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HISTORY AND PRESENT OF THE HELICAL WATERWHEEL; ITS UNIQUE POSITION IN THE MODERN TECHNOLOGY OF JAPAN: PART I/INVESTIGATIONS FOR THE PERIOD OF 1920–1942

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I. *Introduction*

Among many kinds of waterside technologies, the Archimedean screw is worldly well known as an effective device for drainage with acient origin. It is generally considered that it was mostly enpowered by human hands in early times. In the 16th century or earlier, however, there appeared, in Holland, the cases where windmills supplied necessary power to those screws. In Italy, Leonardo da Vinci (1452–1519) hovered on an idea that the Archimedean screw could be enpowered by a separately constructed waterwheel to lift up water, according to [Reynolds (1980, p. 144)].

While the helical waterwheel invented in Japan as recent as in 1920 resembles such an Archimedean screw on its spiral shape, it is functionally quite different from that screw in the sense that its screw-like body by itself is a waterwheel to be capable of suppling relatively high-speed rotary power to outside tools or machines. Most of the modern technologies massively used in Japan have been the imports from Europe and the United States. In constrast to this, the helical waterwheel was a genuine invention by a Toyama prefecture man in the snowy part of Japan. It seems to occupy a unique position in the world history of watermills and of hydraulic prime movers in general. It is neither conventional vertical and horizontal wheels nor the modern Western types of reaction turbine (e.g., Pelton turbine), impulse turbine (e.g., Francis turbine) and axial flow turbine (e.g., Kaplan turbine).

Its mostly 4 or 5 layers spiral reminds one a part of the double helix model of DNA often appearing in contemporary textbooks of biology and genetic engineering. Unlike most other waterwheels, it is transportable only with a few men's hands to moving work sites. Yet, it has the strength around one horse power like other waterwheels. It runs at the rate of some 90–120 rpm (revolutions per minute) without burden and 50–80 rpm with burden, which is much higher than the one of conventional vertical wheels and is lesser than the one of reaction wheel or impulse turbine.

In spite of the practical importance of this unique waterwheel, there has been no academic research on its history and present situation until the pioneering study by [Tanaka (1984)], to which this article owes very much. A very brief, but first introduction of helical waterwheel to the Western world was made by [Kawakami (1985)]. The purpose of this article is to provide a preliminary survey of helical waterwheel for those who are interested in the economic history of watermills or in the history of technology in general. This may be also useful to those who are planning to build waterwheels as a part of renewable energy sources in the future with limited supply of exhaustible resources, not only in Japan but also in other countries.

II. *Permanent Nature of Waterwheels*

Some people seem to consider that waterwheels were almost archeologically old techniques mainly used in pre-modern ages in Japan. But this kind of prejudice is against the historical fact. Though the first documentation on the construction of waterwheel dates back to 610,[1] its massive use is rather a modern phenomena after the Meiji Restoration (1968). As we will show it in Section IV, the peak of water wheel utilization in Japan came in the 1930's when some 80,000 wheels were documented in the official statistics within the confinement to the ones for agricultural use. In addition, there seem to have been many miniscale waterwheels in mountain villages which escaped from statistical surveys. Besides them, there were also many watermills for industrial use then, though their peak age preceded the one for agriculture by a few decades. The clear tendency of the decline of waterwheels for agricultural use started to be seen in the early 1950's. In the age of the Rapid Economic Growth in the late 1950's and in the 1960's, cheap oil products including electricity generated in the oil-fire power stations quickly took the place of waterwheels. However, they were not destined to a complete extinction. Even today, not less than 500 waterwheels seem to be under operation for various, real-life purposes in many regions in Japan, from Hokkaido in the north and to Kagoshima in the south. Moreover, there also arize several cases of newly built ones. In what follows, we briefly sketch the general nature of waterwheels before going to empirical and statistical analyses of helical waterwheels in particular.

Differently from other celestial bodies in the universe, the earth is endowed with the structure of water cycle. Despite of the irreversible increase of entropy in an isolated system, which is the teaching of the Second Law of Thermodynamics, this water cycle has guaranteed the earth to be an open steady system in the sense that surplus entropy is discarded through the functions of that cycle and of air's convection into the outer space in the form of long-wave radiation. This is the primary reason why water power and wind power are renewably created within the atmosphere. Moreover, the earth surface is endowed with topsoil, which is a collection of inumerable microbes. Those microbes are the decomposer of organic wastes of plants' and animals' origins. Topsoil decomposes those waste materials into waste heat and inorganic materials, the former of which is absorbed by the above water cycle and the latter of which is taken up again by plants for their rebirth. Owing to such water cycle and topsoil, the ecocycle (plants→animals→topsoil→plants again) maintains its own open steady nature.[2]

However, the unprecedented abuse of underground, exhaustible resources is characteristic of the contemporary oil civilization spread all over the world. Their abuse is rapidly

[1] As to the detailed documentation of Japanese waterwheels in the ancient and medieval times, see [Rinoue (1985)]. Another survey of them before pre-modern times is available in [Maeda (1980)].

[2] The open steady nature of the earth itself was analyzed in the context of entropy theory first by [Tsuchida (1976)]. Its brief survey and further development are available in [Murota (1984) and (1985b)].

generating excessive amounts of waste materials and of waste heat which cannot be properly handled by the water cycle and topsoil. This is the central cause of grave and global pollution in the contemporary age. It is to destroy the open steady cycles of the ecosystem with humankinds being a part and of the earth system itself.

Amidst such a global crisis, it is of crucial importance for human survival to promote interdisciplinary and international research on renewable energy sources such as water power, wind power, wood fuel, and so on. Regarding water power utilization, Japan as well as other countries in the world already have, and are constructing many, large-scale hydroelectric power stations. Such large power stations require gigantic dams which can be constructed only by using tremendous amounts of cement, iron, oil, and other materials, which often cause grave, environmental disruption, especially in the very mountaneous countries like Japan. Big dams also force many people to evacuate their traditional habitates.[3] For these reasons, it is desirable for water power utilization to be in small scale, if one wants it to be truly renewable and human. In this sense, waterwheels of various kinds, which can consist of a decent part of the global water cycle, have their own merit that will be appreciated in the future under the condition of limited supply of underground, exhaustible resources. In this regard, the helical waterwheel, which will be discussed hereafter, is of a particular interest because it runs with a surprisingly low head of only 50–100 centimeters so that its impact on the surrounding environment can be minimal in comparison with other types of waterwheels and turbines.

III. *The Origin and Uniqueness of Helical Waterwheels*

In the world history of hydraulic prime movers, there have been various kinds of devices developed to harness water power to utilize it for human economic and cultural needs. In Table 1, we tentatively classify those devices into the following six types: *Conventional Waterwheel, Helical Waterwheel, Water Lever, Modern Turbine, Hydraulic Ram,* and *Water Powered Own Mover.* Several subtypes are associated with each major type.

(1) Conventional Waterwheel

A horizontal wheel in this category is the kind of wheel which rotates on a horizontal plane with a vertical axis. The wheels of this kind are said to have a very ancient origin either in Asia Minor or in China. In the past, their geographical distribution was wide including both Western and Eastern worlds, according to [Wilson (1960)]. To the author's present knowledge, however, the use of this wheel was scanty in Japan. According to [Bachmann and Shakya (1982)] and [Kosaka (1985)], many wheels of this kind are currently used in Nepal and Buhtan.

A vertical wheel rotates around a horizontal axis. Depending on the manner in which water is shot to wheel, this subtype is usually reclassified into *overshot, pitchback, breastshot, Poncelet,* and *undershot wheels,* as is clearly illustrated in [Syson (1980), pp. 63–69]. The most frequent use of undershot wheel is for irrigation. The irrigation wheel has a special

[3] Environmental and social problems associated with the already constructed big dams in Japan are analyzed in [Tsuchida and Murota (1979)]. Regarding similar problems for the planned ones in other countries, see, for example, [Drucker (1985)] and [Kalpavriksh (1985)].

TABLE 1. TYPES OF HYDRAULIC PRIME MOVER AND THEIR CURRENT USES IN JAPAN

BASIC TYPE	SUB TYPE	THEIR ACTIVE USES IN JAPAN AS OF THE FIRST HALF OF THE 1980's
CONVENTIONAL WATERWHEEL	1. Horizontal Wheel	None at this moment. It seems that this type has been rarely used throughout the history of Japan.
	2. Vertical Wheel	(a) Overshot Wheel (b) Pitchback Wheel (c) Breastshot Wheel (d) Poncelet Wheel (e) Undershot Wheel — All of these wheels are currently used, some all the year round and some only seasonally. The total number is in hundreds. Major areas of utilization are rice cleaning, wheat milling, paddy field irrigation, stone crashing for ceramics industry, and Japanese cedar leaves milling for incense sticks.
	3. Boat Mill (Floating Mill)	None at this moment. Historically speaking, many boat mills were used in the Edo era and in the early modern times.
	4. Taro Wheel (*Imozuisha*)	Miniature-like wheels of this kind are widely used in many areas of Japan. Mainly for washing and peeling the Japanese taroes harvested in autumn.
HELICAL WATERSHEEL	1. Motoi Wheel	None at this moment, though some are under the condition of still conservation. Within about 30 years after its invention in 1920, this wheel had shown a spectacular prevalence.
	2. Morikawa Wheel	Five wheels are under workable condition. Four among them are in active use. Its history of prevalence was the same as the one of Motoi wheel.
WATER LEVER	1. Conventional Water Lever	Some 50 water levers are used. Some 40 among them are working all the year round for pounding clay for pottery production in Oita Prefecture. Others are for milling grains.
	2. Rope-pulling Water Bucket	Just one, but very fine case for crashing stones to make glaze of pottery in Yamaguchi Prefecture. History of the water lever of this kind is not clear.
	3. Box Wheel	At least 4 are under active use for milling grains. It seems that this was prevalent in many mountain villages in the 1930' through 1950's.

MODERN TURBINE	1. Reaction Turbine	The most popular turbine of this type is a Pelton wheel. Except for large-power Pelton utilized in commercial power stations, there are a few small-power Pelton wheels for demestic uses.
	2. Impulse Turbine	Except for large-power ones in commercial power stations, there are at least some tens of small-power, vertical shaft Francis turbine are used for milling wheat and so on.
	3. Axial Flow Turbine	The propeller turbine and the Kaplan turbine are well known for the uses in large-capacity power stations. However, there is no small-capacity turbine of this type used today.
HYDRAULIC RAM PUMP	—	The theory of hydraulic ram is well known among the specialists of hydrodynamics in Japan. However, it seems that it has been rarely used for actual purposes.
WATER POWERED OWN TRANSPORTER	1. Water Powered Ferry Boat	Experiments and demonstrations with a few men on board in several rives during the period of 1979–1983 by the members of Department of Engineering, Tokyo Institute of Technology.
	2. Paddle Wheel Climber Boat	The same as above.
	3. Water Powered Cliff Railway	None in the history and present of Japan.

Source: The author's own on-the-spot research from Hokkaido to Kyushu during the period of 1980–1985. The results by his bibliographical research are also incorporated.

character in that the wheel body itself performs the roles of power transmission and of work machine as well as of prime mover. All of the five kinds of vertical wheels seem to have long histories in many regions in the world. All of them are in active use in the present-day Japan.[4]

A boat mill is alternatively called a floating mill. This is a variation of vertical, undershot wheel in the sense that a pair of undershot wheels are at both ends of a long axis on a moored boat so that desired works are done on that boat floating on a river. The European history and recent situation of boat mills are described in [Reynolds (1970), pp. 19–20], [Irimie (1969)], [Rivals (1973)] and others. Boat mills were used for polishing rice and/or milling wheat in some parts of Japan in Edo era (1603–1867), according to [Ito (1984), p. 17] and [Tanji (1984), pp. 271–273, and p. 302]. Their modern uses were quite prevalent for cotton weaving and rice polishing as is seen in [Murota (1985b), pp. 113–138], though they seem to have completely disappeared in the 1930's or 1940's.

A taro wheel is a miniature-scale variation of vertical, undershot wheel almost solely used for washing and peeling the Japanese taro inside its bamboo-made drum. As in the case of irrigation wheel, this wheel body performs, by itself, the roles of power transmission and of work machine. Many wheels of this kind are widely used in the present-day Japan.

(2) Water Lever

A conventional water lever has a concave part at its one end to receive falling water and to let water flow down when that end descends due to the increasing weight. A pestle is attached to the opposite end of the lever so that it goes up and down to pound material in a mortar. This simple device seem to have been widely used in various regions in the world, according to [Reynolds (1983), pp. 11–30]. In the present-day Japan, some 40 large water levers (4–6 meters long) are used for pounding clay for pottery production. Several smaller water levers are used for milling grains.

A rope-pulling water bucket is a combination of a bucket dipped in a river and an attached rope. Something to make noise is at a distant end of that rope. Flowing water pushes the bucket on and off so that it pulls and loosens the rope to make noise at a place much higher than the river surface. This noise surprises and scatters birds which cloud in fields to peck crops. There is one picture of this device in an agriculture guidebook in Edo era in Japan.[5] Osaki (1983) reports that there is a currently working case of this in a mountain village of Ruson Island, the Phillipines as of 1982. A large-scale variation of this is currently working in Nagato City, Yamaguchi Prefecture in Japan for crashing stones to make glaze for pottery.

A box wheel is an interesting intermediate between a water lever and a vertical breastshot wheel. The lever has two boxes, each one at its each end. Over the one end, water is shot into the box which comes in that position. The lever then makes discontinuous rotation, half a turn at one time. A horizontal axis penetrating the center of the lever rotates accordingly to give pestles up and down movements, as in the ordinary case of vertical watermill for pounding crops. The currently working example of this box wheel for polishing rice in

[4] Main areas of vertical wheel utilization in the present-day Japan as of 1985 are rice polishing, wheat milling, crashing Japanese cedar leaves for inscence stick manufacturing, crashing stones for pottery production, and irrigation.

[5] See [Hirano (sometime in the late 1780's), a reprint edition (1977), p. 179 and p. 230].

Hita City, Oita Prefecture, Japan, is illustrated in [Murota (1982), p. 85]. There are a few other working cases of this kind in several mountain villages.

(3) Modern Turbine

The modern turbines are usually classified into *reaction turbines, impulse tubines,* and *axial flow tubines.* The most popular one among reaction turbines is *Pelton wheel,* which is widely used with high head in many countries for hydroelectric power generation. *Francis turbine* is the representative of impulse turbines and is very popular as Pelton wheel. The axial flow turbines include *propeller tubine* with blades of a runner being fixed and *Kaplan turbine* with the angle of blades being changeable for it to adjust the water flow.

At present, these modern turbines are applied mostly to large-scale electric power generation in the world. In the present-day Japan, however, there are some working examples of Pelton wheels and Francis turbines used for suppling direct power to machines. They serve as small-scale rotary power to operate tromb mills for pottery material production, pestles for pounding the Japanese ceder leaves for inscence stick manufacturing, a band saw for wood cutting, and so on.

(4) Hydraulic Ram Pump

This is a simple device appling water hammer effect to lift up water by utilizing much larger amount of flowing water. It is capable to bring water up to a place significantly higher than a vertical undershot wheel usually does. Its use is not exceptional in the world, though it is occasionally and briefly mentioned in the literatures. A fine guidance to its practical use is found in [Volunteers in Asia (1981), pp. 206–209]. In Japan, its actual use is not so common while its theory is well known among specialists of hydrodynamics.

(5) Water Powered Own Transporter

A water powered ferryboat is a boat crossing a river without any outside power (engine, human hands, or whatever they are) but with the stream power of the river itself. As a kite goes up in the sky by the lift caused by wind, this boat, which is tied to a rope longer than the width of a river, moves as drawing a part of a circle whose center is a tree or a rock, or the like on the bank of one side of the river to which the other end of that rope is tied. The lift in this case is caused by stream power of the river and works on the horizontal plane in stead of on the vertical plane in the case of a kite. The research on this type of boat started in 1979 in Mori Laboratory, Department of Engineering, Tokyo Institute of Technology, primarily aiming at its practical application in Nepal, as was reported in [Ogawa and Mori (1982)]. Life experiments with a few men on board were repeated in several rivers in Japan and in Nepal in the period of 1979 through 1983, and the practical usefulness of this ferryboat was demonstrated.

A paddle wheel climer boat has been developed also in Mori Laboratory since 1979. This could be meant as a variation of a boat mill in the sense that a boat with two waterwheels at its side goes upstream by winding up a rope onto its wheel axis. The other end of the rope is tied to something in an upstream area. Life experiments were repeated along the ones of ferry boat to result in a tentative conclusion that the stability of this climer boat is not so good. Then, an improvement is made in that this system works better with two boat, the one with paddle wheels being moored as a conventional boat mill on an upstream surface of a river, and the other one with passengers on board is hauled up by a rope which the former boat winds up through the waterwheel power. The former is called a hauler boat, and the latter a hauled boat. The detailed analyses of these climer boats are summarized in [Mori, Kawakita and Ogawa (1984)] together with the ones of ferry boat mentioned above.

A water powered cliff railway has never been seen in Japan to the author's knowledge until now. But it had been practically used with a surprizingly high capacity in Lynton, Devon, England since 1890, according to [Vince (1985, pp. 150–151.)]. It is like an ordinary cable car with two ascending and descending vehicles connected by a cable. The difference is in that this system works by water power. The vehicle at a top of a cliff descends on the track due to the weight of water filled in its tank with a capacity of 100 gallons, and pulls up another vehicle with its tank being empty at the bottom of the cliff through the cable. Once it reaches the bottom, it discharges water from the tank while another is at the top by that time. In this way, two vehicles go up and down on the tracks with the descending one carring the needed loads. Coal, sand, granite and oil were said to be transported by this railway with the vertical lift as high as 500 feet.

Given the above general survey of hydraulic prime movers in the West and the East, what is the position of helical waterwheel? We now proceed to its investigation.

Helical waterwheel is an English translation of *rasen suisha* in Japanese. In Toyama Prefecture, its birth place, it has had its own local names such as *tanishi*, *dairo*, and so on.[6] In English, it can be alternatively called a spiral waterwheel or a screw waterwheel. It was invented by Bunzo Motoi (1888–1927) in 1920 (Taisho 9). His research towards it seemed to have started a few years before that with trials and errors. Motoi was a blacksmith living in Akimoto, Minami Hannya Village, Higashi Tonami County, Toyama Prefecture, Japan. (This place is currently a part of Tonami City.) It is a heart of the Tonami Plain, the place of a typical alluvial cone generated by rich flow of Shoh River, where numerous irrigation channels have been developed for rice paddy fields. He was a capable man interested in improvements of agricultural tools and machines. To the author's most recent knowledge, Motoi is said to have invented the helical waterwheel by catching a hint from the shape of ship crew,[7] while a myth has been prevalent saying that he got a hint from a screw driver accidentally falling down from somewhere near a ceiling of a house, similarily as in the story that Issac Newton had been said to reach the idea of the universal law of gravity by accidentally looking at a falling apple in an orchard.

The structure of helical waterwheel of Motoi Type is as follows. Iron boards are connected with each other and are attached to a wooden drum in a spiral fashion. A long iron axis penetrates the drum. The runner constructed in this way is set in a half-open, cylinder-like flume made of thin iron boards. This whole thing is brought to a head race in such a way that the angle of the axis to a horizontal plane is about 30 degrees. A pulley is attached to the upstream end of the axis so that rotary power is obtained from a rope or a belt around it.

[6] According to [Tanaka (1982)], *tanishi* (which means a mud-snail or pond-snail) was often used as a nickname of helical wheel in Tonami area because its appearance resembles a mud-snail. In the eastern part of Toyama Prefecture, *dairo* was often used because of a similar reason, where *dairo* means a shell of snail. *Neji-neji* was also used, where neji means screw.

[7] This new information was given to the author by [Tanaka (1986], depending on his communications with Mrs. Hanae Saikawa, one of the daughters of Shosaku Saikawa whom we will mention later. [Saikawa (1985)] was helpful as one of the introductions to the early history of helical waterwheel.

Following the Motoi Type, other people immediately started their own attempts to innovate it and to manufacture its variations. The most successful one among those variations was the invention by Shosaku Saikawa (1884–1951) in 1923 (Taisho 12). Saikawa was also a blacksmith in Higashi Nojiri Village next to Minami Hannya Village of Motoi. His wheel was sometimes called the Iron Axis Type because it removed away a wooden drum and the iron boards (blades) were supported by iron bars directly attached to the axis. This was considered to last longer that the Motoi Wooden Drum Type whose wood parts might incur quick decay. Due to still unknown reasons, Saikawa gave the rights of manufacturing and sales of this Iron Axis helical waterwheel, in 1923, to Keisaku Morikawa (1889–1952) and Chotaro Kawai, both of whom were the men of the same village as his. But Kawai left Toyama Prefecture soon afterwards. As a result, the Iron Axis Type became the one that was almost monopolistically produced and sold by Morikawa. This type was then started to be called the Morikawa Type. The mass production of this type began in 1928 (Showa 3), when The Morikawa Agriculture Equipment Trade Company was set up in Higashi Nojiri Village. Towards the end of the 1920's, both Motoi and Morikawa Types and some other variations of helical waterwheel were massively produced and sold to farm families, first within Toyama Prefecture and then in other prefectures too.

Considering the reasons of rapid prevalence of helical waterwheels, they had the following merits:

A. Hydrodynamic Merits
   (1) The required head is very small, i.e., only 50–100 centimeters for the capacity of nearly one horse power.
   (2) Yet, its rotary speed is as high as 90–120 rpm without burden and 50–80 rpm with burden, which are much higher than the corresponding figures of conventional vertical waterwheels.

B. Techno-economic Merits
   (*o*) Because of its technically simple structure, mass production and standardization are easy. Production can be handled by rural village industry without requiring advanced technologies.
   (2) The system consisting of wheel body and attached flume weighs only about 80 kilograms so that it can be transportable by a few men's hands to a stream in the vicinity of necessary work site.

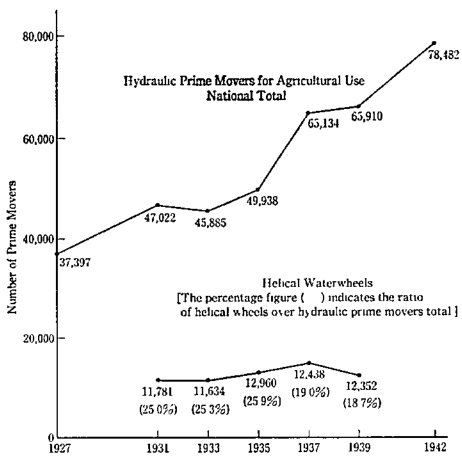
These merits cannot be expected from conventional waterwheels and small-power modern turbines.

IV. *Explosive Rise of Helical Waterwheels*

As to the number of waterwheels for industrial use in Japan, it is almost certain that it reached the historical peak in the 1920's followed by gradual decline thereafter.[8] Then, what about the ones for agriculture? There has been, thus far, no explicit analysis of this point in the waterwheel-related literatures. In this article, we investigate it using the rarely quoted set of statistical data by Norinsho Nochikyoku [The Agricultural Land Agency of The Ministry of Agriculture] and Noshomusho [The Ministry of Agriculture and Trade] for the period of 1927 through 1942. The former's official statistics including the data on waterwheels is "Nogyo Kigu Kikai narabini Sagyoba Fukyu Jokyo Chosa" [The Survey of Tools, Machines, and Work Spaces for Agriculture], to which we refer as NKKSFJC hereafter. The latter is "Daiichiji Noshomusho Tokeihyo" [The First Statistical Survey of The Ministry of Agriculture and Trade], to which we refer as DNT hereafter. Regarding waterwheels for agricultural use, NKKSFJC lists the total number of hydraulic prime movers for 1927 (Showa 2) and the classified numbers of them for 1931 (Showa 6), 1933 (Showa 8), 1935 (Showa 10), 1937 (Showa 12), and 1939 (Showa 14) for each prefecture of Japan. Here, the hydraulic prime movers are classified into three major categories; (1) ordinary waterwheel, (2) Pelton, and (3) turbine,[8] and furthermore, the ordinary waterwheel is classified into three sub-categories; (i) wooden, (ii) iron, and (iii) helical. Since this NKKSFJC survey ends in 1939, we use DNT for 1942. DNT classifies the hydraulic prime movers into three major categories as in the case of NKKSFJC, but not further.

All of the figures in these NKKSFJC and DNT data are shown in the Statistical Appendix at the end of this article. Although there are much more than several inconsistent and/or unnatural numbers in these data, they are, perhaps, the best quantification of waterwheels used for the modern Japanese agriculture. To know the position of helical waterwheels, NKKSFJC data are especially precious. Based on these data, Graph 1 is constructed. It shows the change of the total number of hydraulic prime movers and the position of helical waterwheels in that total. From this, it is found that the role of helical waterwheels was quite significant in a rising trend of small-scale water power utilization in agriculture in the 1930's and the early 1940's. Among many wheels including conventional vertical wheels inherited from the pre-modern age on the one hand, and modern turbines of the European origin, the helical waterwheels occupied as large as 25 per cents of the national total number in the 1930's.

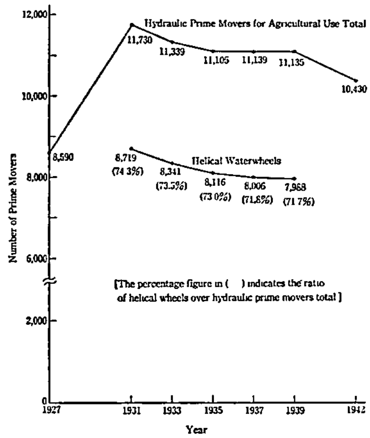
FIGURE 1. THE POSITION OF HELICAL WATERWHEELS IN THE TOTAL NUMBER OF HYDRAULIC PRIME MOVERS FOR AGRICULTURAL USE IN JAPAN



Source: This graph is made from the data in Statistical Appendix at the end of this article.

[8] The turbine in this context means, in most of the times, the Francis turbine.

FIGURE 2. THE POSITION OF HELICAL WATERWHEELS IN THE TOTAL NUMBER OF HYDRAULIC PRIME MOVERS FOR AGRICULTURAL USE IN TOYAMA PREFECTURE



Source: This graph is made from the data in Statistical Appendix at the end of this paper.

Next, we focus on Toyama Prefecture, where the first invention of helical waterwheel was made in 1920. Graph 2 is also constructed by using NKKSFJC and DNT. In this prefecture, the prevalence of helical waterwheels seems to have been explosive in the 1920's, though its year by year statistics in that period is not available within the author's research up to now. Anyway, helical waterwheels occupied more than 70 per cents of the prefectural total number of hydraulic prime movers in the 1930's. Besides Toyama Prefecture, one can see that helical waterwheels were widely used in the prefectures like Tochigi, Niigata, Hokkaido, Iwate, Yamagata, Fukushima, and Tottori.

We have already pointed out the hydrodynamic and techno-economic merits of helical waterwheels in the previous section. However, those merits alone are not enough to explain their explosive prevalence not only in Toyama but in other prefectures soon after the invention. Then, we have to investigate socio-economic conditions for their utilization. Regarding this point, we can point out that the Japanese agriculture as a whole was under a sway of small-scale mechanization at the beginning stage of the 20th century. Especially in the field of threshing rice, the invention of rotary tread-thresher by Torajiro Watanabe in 1911 (Meiji 44)[9] had a strong influence on the productivity increase in that field of rice processing. In the olden time, rice threshing had been made by *atsukai bashi* method (the chopsticks method —a way of threshing in that a man holds, by one hand, a bundle of harvested rice plants between a pair of chopstick-like woods and pulls them out, by another hand, so that grains of rice are separated from ears and fall down). In some time in the Edo era, *senbakoki* (the

[9] See [Mori (1948), p. 210)].

thousand teeth thresher) was invented. This device is as follows. Many lined-up bamboo or wood-made sticks are attached to a board on a stand. A man or woman in front of the stand holds a bundle of rice plants by both hands, and pulls them out between those sticks like the teeth of a comb. The invention of this device greatly contributed to the productivity increase in rice threshing. Then, towards the end of the Meiji Era (1868–1912), a rotary tread-thresher was invented to result in a further leap of productivity. The rotary nature of this thresher was ready for it to be enpowered by outside rotary force in stead of human hand. A helical waterwheel was, then, an ideal prime mover for this rotary thresher from the viewpoints of capacity and of speed of rotation. Besides such an invention of threshing machine, the technique of *tsuchi usu* (a rotary soil-made mill) mostly made of soil and bamboo had been renovated by the 1910's to the extent that it became sophisticated enough to be enpowered by animal power or by a waterwheel. To such a rotary rice hulling mill, the helical waterwheel was suitable too.

From a purely monetary viewpoint, the total cost of purchase and maintenance of helical waterwheel seems to have been much cheaper than the one of oil-fired internal combustion engine or of electric motors for the same capacity of agricultural work, according to [Tanaka (1984), pp. 71–73].

Because of all of these hydrodynamic, techno-economic, and socio-economic merits mentioned in the previous and present sections, helical waterwheels of both Motoi and Moricawa Types and of some other variations explosively increased their number of utilization in many areas of Japan. They were mainly used for threshing and processing rice. But there seem to have been also other uses such as the ones for wood cutting, blowing air into animal houses, pounding rice straws for straw crafts, and so on.

(to be continued to Part II)

HITOTSUBASHI UNIVERSITY

Statistical Appendix

The Change of the Number of Hydraulic Prime Movers for Agricultural Use in Each Prefecture of Japan in the Period of 1927–1942

		1927	1931	1933	1935	1937	1939	1942
HOKKAIDO	Hydraulic Prime Movers Total	1,334	2,351	2,878	2,483	3,160	2,497	2,299
	Ordinary wheels subtotal		2,305	2,810	2,435	3,029	2,349	2,054
	Wooden wheels		2,016	2,332	1,973	2,319	1,931	
	Iron wheels		11	11	23	47	32	
	Helical wheels		278	467	439	663	386	
	Pelton		4	4	2	5	7	27
	Turbine		42	64	46	126	141	214
AOMORI	Hydraulic Prime Movers Total	352	381	318	103	299	686	395
	Ordinary wheels subtotal		313	313	86	270	523	359
	Wooden wheels		313	313	83	224	471	
	Iron wheels		—	—	3	4	4	
	Helical wheels		—	—	—	42	48	
	Pelton		—	—	—	4	20	4
	Turbine		5	5	5	25	143	32
IWATE	Hydraulic Prime Movers Total	447	1,585	1,629	2,121	3,572	2,778	2,865
	Ordinary wheels subtotal		1,575	1,601	2,096	3,494	2,752	2,721
	Wooden wheels		1,244	972	1,557	2,909	2,276	
	Iron wheels		52	29	30	100	60	
	Helical wheels		279	600	509	485	343	
	Pelton		—	5	—	—	—	26
	Turbine		10	23	25	78	99	118
MIYAGI	Hydraulic Prime Movers Total	188	135	607	607	391	340	331
	Ordinary wheels subtotal		134	598	599	376	314	340
	Wooden wheels		121	565	552	341	284	
	Iron wheels		1	1	5	5	1	
	Helical wheels		12	32	42	30	29	
	Pelton		—	—	—	—	—	10
	Turbine		1	9	8	15	26	31
AKITA	Hydraulic Prime Movers Total	564	163	116	220	408	384	449
	Ordinary wheels subtotal		156	109	213	393	355	390
	Wooden wheels		101	50	132	284	283	
	Iron wheels		14	18	6	17	1	
	Helical wheels		41	41	75	92	71	
	Pelton		—	—	—	—	2	18
	Turbine		7	7	7	15	27	41

		1927	1931	1933	1935	1937	1939	1942
YAMAGATA	Hydraulic Prime Movers Total	459	438	490	111	1,041	709	464
	Ordinary wheels subtotal		435	484	105	1,008	653	382
	Wooden wheels		204	272	46	558	374	
	Iron wheels		34	41	10	19	34	
	Helical wheels		197	171	49	441	245	
	Pelton		—	—	1	—	3	22
	Turbine		3	6	5	33	53	60
FUKUSHIMA	Hydraulic Prime Movers Total	4,648	2,302	1,750	385	972	664	1,240
	Ordinary wheels subtotal		2,296	1,750	373	930	610	981
	Wooden wheels		1,620	1,500	281	660	388	
	Iron wheels		315	—	1	6	6	
	Helical wheels		361	250	91	264	261	
	Pelton		1	—	5	4	3	71
	Turbine		5	—	7	38	51	188
IBARAKI	Hydraulic Prime Movers Total	8	38	58	85	661	595	537
	Ordinary wheels subtotal		35	53	82	532	452	385
	Wooden wheels		32	35	65	524	446	
	Iron wheels		—	—	—	1	1	
	Helical wheels		3	18	17	7	5	
	Pelton		—	—	—	—	—	3
	Turbine		3	5	3	129	143	149
TOCHIGI	Hydraulic Prime Movers Total	799	1,083	1,134	1,845	1,658	2,900	1,952
	Ordinary wheels subtotal		1,061	1,109	1,813	1,605	2,821	1,845
	Wooden wheels		419	407	366	988	1,670	
	Iron wheels		2	2	35	18	10	
	Helical wheels		640	700	1,412	599	1,141	
	Pelton		9	9	—	13	4	13
	Turbine		13	16	32	40	75	94
GUNMA	Hydraulic Prime Movers Total	3	847	864	516	1,627	2,131	1,658
	Ordinary wheels subtotal		835	852	500	1,587	2,056	1,597
	Wooden wheels		731	740	403	1,448	1,896	
	Iron wheels		23	27	60	75	120	
	Helical wheels		81	85	37	43	40	
	Pelton		5	5	3	5	15	20
	Turbine		7	7	13	35	60	41
SAITAMA	Hydraulic Prime Movers Total	—	114	155	176	196	106	606
	Ordinary wheels subtotal		113	152	175	194	103	571
	Wooden wheels		112	152	152	147	82	
	Iron wheels		—	—	—	—	—	
	Helical wheels		1	—	23	47	21	
	Pelton		—	—	—	1	—	9
	Turbine		1	3	1	1	3	26

		1927	1931	1933	1935	1937	1939	1942
CHIBA	Hydraulic Prime Movers Total	72	42	51	63	102	121	230
	Ordinary wheels subtotal		34	46	55	74	83	140
	Wooden wheels		31	43	52	72	70	
	Iron wheels		—	1	—	—	—	
	Helical wheels		3	2	3	2	13	
	Pelton		—	—	—	—	8	6
	Turbine		8	5	8	28	30	84
TOKYO	Hydraulic Prime Movers Total	11	—	—	56	209	149	103
	Ordinary wheels subtotal		—	—	56	206	145	101
	Wooden wheels		—	—	54	200	142	
	Iron wheels		—	—	2	6	3	
	Helical wheels		—	—	—	—	—	
	Pelton		—	—	—	—	—	1
	Turbine		—	—	—	3	4	1
KANAGAWA	Hydraulic Prime Movers Total	—	264	278	306	565	183	550
	Ordinary wheels subtotal		262	276	302	559	179	550
	Wooden wheels		260	275	296	551	179	
	Iron wheels		—	—	2	1	—	
	Helical wheels		2	1	4	7	—	
	Pelton		—	—	—	—	—	—
	Turbine		2	2	4	6	4	—
NIIGATA	Hydraulic Prime Movers Total	289	1,268	1,193	3,346	3,177	2,796	13,376
	Ordinary wheels subtotal		1,255	1,167	3,296	3,118	2,654	13,110
	Wooden wheels		775	732	1,914	1,874	1,663	
	Iron wheels		—	—	35	65	17	
	Helical wheels		480	435	1,347	1,179	974	
	Pelton		—	—	—	—	—	93
	Turbine		13	26	50	69	145	173
TOYAMA	Hydraulic Prime Movers Total	8,590	11,730	11,339	11,105	11,139	11,135	10,430
	Ordinary wheels subtotal		10,167	9,703	9,460	9,499	2,460	9,385
	Wooden wheels		1,012	860	818	885	869	
	Iron wheels		436	502	526	608	603	
	Helical wheels		8,719	8,341	8,116	8,006	7,988	
	Pelton		647	611	590	572	583	
	Turbine		916	1,025	1,055	1,068	1,092	880
ISHIKAWA	Hydraulic Prime Movers Total	295	479	331	322	133	236	388
	Ordinary wheels butotal		468	320	320	128	204	313
	Wooden wheels		238	247	245	70	132	
	Iron wheels		—	1	—	5	9	
	Helical wheels		230	72	75	53	63	
	Pelton		—	—	—	—	24	14
	Turbine		11	11	2	5	8	61

		1927	1931	1933	1935	1937	1939	1942
FUKUI	Hydraulic Prime Novers Total	631	262	290	365	566	742	614
	Ordinary wheels subtotal		250	280	360	558	715	549
	Wooden wheels		197	213	260	453	528	
	Iron wheels		22	32	48	45	120	
	Helical wheels		31	35	52	60	67	
	Pelton		1	—	1	2	5	20
	Turbine		11	10	4	6	22	45
YAMANASHI	Hydraulic Prime Movers Total	2	243	247	291	755	849	1,044
	Ordinary wheels subtotal		238	241	264	709	759	973
	Wooden wheels		218	221	232	675	678	
	Iron wheels		17	17	27	34	41	
	Helical wheels		3	3	5	—	—	
	Pelton		3	3	4	3	—	5
	Turbine		2	3	23	43	90	66
NAGANO	Hydraulic Prime Movers Total	16	3,366	3,223	2,686	2,014	2,609	6,014
	Ordinary wheels subtotal		3,291	3,154	2,643	1,967	2,514	5.707
	Wooden wheels		3,163	2,947	2,333	1,638	1,904	
	Iron wheels		85	171	224	226	396	
	Helical wheels		43	35	86	103	214	
	Pelton		4	4	2	2	20	58
	Turbine		71	65	41	45	75	249
GIFU	Hydraulic Prime Movers Total	134	1,384	1,365	2,530	3,793	3,802	3,232
	Ordinary wheels subtotal		1,380	1,361	2,521	3,762	3,745	3,134
	Wooden wheels		1,362	1,320	2,344	3,410	3,453	
	Iron wheels		12	12	130	305	277	
	Helical wheels		6	9	47	47	15	
	Pelton		—	—	4	8	5	38
	Turbine		4	4	5	23	52	60
SHIZUOKA	Hydraulic Prime Movers Total	750	1,286	1,163	2,686	2,773	1,884	1,823
	Ordinary wheels subtotal		1,261	1,140	2,616	2,694	1,825	1,700
	Wooden wheels		1,213	1,080	2,455	2,544	1,734	
	Iron wheels		47	60	156	142	87	
	Helical wheels		1	—	5	8	4	
	Pelton		6	6	51	54	28	85
	Turbine		19	17	19	25	31	38
AICHI	Hydraulic Prime Movers Total	18	2,009	10959	1,118	1,063	1,377	1,675
	Ordinary wheels subtotal		1,970	1,920	1,091	1,032	1,272	1,295
	Wooden wheels		1,970	1,770	911	868	1,103	
	Iron wheels		—	150	180	164	218	
	Helical wheels		—	—	—	—	—	
	Pelton		—	—	—	5	15	333
	Turbine		39	39	27	26	90	47

		1927	1931	1933	1935	1937	1939	1942
MIE	Hydraulic Prime Movers Total	109	950	787	647	1,172	1,154	795
	Ordinary wheels subtotal		936	773	635	1,134	1,115	711
	Wooden wheels		821	657	508	948	871	
	Iron wheels		97	97	118	167	228	
	Helical wheels		18	19	9	19	16	
	Pelton		—	—	1	—	1	15
	Turbine		14	14	11	38	38	69
SHIGA	Hydraulic Prime Movers Total	142	468	361	391	420	590	433
	Ordinary wheels subtotal		466	355	385	407	580	410
	Wooden wheels		432	307	323	347	501	
	Iron wheels		28	45	61	60	78	
	Helical wheels		6	3	1	—	1	
	Pelton		—	1	—	—	—	
	Turbine		2	5	6	13	10	23
KYOTO	Hydraulic Prime Movers Total	243	642	648	749	1,167	1,264	1,838
	Ordinary wheels subtotal		635	639	731	1,144	1,232	1,772
	Wooden wheels		583	587	584	925	976	
	Iron wheels		46	46	136	213	253	
	Helical wheels		6	6	11	6	3	
	Pelton		—	—	—	—	5	8
	Turbine		7	9	18	23	27	58
OSAKA	Hydraulic Prime Movers Total	474	184	191	114	493	214	379
	Ordinary wheels subtotal		183	190	114	480	209	322
	Wooden wheels		113	100	92	365	118	
	Iron wheels		70	90	22	114	91	
	Helical wheels		—	—	—	2	—	
	Pelton		—	—	—	10	1	
	Turbine		1	1	—	3	4	26
HYOGO	Hydraulic Prime Movers Total	733	957	822	1,178	2,768	1,955	2,074
	Ordinary wheels subtotal		954	809	1,172	2,741	1,906	1,988
	Wooden wheels		829	729	909	2,428	1,645	
	Iron wheels		122	78	257	312	260	
	Helical wheels		3	2	6	1	1	
	Pelton		—	5	6	12	15	20
	Turbine		3	8	—	15	34	66
NARA	Hydraulic Prime Movers Total	1,090	411	413	1,393	1,391	2,092	805
	Ordinary wheels subtotal		411	413	1,382	1,387	2,088	746
	Wooden wheels		397	395	1,004	999	1,356	
	Iron wheels		13	17	378	382	732	
	Helical wheels		1	1	—	—	—	
	Pelton		—	—	—	—	—	9
	Turbine		—	—	11	4	4	50

		1927	1931	1933	1935	1937	1939	1942
WAKAYAMA	Hydraulic Prime Movers Total	107	552	553	605	605	505	252
	Ordinary wheels subtotal		550	550	601	601	492	221
	Wooden wheels		500	500	548	548	467	
	Iron wheels		50	50	53	53	25	
	Helical wheels		—	—	—	—	—	
	Pelton		1	1	2	2	1	6
	Turbine		1	2	2	2	12	25
TOTTORI	Hydraulic Prime Movers Total	1,659	1,916	2,027	1,934	2,054	3,631	2,343
	Ordinary wheels subtotal		1,899	1,995	1,764	2,016	3,552	2,236
	Wooden wheels		1,511	1,625	1,166	1,663	2,288	
	Iron wheels		150	168	349	221	940	
	Helical wheels		238	202	249	133	324	
	Pelton		—	1	123	5	3	15
	Turbine		17	31	47	33	76	92
SHIMANE	Hydraylic Prime Movers Total	1,176	2,373	2,095	1,715	2,172	1,641	2,081
	Ordinary wheels subtotal		2,371	2,092	1,712	2,151	1,623	2,055
	Wooden wheels		2,332	2,054	1,627	2,069	1,537	
	Iron wheels		6	1	21	40	21	
	Helical wheels		33	37	64	42	65	
	Pelton		—	—	—	2	1	1
	Turbine		2	3	3	19	17	25
OKAYAMA	Hydraulic Prime Movers Total	750	1,896	1,941	2,491	2,608	3,247	2,040
	Ordinary wheels subtotal		1,887	1,928	2,470	2,596	3,215	1,932
	Wooden wheels		1,716	1,750	2,257	2,330	2,906	
	Iron wheels		156	163	204	264	303	
	Helical wheels		15	15	9	2	6	
	Pelton		1	1	9	—	8	61
	Turbine		8	12	12	12	19	47
HIROSHIMA	Hydraulic Prime Movers Total	8,692	1,319	1,388	1,590	3,358	3,865	2,974
	Ordinary wheels subtotal		1,316	1,359	1,579	3,325	3,835	2,922
	Wooden wheels		1,311	1,354	1,566	3,283	3,104	
	Iron wheels		5	5	10	23	37	
	Helical wheels		—	—	3	17	25	
	Pelton		2	25	4	9	9	25
	Turbine		1	4	7	24	20	27
YAMAGUCHI	Hydraulic Prime Movers Total	660	882	820	1,887	1,370	670	1,035
	Ordinary wheels subtotal		860	789	1,877	1,326	641	818
	Wooden wheels		812	751	1,833	1,312	633	
	Iron wheels		15	20	27	12	8	
	Helical wheels		33	18	17	2	—	
	Pelton		2	3	1	16	6	147
	Turbine		20	28	9	28	23	70

		1927	1931	1933	1935	1937	1939	1942
TOKUSHIMA	Hydraulic Prime Movers Total	218	587	249	253	548	582	1,918
	Ordinary wheels subtotal		584	244	248	526	549	1,874
	Wooden wheels		568	224	228	481	499	
	Iron wheels		2	—	—	28	33	
	Helical wheels		14	20	20	17	17	
	Pelton		2	—	—	11	16	19
	Turbine		1	5	5	11	17	25
KAGAWA	Hydraulic Prime Movers Total	—	—	58	69	228	937	269
	Ordinary wheels subtotal		—	58	69	228	937	296
	Wooden wheels		—	58	68	226	913	
	Iron wheels		—	—	1	2	24	
	Helical wheels		—	—	—	—	—	
	Pelton		—	—	—	—	—	—
	Turbine		—	—	—	—	—	—
EHIME	Hydraulic Prime Movers Total	5	206	195	233	563	516	734
	Ordinary wheels subtotal		202	190	224	540	475	639
	Wooden wheels		200	188	199	513	457	
	Iron wheels		—	—	8	24	18	
	Helical wheels		2	2	17	3	—	
	Pelton		—	—	5	5	8	21
	Turbine		4	5	4	18	33	74
KOCHI	Hydraulic Prime Movers Total	72	204	187	204	416	593	1,163
	Ordinary wheels subtotal		181	164	181	401	575	1,124
	Wooden wheels		180	160	180	371	540	
	Iron wheels		—	3	—	25	29	
	Helical wheels		1	1	1	5	6	
	Pelton		11	11	11	1	5	9
	Turbine		12	12	12	14	13	30
FUKUOKA	Hydraulic Prime Movers Total	144	325	344	344	446	481	2,651
	Ordinary wheels subtotal		208	215	215	315	336	2,560
	Wooden wheels		208	214	214	301	324	
	Iron wheels		—	—	—	13	12	
	Helical wheels		—	1	1	1	—	
	Pelton		—	—	—	—	—	24
	Turbine		117	129	129	131	145	67
SAGA	Hydraulic Prime Movers Total	311	271	270	168	369	376	281
	Ordinary wheels subtotal		268	260	150	342	338	233
	Wooden wheels		268	260	149	339	332	
	Iron wheels		—	—	1	3	6	
	Helical wheels		—	—	—	—	—	
	Pelton		—	1	6	—	—	2
	Turbine		3	9	12	27	38	46

		1927	1931	1933	1935	1937	1939	1942
NAGASAKI	Hydraulic Prime Movers Total	1	1	1	16	15	29	175
	Ordinary wheels subtotal		1	1	9	1	1	140
	Wooden wheels		1	1	3	1	1	
	Iron wheels		—	—	6	—	—	
	Helical wheels		—	—	—	—	—	
	Pelton		—	—	—	—	—	2
	Turbine		—	—	7	14	28	33
KUMAMOTO	Hydraulic Prime Movers Total	—	229	921	75	1,096	1,038	574
	Ordinary wheels subtotal		216	902	73	1,086	863	469
	Wooden wheels		210	902	65	1,063	837	
	Iron wheels		6	—	4	19	26	
	Helical wheels		—	—	4	4	—	
	Pelton		3	3	—	—	15	25
	Turbine		10	16	2	10	160	80
OITA	Hydraulic Prime Movers Total	1,167	788	65	68	799	730	820
	Ordinary wheels subtotal		739	14	17	706	615	695
	Wooden wheels		730	5	8	700	605	
	Iron wheels		9	9	9	3	7	
	Helical wheels		—	—	—	3	3	
	Pelton		—	1	1	3	—	54
	Turbine		49	50	50	90	115	71
MIYAZAKI	Hydraulic Prime Movers Total	—	22	16	132	366	512	435
	Ordinary wheels subtotal		21	7	118	317	405	378
	Wooden wheels		21	—	118	317	404	
	Iron wheels		—	—	—	—	1	
	Helical wheels		—	7	—	—	—	
	Pelton		—	—	—	3	16	5
	Turbine		1	9	14	46	91	52
KAGOSHIMA	Hydraulic Prime Movers Total	36	97	78	123	413	307	104
	Ordinary wheels subtotal		90	76	113	374	275	77
	Wooden wheels		71	56	110	368	256	
	Iron wheels		13	17	1	6	17	
	Helical wheels		—	3	2	—	2	
	Pelton		1	—	—	3	4	4
	Turbine		6	2	10	36	28	23
OKINAWA	Hydraulic Prime Movers Total	—	41	37	33	23	20	7
	Ordinary wheels subtotal		39	35	30	20	17	6
	Wooden wheels		39	35	30	20	17	
	Iron wheels		—	—	—	—	—	
	Helical wheels		—	—	—	—	—	
	Pelton		—	—	—	—	—	—
	Turbine		2	2	3	3	3	1

		1927	1931	1933	1935	1937	1939	1942
JAPAN TOTAL	Hydraulic Prime Novers Total	37,394	47,022	45,885	49,938	65,134	65,910	78,482
	Ordinary wheels subtotal		44,845	43,477	47,342	61,889	61,684	73,160
	Wooden wheels		31,205	29,959	31,313	45,558	44,143	
	Iron wheels		1,859	1,884	3,169	3,877	5,189	
	Helical wheels		11,781	11,634	12,960	12,438	12,352	
	Pelton		703	700	832	760	856	1,539
	Turbine		1,474	1,708	1,764	2,485	3,370	3,783

Source: The data for 1927, 1931, 1933, 1935, 1937 and 1939 are taken from "Nogyo Kigu Kikai narabini Sagyoba Fukyu Chosa" [The Survey of Tools, Machines, and Work Spaces for Agriculture] by Norinsho Nochikyoku [The Agricultural Land Agency of The Ministry of Agriculture]. The data for 1942 are from "Daiichiji Noshomusho Tokeihyo" [The First Statistical Survey of The Ministry of Agriculture and Trade] by Noshomusho [The Ministry of Agriculture and Trade]. For the compilation of these data, the author benefited from the assistance of Mr. Hayato Tanaka.

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