smaller streams. In those cases the lades did not proceed directly to a mill, but fed a mill pond nearby, topping it up at all times, especially when the mill was not operating. In this way the mill could be driven by a larger and steadier flow, controlled by a sluice gate where the lade left the pond, than the stream in question could have provided directly, but of course operation could only be intermittent.

Having touched on the power-generation side of watermills, I will look very briefly at some of the basic tasks they were intended to undertake, and the arrangements put in place to accomplish these tasks. In order to do so rationally, it is necessary to make a distinction between two families of watermills, (i) commercial or stand-alone mills, in their own, sometimes extensive, premises, including cornmills and textile mills, and (ii) farm mills usually located in a barn within a farm steading, and especially associated with threshing, though a few drove churn paddles to produce butter from milk. It should be noted that the categorisations are not absolute; many sawmills are rightly regarded as commercial mills, but some were located on farms and other estates, performing tasks mainly confined to local needs. Indeed, more than a century ago, I think that one of my grandfathers spent a few years working on such a sawmill, before he moved to a more responsible position. However, to avoid over-complicating matters, we have considered all sawmills to be in the commercial category in this document.

2. Commercial Mills

I start this brief account of operations carried out in commercial watermills, in the obvious place with corn mills, the most common type. The first requirement after the corn had been harvested and brought in from the fields, was to separate the grains from the stems and husks, ‘the wheat from the chaff’, which was most often carried out on the farm where the corn had been grown; this was threshing and will be discussed later. There were two good reasons for doing this on the farm; firstly, the straw (dried stems) was valuable feedstock for farm animals, and had other uses, and secondly the operation greatly reduced the bulk of the material which had to be transported to the commercial cornmill. So, the raw material brought to commercial corn mills was usually grain in sacks which were hoisted up to an upper floor of a mill building. There, operations like dust removal and drying were carried out using machinery, which was often powered by way of a separate drive system taken from the waterwheel shaft. The cleaned and dried grain was then passed in time, into a hopper from which it could be released at a controlled rate to pass into the gap between the horizontal, grindstones, driven as shown in the diagram. There, the grain was ground into flour, which was collected at the edges of the stones, arriving by way of grooves. This is of course a simplified account of operations, which have taken place over millennia, and says nothing about the way in which the rate of grain supply was tailored to the rotational speed of the moving grindstone, about the adaptations needed for different grains (wheat, barley, oats, maise or rye), or about how the characteristics of the flour can be influenced. Finally, although watermills are discussed here, arrangements were much the same if the power came from windmill vanes, steam engines, or electric motors.

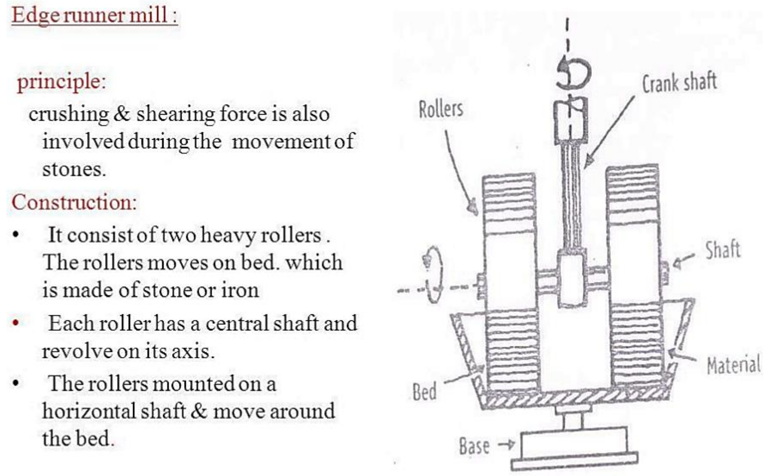
Textile mills will only be touched on; the subject is vast, and I do not intend to consider the inventions and other developments which transformed such operations as spinning and weaving from rural cottage industries into mass-producing factory-based operations. Inventors including Hargreaves, Cartwright, Crompton and Arkwright were responsible for this, in the century after 1750. I shall however mention a few operations which were performed in the watermills on the Fife rivers before that transformation took place. One such was fulling, which originally involved trampling on woven cloth immersed in a bath of liquid, to soften and bulk it up. This cannot have been a very pleasant task as urine was a key constituent of the fulling liquid, so it must have been a boon to the workforce, when watermills took over the task with wooden blocks on rotating wheels replacing the action of feet. The name Waulk Mill derives from that history and the process was still used into the 19th century.

Lint mills, prepared flax for spinning and weaving into linen cloth. As I understand the matter, the fibres which have to be taken from the flax plants are embedded in the stems. The manual approach involved immersing the plants in water for long enough for some rotting to take place; a process called retting. Lint ponds dug to enable this, survive in the Fife river catchments. The next step was to use a knife to separate the usable fibres from the softened residue; a process called scutching, which must have been time-consuming and requiring of some skill. Lint mills replaced this with a two stage process involving rollers to weaken the stems by bruising, and then rotating knives to separate out the desired fibres. In the process, grossly simplified in this account, the waterwheel drove both the rollers and the rotating knives. Downstream, I think the fibres were treated no differently from other textiles, and hand spinning and weaving as a cottage industry, eventually gave way to water powered commercial mills doing things on a far larger scale.

When reading about leather-making as carried out in medieval times, and into the modern age, it is quite hard to imagine how the revolting techniques could ever have been developed, and easy to understand why tanneries were normally sited as far from human habitation as possible, and definitely down-wind. After slaughter of a cow and skinning of the resulting carcass, preparation of a hide involved the removal of all fleshy remnants from the inner surface, and hair from the outer, and it appears that the most effective aids to the necessary scouring were animal and human urine and dung, sometimes used separately, sometimes mixed, and worked in by human feet. Latterly Waulk Mills were adapted to replace human trampling. The actual tanning process involved soaking in an aqueous solution of powdered oak bark.

Paper mills are next on the list, and after what has gone before, it is a relief to state that clean water, rather than any noxious solution, was indispensable to the production process. Until late in the 18th century, the power supplied by the waterwheel was utilised only in the first step, in which stampers driven by way of a crank pulverised a mix of thoroughly cleaned rags and water in a vat, to produce a cellulose slurry. The next manual step, must have resembled a child's method of producing large bubbles from soapy water, where a ring is immersed, and a film formed across the aperture is gently blown off, and surface tension creates the bubble. In the original paper-making process, a fine metal mesh held horizontally in a rectangular frame was immersed in the afore-mentioned slurry. The frame was then withdrawn, the water dripped off, and further drying yielded a single sheet of paper. The crucial advance towards obtaining a mass production route involved the replacement of the frame by a continuously moving strip, still meshed, which after leaving the vat of cellulose slurry was passed through rollers to squeeze out water. The lengthening paper strip was then dried, separated from the mesh, and collected as large rolls. The power to drive the various rollers and fans normally came from the waterwheel.

My next category, includes Snuff Mills and Flint Mills; the grouping is mainly for convenience, though usually the processes are small scale, and utilise grinding wheels, stamping machines or edge runner mills. The last of these is shown in the schematic. All were powered by a waterwheel, though electric motors were employed in later years. As regards snuff mills, the raw material was tobacco, and the process involved stamping initially, and then grinding, both of which would be powered by waterwheels in what were small mills. Flint Mills were indispensable for the manufacture of glass and pottery; though these were not important industries in Fife and Clackmannan, save in and around Kirkcaldy in the 19th century. Early flint mills had stampers, to break up the material, but later, water-powered stirrers pushed grinding stones across the flint in water-filled vats, thereby avoiding the evolution of large amounts of harmful dust. A similar process refined China clay to the grade required for making pottery. A surprising absence from the watermill types present in Fife and Clackmannan, was the gunpowder mill, as its product was indispensable for quarrying; presumably gunpowder was supplied from elsewhere.



Edge runner mill :

principle:

crushing & shearing force is also involved during the movement of stones.

Construction:

- It consist of two heavy rollers . The rollers moves on bed. which is made of stone or iron
- Each roller has a central shaft and revolve on its axis.
- The rollers mounted on a horizontal shaft & move around the bed.

Many saw mills were located either the source of raw material, i.e., near woods, and I have already referred to the fact that many such estate mills bear a close relationship to farm mills, as regards locations and the limited populations they serve. However, those with wider customer bases were sited in settlements near to customers, remembering that their products like the raw material could be bulky and difficult to transport. As regards the devices themselves, water power replaced two men moving a saw blade back and forward across the wood to be cut during the 18th century. The mechanised version employed a weighted saw blade which moved back and forward in a vertical frame, driven in reciprocal motion by a waterwheel through a crank. At first the wood had to be moved manually, between each operation, but driven carriers soon mechanised this aspect as well. The invention of the circular blade greatly enhanced the flexibility and speed of operation, but the vulnerability of the blades to overheating and other damage was a problem, which has not really been entirely solved in powered saws to this day.

As regards the use of watermills in the iron industry, there was a short-lived ironworks during the 19th century, in the Bluther Burn catchment, but otherwise no primary production units, i.e. blast furnaces or bloomeries, were located in Fife and Clackmannan, but secondary processes were carried out. In foundries, the power derived from waterwheels was used to drive air bellows supplying burners attached to heating furnaces, and to operate presses and a multitude of machining tools by way of geared trains and belt systems in conventional ways, but

Fife and Clackmannan were minor players in this Scottish industry, famously associated at first with the River Carron. Following on from one industrial application of water-power, readers may wonder about the omission of any consideration here of the large scale mining operations which took place across Fife and Clackmannan until fairly recently. The explanation is that although water wheels drove pumps which drained and ventilated mines, and in a few cases powered the lifts which carried miners underground, these applications were not common, and by no stretch of the imagination could they be regarded as taking place in watermills.

3. Farm Mills, especially Threshing Mills

Until the late 18th century, threshing (or thrashing) was a manual, labour-intensive, and wasteful operation. Once harvested, corn stems carrying cobs were laid out on a hard core floor and beaten with flails. This process detached the grain, but separation was a haphazard process, involving the removal by hand of the stems or straw, and sweeping up the remaining detritus on the floor and sieving it, so isolating the grain. It was thought that there was no activity on a medium-sized arable farm, that occupied more man hours in a year; there was obvious waste during the process, while it was so slow that deterioration of the crop was probable before the operation could be completed. Unsurprisingly, inventive engineers and millwrights designed machines to do the job in the 18th century, with varying but limited degrees of success, until Andrew Meikle came up with his successful prototype around 1790. The flailing operation was replicated by a rotating drum with curved vanes which beat the corn stalks fed in from above against bars making up a cage around the drum, so tearing off the grain, which fell into judiciously placed sacks. I should like to have added an illustration, but have failed to find one that adds to that brief description. Meikle’s machine could be driven by horses, so-called horse gins and probably most often was initially, but the added power and drum rotation speeds achievable with a waterwheel made the process more effective and cheaper to run, if costlier to install. Water power was an option, even if an available water source was small, but farms sometimes stuck with horse gins. When not named on early OS maps, they can be identified by semi-circular platforms, round which horses were led, as pointed out to us by Professor Paul Bishop, while water powered threshing mills have been found by Alastair Robertson, who has identified the mill-ponds, and lades beside farm steadings, which supplied the water.

The story thereafter is of astonishingly rapid spread, not just in the Lothians where Meikle lived and worked, but far beyond. Shaw suggests that up to 5000 were installed in Scotland, and the numbers, we have identified are in line with that estimate. The technology spread into England as well, but this part of the story differs in two regards; firstly, installations caused rioting in Cumbria and parts of southern England, because farmworkers quite correctly saw them as a threat to employment, and secondly, the spread took time, so threshing mills were evolving into portable units powered by steam by the time they reached counties like Norfolk. By this time the threshing machine could be belt driven by a steam traction engine, which doubled as the means of moving the machine as required. (This meant that threshing machines were not identifiable on OS maps.) The final step in the process was the development of the combine harvester, which incorporated a reaper, a threshing machine, and a mechanism for bundling straw into bales. Nowadays, these machines are often owned by contractors who service many farms, driving the large vehicles at a few miles per hour, often along narrow roads between venues.

To complete this discussion, we have found no water powered churns used for making butter in Fife and Clackmannan, which is probably a measure of the relatively low occurrence of stock-rearing.

4. Overview of the Watermills of Fife and Clackmannanshire

These descriptions of commercial and farm mills are no more than a cursory glance at a very complex topic. I have referred to Shaw's book which is the source of a mass of information, but although I know of no better way of amplifying the snippets in this document than consulting its pages, I cannot pretend that it is an easy task to develop coherent accounts of developments over time of any type of milling, even with its aid. The watermills identified in each catchment area appear in appendices at the end of each historical journey down a river, but here I have included Table 1 which summarises the results, as regards numbers of threshing mills.

Table A2.1. Numbers of Watermills of Different Types in each Catchment in Fife and Clackmannanshire

	Catchment					Totals in Fife & Clackmannan
	Eden	**Leven**	**Devon**	**Lesser Streams**	**Other Streams**	
Corn, flour	46	43	3	31	28	151
Textiles, leather	28	41	29	14	14	126
Saw	12	20	5	10	5	52
Brewing, distilling	2	1	1		4	8
Paper, printing	1	4	2			7
Iron		2		4	1	7
Snuff	1	1			1	3
Starch	2					2
Flint		1			2	3
Slate Pencil		1				1
Coffee	1					1
Bone				1		1
Unknown	10	2		5	7	24
Total: Commercial Mills	**94**	**111**	**39**	**64**	**60**	**368**
Threshing	50	37	12	20	27	146
Grand Total	**140**	**147**	**51**	**82**	**85**	**505**

Notice that in the Table above, the numbers do not always add to give the values in the Totals row; this is because a good proportion of the mills had more than one function over time, and all of them are recorded, whereas the totals give numbers of actual mills.

A few comments can be made;

1. The total number of water mills operating in the Fife and Clackmannan river catchments at some time after 1750 was 505. This seems to us a very large number, and while we may have missed a few, and included a few which were not water-powered, we believe our estimate to be accurate.
2. Of these watermills, 368 were commercial mills as we have defined them, and 146 were farm mills; that balance would have been altered if we had assigned 52 saw mills differently, as discussed earlier.

3. Not far short of half of the commercial mills were corn mills, and this should cause no surprise, given that arable farms predominated in large parts of the countryside. The exception was the River Devon catchment, where even given the landscape the number is remarkably small.
4. The Table highlights the importance of textile production throughout Fife and Clackmannan, though the Table hides differences in that woollen materials were produced in the River Devon catchment, whereas linen was produced elsewhere.
5. As regards water powered threshing mills, they were fairly uniformly spread through all the catchments, including those of the lesser and smallest streams except unsurprisingly that of the River Devon.
6. Obviously horse driven threshing mills (horse gins) have no particular connection with the river catchments, and so are not really in the remit of river journeys. However, for interest, Alastair Robertson has determined the number in the River Eden catchment, and found evidence for 179 horse gins as compared with 50 water powered threshing mills. It should be remembered that we are dealing with quite a dry region, so the balance might have been different, where there were more abundant water sources.
7. It is important to be clear that the numbers in the Table refer to watermills which operated for a part of the period after 1750. None should be assumed to have operated concurrently with any other, or for the whole defined period. It is possible to specify exactly when some of them operated, and sometimes that is stated for individual mills as part of river journey texts.

Tables similar to A1.1 appear in overviews for the river journeys of the Lothians, Dumfriesshire, and those of Galloway, and on this website. It is our intention to bring all our information on Scottish watermills together and then we might be able to draw more general conclusions about distributions of watermills, and augment the estimable work of Shaw.