Report

Water Lifting Devices with Renewable Energy for Agriculture in Asian Developing Countries
— With emphasis on the Chinese experience —

Hikaru Tsutsui*

Summary Many small-scale on-farm water development projects depend on groundwater and low-level surface water for their water resources; water lifting is indispensable for taking advantage of these resources. While there is a tendency to replace some of the traditional devices with modern pump equipment, there is a need to promote traditional means of lifting water by human, animal, wind, and water power. The paper introduces water lifting technologies which have been developed and are being used in China using renewable energy, with emphasis on the water turbine pump. Technical characteristics and installation/operation of the pump as well as points for future consideration are also discussed.

I. Background and Introduction

In order to cope with the rapid increase in population and the corresponding need for food production, countries are placing great emphasis on irrigation development. While large-scale water resources development utilizing modern technology should play an important role in such a venture, small-scale and on-farm water development and efficient use of water are receiving special attention from member countries and the various financing agencies. Many such small-scale on-farm water development projects depend on groundwater and low-level surface water for their water resources, and water lifting is an indispensable part of their use. While there is a tendency to replace some of the traditional devices with modern pump equipment, the majority of developing countries feel that the improvement of traditional facilities, which are locally produced, repaired and used by farmers, must receive due attention. Furthermore, in view of the increasing shortage and rising cost of energy, the traditional means of lifting water by human, animal, and wind power, as well as water power, are becoming increasingly important.

On the occasion of the FAO Workshop on Water Lifting Devices held in Bangkok in December 1979, the need for further detailed information on water

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lifting technology from China and for the promotion of transfer of suitable technology to other countries, especially in the Asian region, was stressed. In pursuit of this, FAO organized the Workshop on Water Lifting Devices and Water Management in China from 2-26 November 1981 and 21 April to 3 May 1986. The purpose of the Workshop was to promote irrigated agriculture through the introduction of improved water lifting techniques and water use practices. More specifically, the Workshop was intended to provide participants with an opportunity to observe and study the water lifting devices and water management practices actually being employed in China. Emphasis was placed on studying the design, construction, and operation of water lifting devices currently being used in China using renewable energy resources.

This paper summarizes the highlights of the findings in workshops and suggests the follow-up action needed to pursue further the promotion of water lifting irrigation using renewable energy sources. The author wishes to extend his sincere thanks to two Japanese colleagues associated with him in organizing the workshops, Mr. Takahito Misaki for the 1981 workshop and Mr. Masaki Shimizu for the 1986 workshop; both of them have now returned to the Ministry of Agriculture, Forestry and Fisheries, Government of Japan.

II. General Remarks

1. Global Energy Situation in the Agricultural Sector

A comparison between the estimated total and agricultural use of energy shows that the average percentage on a world basis is around 3.5%, with a maximum of 6.4 for the Near East and a minimum of 1.8 for Europe2) (source: Energy for World Agriculture, FAO, page 47). That is to say that energy requirements for irrigation should indeed not be too difficult a target on a macro-level base.

2. Non-renewable vs Renewable Energy Systems

At present, the most common sources of energy used in most of the developing world are still the conventional systems (diesel, kerosene, electric). It is estimated that nearly 4 million electric and 2.5 million diesel pump sets had been installed in India alone by 1980, and by 1985 installation had increased by about 10% and 5% respectively (Hurst, Christopher, 1985, Energy and Irrigation in India, ILO).

However, under many circumstances, diesel pumps are not necessarily the best choice on the basis of cost, fuel availability, and the level of technical skills required to operate and maintain this equipment. Consequently, significant effort has been made to develop several alternative energy conversion systems, primarily solar, wind, hand, animal, and hydro.

Small-scale renewable (SSR) energy technologies have been widely promoted as an attractive means to pump or lift water, but their viability is often not well documented and/or is disputed. Like all new products, they must be field-tested.

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Table 1 Estimated and projected total energy requirement and percentage for each agricultural input, 1972/73 and 1985/86

<table>
<thead>
<tr>
<th></th>
<th>Total agriculture</th>
<th>Fertilizer</th>
<th>Farm machinery</th>
<th>Irrigation</th>
<th>Pesticides</th>
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<td>328</td>
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<td>Far East</td>
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<td>863</td>
<td>76.4</td>
<td>79.1</td>
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<td>Eastern Europe and the U.S.S.R.</td>
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<td>44.5</td>
<td>56.5</td>
<td>51.0</td>
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</tbody>
</table>

Source: Energy for World Agriculture—FAO, Table No. 23

and evaluated from both the technical and socio-economic performance perspectives before they can be recommended as an alternative to any significant extent. Conventional and traditional/renewable technologies must be similarly tested to determine where they can best be used and how they compare.

The following conclusions may be drawn from the the latest generation of literature:

— The developing countries cannot be expected, in the foreseeable future, to solve the macro-economic problems by a shift to renewable energy systems. The benefits with regard to employment, balance of payments, and reduction of dependency on imports are often marginal, except where favorable conditions, such as local manufacturing, are assumed.

— Further and continuing empirical investigation of the relative worth of the various options under genuine field conditions and on a larger sample must be pursued.

— Serious attempts should be made to monitor, evaluate, and compare the demonstration projects which install small-scale energy devices.

— Concurrent with the search for better water lifting devices, it is essential to concentrate efforts for improving O & M of conventional systems, to identify the reasons for poor performance, and to establish remedies.

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It was noted that more than one million of various types of water lifting devices are operated for agricultural purposes in China, utilizing human, animal, wind and water power, and that most of these devices have potential applicability to the majority of Asian countries. Particularly noteworthy was the water-turbine pump, which is widely used in south China utilizing tidal current in the coastal area and river/stream flow in the mountainous and flat areas. The applicability of this technology to member countries in their mountainous, flat, and deltaic areas should be examined through pilot projects.

Whilst the improvement of the mechanical efficiency of any water lifting devices is important and should be pursued, the key requirements of water lifting devices, i.e. reliability and durability, must receive increased attention. It may not be justifiable to adopt modifications of devices which would result in slightly higher mechanical efficiency at the expense of reduced reliability and durability. It was found that the water lifting devices currently being used in China have a long history, through which the trial and error process has made them more reliable and durable.

III. Features of Several Water Lifting Devices

1. Dragon-bone Water Lift

The dragon-bone water lift has been used in China for more than 1800 years and is still in use. This device is also being used in Thailand and Vietnam. It is made of wood and works in conformity with the principle of simple mechanical gear and chain transmission; water is lifted continuously. There are three types of dragon-bone water lift—man-, animal- and wind-powered.

![Figure 1 Wind-powered dragon-bone water lift](image)

1) From “WATER LIFTING DEVICES in CHINA by Gao Rushan” included in Reference 3).
Man-powered water lift  The man-powered water lift is divided into two categories: hand-turning lift and foot-stamping lift. The former is operated by one or two persons and the latter by two to four persons (or more) acting simultaneously. The appropriate head for this device is usually less than 2 m. The discharge of the hand-turning lift is 34 m³/h for a lift of 0.4 m; it is reduced to 12 m³/h when the lift is increased to 0.8 m. The maximum lift and inclination are limited to 2.5 m and 1 to 2, respectively. In order to increase the efficiency of this device, modification of the intervals between the vanes as well as application of metallic bearings has been introduced.

Animal-powered water lift  The animal-powered water lift is usually operated by one buffalo with a cog wheel power transmission mechanism. It has been used extensively in Jiangsu and Zhejiang Provinces.

Wind-powered water lift  Where adequate wind is available wing power has been and is being used, mainly to save manpower and reduce labor costs. The “diagonal web member” or inclined shaft sail-type wind wheel, which transmits wind energy to the dragon-bone water lift, is predominantly used in the coastal zone of China and Thailand. The discharge capacity of the wind wheel with a diameter of 6 m is from 25 m³/h when the wind scale is third degree (3.4—5.4 m/s). During the course of discussion it was mentioned that new materials, such as PVC, may be adopted, at a lower cost, to improve the efficiency and applicability of this device and that the use of the Archimedean screw type pump in place of the dragon-bone water lift merits attention.

2. Wind-powered Water Lifting Devices

In several Asian countries, particularly Indonesia, Sri Lanka and Thailand, considerable effort is at present being invested in the development and application of wind power generation for irrigation water pumping.

Wind-powered water lifting devices have been used in China for 1700 years. In the pastoral areas of northern China and the coastal areas of southern China, windmills are still in use for water lifting. In Jiangsu and the coastal area windmills are being widely used to drive the dragon-bone water lift. In recent years, however, emphasis has been placed on wind-powered water lifting devices in pastoral areas of the country, and multi-bladed windmills with reciprocating pumps are used.

Based upon information gained, it was felt that a broad classification of wind pumps could be based on head as shown below:

<table>
<thead>
<tr>
<th>No.</th>
<th>Type of wind pump</th>
<th>Typical lift range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Sail-type, e.g. diagonal web with dragon-bone pump</td>
<td>Low, 1 to 2 m.</td>
</tr>
<tr>
<td>2.</td>
<td>Multi-bladed or sail-type with various positive displacement type pumps</td>
<td>Medium, 2 to 10 m.</td>
</tr>
<tr>
<td>3.</td>
<td>Multi-bladed with bucket (piston) type pump</td>
<td>High, up to 100 m.</td>
</tr>
</tbody>
</table>
Although wind is freely available, the low density of air relative to water implies that windmills tend to be rather large and therefore expensive. In general, wind pump size requirements and the need for water storage combine to make wind-powered irrigation capital-intensive. High wind speeds, low lift and double-acting pumps tend to favor wind-powered water lifting.

The type of system recommended, on the grounds of low-starting wind speed (~3.5 m/s) and high efficiency, is the well-established multi-bladed low-speed windmill rotor coupled to a surface-mounted single or double-acting piston pump. Systems with a sail-type rotor coupled to a piston pump are also well proven and recommended. The water storage tank needed for wind pump systems represents a significant cost penalty, and optimization studies are needed to quantify the precise water storage requirements for wind-powered irrigation.

For realistic performance estimates there is a need to obtain data from a wide range of existing sources or from field measurements of long-term average wind speed, preferably at a height of 10 m. This would then provide a basis for pre-feasibility studies of wind-powered water lifting.

Concerning the use of suction or siphon pumps, the nearer the pump is to the water the more efficient it will be; the total suction head should not exceed 5.5 m. A suction chamber must always be used with direct-drive wind pumps. For geared windmills a suction chamber can be used if the pump is more than 30 m from the water or if the total suction head is more than 4.5 m. This is standard commercial practice.

(a) Favourable conditions for wind power utilization require
(i) well-exposed sites, preferably with high average wind speed, low altitude and low temperature, and
(ii) low lift and high irrigation efficiency.
(b) System design should aim at
(i) reasonable $C_F$ (capacity factor), high $C_E$ (energy conversion efficiency and/or trade efficiency against reliability);
(ii) high rotor starting torque using multi-bladed or sail rotors;
(iii) low starting torque pumps, e.g. at low heads by using smooth torque dragon-bone or Archimedean screw, or at higher head by using double-acting reciprocating bucket-type and single-acting type counterbalanced; and
(iv) lower cost with careful detail design.

3. **Bucket Type Waterwheel**

A historical record notes: “Deng Xuanting entered the temple to burn joss sticks. Accompanied by the monks, he went to see vegetable planting in the garden of the temple where he saw the waterwheel lifting water from the well with linked wooden buckets.” Deng Xuanting died in 689 A.D.; accordingly the bucket type is said to have a history of more than 1300 years.

Owing to the shape of its cog wheel for transmission, which looked like the “Eight Diagrams” (the eight combinations of three whole or broken lines formerly
used in divination), the bucket type waterwheel was also known as the “Eight-diagram waterwheel” in the rural area of North China. This device is made entirely of wood and is usually operated by animals. Later on, the bucket is changed into iron instead of wood and the transmission wheel into iron gear; it is then similar to the iron bucket Persian wheel (Figure 2).

The old bucket-type waterwheel is not so durable. Its annual maintenance charge is relatively high and it requires large pulling force to operate. It has therefore been gradually eliminated with the introduction of the tube-chain waterwheel.

4. Tube-chain Waterwheel1) (Figures 3 and 4)

The device works by the action of an endless chain which is pulled up inside the rising pipe, carrying water with it between rubber washers linked to the chain and discharging the water at the top of the pipe into a trough.

The washers make a tight fit in the pipe, and vacuum suction is created when the washer is pulled up in the pipe with the chain.

A power transmission mechanism consisting of a frame, a pair of meshed bevel gears, and pulling rod support is needed in addition to a water lifting mechanism. One draught animal or 2-4 men can lift 7 m³/h over a lifting head up to 12.5 m.

Due to its high reliability, durability, and efficiency, this device is widely used in China. While it seems to have a wide applicability to other countries, further applied research in comparison with handpumps, which do not require a well of large diameter, will be of interest. It was also suggested that the use of the plastic pipe, wind power, and a geared electric motor should be examined.

In view of its relatively simple mechanism, this device can be easily manufactured by local/small workshops and may have direct applicability to countries/
regions where bucket-type waterwheels are still being used.

5. Water-powered Devices

All water-powered lifting devices, except for the tidal power turbine pump, have a 24-hour operating potential with zero fuel/power cost. Year-round performance

Figures 3 and 4 are taken from Mr. Gao Shoufan's paper "TUBE-CHAIN WATER-WHEEL" included in Reference 3).
may be limited by seasonal variations in the supply source. These variations can be compensated for water storage, which may also be required to utilize the full 24-hour pumping potential of the device.

Ram pumps and water-turbine pumping installation require rather extensive site engineering and associated structures. This is generally not necessary for the Plata pump, river-current turbine pump, spiral pump, and waterwheel pump. However, some of these devices are still in the early stages of development, and their extensive application to irrigation may take time.

All river installations are vulnerable to damage caused by floods or floating debris. In extreme cases, this could result in severe damage or total loss of facilities and equipment.

The waterwheel is still being used in China and in several Asian countries. It is highly practicable where favorable site conditions, materials, and skills exist, but its limiting height usually confines its irrigation applicability to relatively narrow zones of cultivated areas close to streams and rivers. Within this limitation, the waterwheel is reliable, easily manufactured, installed, and repaired, but is subject to damage when floods occur.

The bamboo-made waterwheel, which originated in northern Thailand, has been successfully introduced to Sri Lanka and merits careful attention.

The hydraulic ram pump, which is used in hilly and mountainous areas, primarily for domestic and livestock water supply and occasionally for small-scale irrigation, constitutes a proven technology. It is a relatively expensive and complex device requiring periodic attention and inspection. It is being used in northern India and Thailand for small-scale irrigation on a pilot-cum-research basis, but its potential for immediate application to irrigation development is limited.

The water-turbine pump, which is widely used in south China, has been identified by the workshops as one of the most promising devices for immediate applicability to some Asian countries.

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**Figure 5** Waterwheel
1. bamboo tube  2. blade  3. receiving trough

*Figure 5* is taken from Mr. Gao Rushan's paper "ON THE DEVELOPMENT OF HUMAN, ANIMAL, WIND AND WATER POWER WATER LIFTING DEVICES in CHINA" included in Reference 1).
6. Water-turbine Pump

(1) General remarks The water-turbine pump is a water lifting device in which the turbine and pump are coaxial or conjugating as a whole through gear transmission. The whole unit is submerged in water during operation. The turbine is the prime mover; the pump follows the turbine to rotate under the action of a definite water flow and head. Water is thus pumped to the upland area where irrigation is needed. Simply considering the utilization of hydraulic energy, the water-turbine pump is a device of the highest hydraulic efficiency. Water energy is applied directly to do work for lifting water, and no intermediate energy is lost through turbine transmission. Obviously, under the same condition of hydraulic energy, lifting water by electrical power generated will inevitably cause

![Figure 6 Principal parts diagram of the water-turbine pump](image)

- 1. impeller
- 2. volute casing
- 3. runner
- 4. draft tube
- 5. delivery pipe

2) Taken from the paper “AN INTRODUCTION TO THE WATER-TURBINE PUMP” by Xiao Guanying and Weng Aihe, included in Reference 2, and “THE PLANNING AND DESIGN OF WATER-TURBINE PUMP ENGINEERING WITH ITS MULTIPURPOSE UTILIZATION” by Shen Lunzhang, included in Reference 3).

Figures 6 and 7 are taken from “AN INTRODUCTION TO THE WATER—TURBINE PUMP” by Xiao Guanying and Weng Aihe, included in the Reference 2).
a series of energy losses between generator-step-up and step-down transformers-
power transmission lines-motor, so the efficiency is much lower than that of the
water-turbine pump using the same hydraulic energy.

The period of irrigation is not too long within a calendar year, so the hydraulic
energy cannot be fully utilized. Hence many water-turbine pump stations in China
were constructed in processing and generating electricity in order to fully exploit
hydro-power resources. Some rivers lack water during the drought-combatting
season, or even dry up, so that the water-turbine pumps are unable to work. Hence
they have to be used together with other water conservancy facilities; e.g., pump
stations are constructed in series with reservoirs and ponds. Water may be stored
in reservoirs and ponds by means of the water-turbine pump in the wet season and
reused to irrigate fields in the dry season—in other words, it is stored up in the fat
years to make up for the lean ones.

(2) Hydraulic principles The water-turbine pump is a device which
converts hydraulic energy directly into mechanical energy and in turn to potential
and kinetic energy. A coaxial water-turbine pump which works below the water
surface is shown in Figure 6. Its lower half-section is an axial-flow turbine and
the upper one, a centrifugal pump. In the first place, a certain amount of water
head and flow should be required. The flow with a certain amount of energy
passes through the water turbine and puts it into rotation; then the rotating
runner drives the impeller which is connected with the runner. By the action of
the centrifugal force of the impeller, the water is drawn in and thrown out

![Figure 6](image)

**Figure 6** Two-stage coaxial 60-16 water-turbine pump

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continuously, collected by a volute casing, and flows through the water pipeline to the higher elevation in a steady stream.

Multistage coaxial water-turbine pump: In order to increase the lift of the water-turbine pump under the same head, a multistage pump structure is adopted for its pump part. A two-stage coaxial water-turbine pump is shown in Figure 9. The first-stage impeller and the second one are assembled back to back, each with its own volute casing. The inlet is in the middle of the machine, and the outlet of the first volute casing (low) is connected to the inlet of the second one (upper) by a bend pipe. The energy of water is increased after flowing from the first stage into the second, thus doubling the lift. The external form diagram is shown in Figure 7.

(3) Hydraulic character of water-turbine pump The water-turbine pump is a kind of pumping machine which is a combination of hydraulic turbine runner and pump impeller mounted on the same axial shaft. It makes use of the energy from a concentrated water drop to drive a water turbine and rotate a pump impeller mounted on the same shaft. It is completely submerged in water, in operation to lift water.

Although the water-turbine pump is a combined water turbine and pump, its mechanical character is not simply equal to the integration of both machines. Acceptable hydraulic models of both machines must be selected so that the combined water-turbine pump can be operated under optimum working conditions and maximum efficiency.

Currently, models of the water-turbine pump are classified according to the diameter of the water turbine runner and the head ratio. A series of models now available range from 10—120 cm in rotor diameter and from 4:1 to 6:1 in head ratio. In recent years, as more and more water-turbine pump stations have been built every year, the research work and manufacturing technology and water-turbine pumps have also advanced accordingly. Some new products with high head ratio such as 8:1, 10:1, 12:1, 18:1, and 20:1 have been manufactured. The working head has been raised from several meters to 30 m to meet the need of irrigation water uplift in mountainous areas. The overall efficiency of two new models, 40 and 60, have been raised from 60% to 65% and 70% respectively.

The performance of some water-turbine pumps widely used in existing projects is shown in Tables 2 and 3.

(4) Water-turbine pump installation and operation Before starting the design of a turbine pump station, a thorough investigation of the hydrological, topographical and geological features of the project site, together with the available hydraulic head, is essential. A survey of the extent and elevation of the fields to be irrigated should then be conducted to select the optimal lifting head and capacity of irrigation canals to provide the basis for economic comparison. The water requirement should be determined in accordance with the type of crops to be grown and the soil and climatic conditions. After the heads, discharges, and lifts, have been determined suitable models and the number of pump units are selected.
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Table 2 Performance data of Long Wave 20-4 and 20-6

<table>
<thead>
<tr>
<th>Model</th>
<th>Long Wave 20-4</th>
<th>Long Wave 20-6</th>
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<tbody>
<tr>
<td>H (m)</td>
<td>Q (l/s)</td>
<td>n (rpm)</td>
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<tr>
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<td>1035</td>
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Table 3 Performance data of Long Wave 60-4 and 60-6

<table>
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<th>Model</th>
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<th>Long Wave 60-6</th>
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<tbody>
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<tr>
<td>4</td>
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<td>634</td>
</tr>
</tbody>
</table>

Note: H=working head, Q=inflow rate of water turbine, n=speed of water-turbine pump, p=output of turbine, q=lifting discharge of pump, h=lift of pump, η=efficiency of water-turbine pump, Long Wave=Trade mark, 20 (in 20-4)=Runner diameter in cm, 4=Hea ratio

In order to create the necessary hydraulic head, diversion dams and/or diversion canals are usually constructed (Figure 8). In some cases the drop structure of large irrigation canals is used to install pumps. Associated with the structures to create the hydraulic head, considerable engineering works, such as inlet channels and tailraces, sluice gates and trash racks, pump pits, and provision for silt clearing are needed.

(5) Types of water-turbine pump installation The open trenched water-turbine pump pit is usually adopted to install water-turbine pumps vertically or horizontally. Vertical water-turbine pumps are more convenient for installation. The horizontal type has the following advantages: with a low head, the underwater excavation is less and the bends of the outlet pipe are fewer. This results in a convenient arrangement and smaller loss of lift. Such advantages can be seen more clearly with a very low head and fewer units. The vertical installation of

Tables 2 and 3 are taken from "THE PLANNING AND DESIGN OF WATER—TURBINE PUMP ENGINEERING WITH ITS MULTIPURPOSE UTILIZATION" by Shen Lunzhang included in the Reference 3).

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Installation in series

In order to broaden the scope of application of the water-turbine pumps and to raise their lift, the outlet pipe of the first pump is connected with the inlet of the second unit. This form of installation is termed installation in series (see Figure 10). When the number of pumps connected in series is

Figure 8 is taken from "THE PLANNING AND DESIGN OF WATER TURBINE PUMP ENGINEERING WITH ITS MULTIPURPOSE UTILIZATION" by Shen Lunzhang included in the Reference 3).

Figures 9 and 11 are taken from "WATER—TURBINE PUMP ENGINEERING" by Cheng Guanghua included in the Reference 2).

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increased, the lift is increased as many times correspondingly. Therefore, the multiple pumps installed in series may be applied provided that the pump is insufficient and no other suitable model of water-turbine pump is available.

In most cases, the arrangement of the water-turbine pumps connected in series adopts the vertical type of installation. However, more bends have to be used and the loss in lift is greater.

When the water-turbine pumps in series are installed horizontally, the walls of the water-turbine pump pit may be interlaced front and back, resulting in a smaller number of bends to be used (see Figure 11).

(6) Multiple utilization of water-turbine pump stations A considerable number of water-turbine pump stations have multi-purpose uses of the water-turbine: these are irrigation water lifting, hydropower electricity generation, and shaft power supply for agricultural processing. In the case of water-turbine pump stations, it is the usual practice for separate turbine pits to be constructed for water lifting and electricity generation. In general, direct water lifting from the water-turbine pump is preferable to electric power pumping since the former ensures a much higher overall efficiency and lower investment, as well as lower operation and maintenance costs. However, in the event that the irrigation area is scattered and water distribution through the channels is not economically feasible, use of electric power pumps utilizing the power generated at the water-turbine
station merits careful attention. 

Remarks It has been found that, in some cases, water storage is an essential part of the irrigation scheme to ensure an adequate supply of water during periods of low river flow. It was concluded that although there are many opportunities for application of this technology, any attempt at replication should begin with modest pilot projects aimed at verifying the feasibility for local conditions whilst simultaneously building up local expertise and confidence. 

On the question of further technical improvement in the performance of water-turbine pump stations, it was pointed out that careful siting of the installation to minimize interference from floating debris, provision for silt removal, anti-vortex and cavitation measures under adverse operating conditions, improvement in bearing performance and frequency control of electric power generation are worthy of further investigation.

IV. Conclusions and Recommendations

1. Applied Research and Information Exchange

Applied research should be accelerated at both the international and national level. 

Applied research should cover, among others, the following subjects:

- improvement of the mechanical efficiency, reliability, durability and mean time between replacement of wearing parts and repair time of existing water lifting devices;
- development and presentation of designs suitable for manufacture, installation, operation, and maintenance in the countries concerned;
- field testing and evaluation of prototype devices;
- input and output relations;
- economic analysis on the basis of all relevant costs;
- efficient use of lifted water;
- countrywide survey of the potential renewable energy resources available for waterlifting.

2. Application of Improved and/or New Technology and Systems through Demonstration-cum-trial Schemes

Proven technology in one country should be introduced to other countries, taking into account natural, human, and socio-economic conditions in recipient countries. The first step to be taken is to identify the applicability of technologies and systems to potential recipient countries. Demonstration-cum-trial schemes should then take place with the full participation of the national institutions concerned, to examine the acceptability of such devices and water management to farmers.

3. Specific Recommendations

1) When analyzing different types and models of devices to determine their
total costs, all relevant costs should be taken into account. These include both initial costs and any recurrent costs for maintenance, servicing, replacement of parts, and repair.

2) Improvement of water lifting devices should aim at, as a final goal, easing the burden of grinding poverty and hardship on the small farmer and his family. In this context, due attention should be given to improving the human-powered devices. Although it might be preferable to replace such devices, there are many situations where human power will, of necessity, continue to be used in the years to come. Improvement in the working conditions of human beings and the fundamental problem of employment opportunity must receive priority in some countries.

3) Improving water lifting for irrigation can also contribute to improvement in the rural community water supply, and cooperation with the authorities dealing with this and other related aspects, such as health and sanitation, should be strengthened.

4) As fuel costs rise, windmills and hydropowered devices partially replace the diesel engines currently being used for water pumping. It is recommended that this trend be encouraged by early research into methods of designing, matching, and sizing suitable machines.

5) Analytical and field research needs to be undertaken into the optimal size of water storage tanks and suitable water management techniques required for wind-powered irrigation. The size required might be reduced by the provision of a hand or foot-operated lever or similar arrangements to allow manual pumping during calm periods.

6) The possibilities of developing fuel-saving engines and pumps should be fully exploited, and the whole problem of proper matching between engines, pumps, water source, and water use should be examined further and standards developed therefrom.

7) Traditional lifting devices, although of lesser capacity, may serve as standby equipment for fuel or electric engine-powered pumps, thereby helping to reduce possible crop losses during times of breakdown. Good examples exist in China.

8) There is an urgent need for governments to control and check aquifer depletion that is taking place in many irrigated areas and to subsidize small farmers who have to give up traditional means of water lifting because of excessive lifting head. The workshop also drew attention to the fact that the lowering of the groundwater table can lead to substantial increases in energy consumption for water pumping.

References