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# Hybrid Water Pumping System for Natural Water Resources

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## Abstract

The main goal of this paper was to develop the appropriate water pumping system for natural water sources in Northern Thailand. Optimal pumping volume flowrate and head was the target of the water pumping system development. Three types of pumping systems were evaluated with the prototype water sources, namely, Hydraulic Ram Pump (H.R.P.), Water Wheel Pump (W.W.P.) and Hybrid Water Pump (H.W.P.). For the overall performance, H.R.P. and W.W.P. provided delivery head of 3 - 13 m, evaluated with the prototype waterfall and stream. The inlet flowrate had little effect on H.R.P., because higher inlet flowrate resulted in higher water loss without discharge increased. However, when the inlet flowrate was less than 100 L/min, H.R.P. was not be able to pump water. When the supply head increased from 2 to 5 m, the discharge and delivery head also increased significantly. For the W.W.P., the supply head of the waterfall did not affect the performance of the pump. The appropriate operating velocity were at 0.5 - 1.5 m/s to yield discharge of 10 - 14 L/min which was higher than H.R.P. by 1 - 13 L/min. Greater velocity than 1.5 m/s could not provide higher discharge or delivery head.The performance of H.W.P. was the combination of the performance from H.R.P. and W.W.P. The waste water from the H.R.P. would be reused for the W.W.P. with the combined H.W.P. system. Therefore, the natural water could then be fully utilized. H.W.P. could be used in the remote area without electricity access. The natural water pumps could be

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operated continuously and use clean energy from nature. This system could be used in other applications such as maintaining the watershed, creating moisture in the forest, preventing forest fire, and treating air and waste water.

**Keywords:** Hydraulic Ram Pump; Water Wheel Pump; Hybrid Water Pump; Mechanical Efficiency

## Introduction

All natural sources of water on earth originated from rain [1]. Some portion of the precipitation remains above the ground and some seeps into the ground to replenish Earth's ground water. When the quantity of water is too much, it will saturate the ground and is able to move underground through rocks and soil. The water flows from higher ground to lower ground and it eventually creates streams and rivers before they flow into the ocean. Most of the natural water sources are used for agricultural activities such as farming and plantations. Most of the water comes from streams, canals, swamps, wetlands, dams, rivers, and underground water. The method used to move water into agricultural areas is electronic pumping system or other mechanic devices that use fossil fuel - the energy resource that causes pollutions. Therefore, there have been numerous experiments regarding the alternative energy sources from natural sources in recent years. As for water resources, there also have been the attempts to find and use water as an alternative energy source as well. The natural water sources which have been used in the experiments are the water sources that possess water velocity such as waterfalls and weirs. Such water sources can be used as an efficient energy generator more than other kinds of water sources [2]. Most of the waterfalls and weirs in Thailand have the height of 1 - 10 m. The technology that is used with water sources that flow from high point to lower point is Hydraulic Ram Pump (H.R.P.). It is a system that employs the Water Hammer Principle. There are some advantages of using this system. It does not need any fossil fuel or any kind of fuel to drive the system, and it possesses fewer numbers of mechanical gears and parts. That is why it is inexpensive. It can be easily installed and it is also very easy to maintain. Until recent years, there have been many researchers who have attempted to conduct experiments on the system for agricultural activities. Shuaibu and coworkers designed and created H.R.P. system which could pump water from the level of 2 m above the ground with the velocity of water flow of 3.7 L/min without using external energy [3]. The system could pump the water to a height level of 9 m [1]. Nirun and coworkers also designed and evaluated the H.R.P. system to achieve 10 m height with 15.75 L/min [4]. In addition, Akarat and coworkers determined and improved the performance of hydraulic ram pump to achieve pump height of 18 m and 21.4 L/min from the starting water of 5 m [5].

Using H.R.P. system with waterfall or weir that has low level of height provides low quantity of water. The quantity of water pumped into the system does not match the quantity of water that can be used. The water sources that flow from high ground to lower ground could create energy from their current, such as stream, canals, rivers, and irrigation canals for agricultural activities by the Royal Irrigation Department. The normal current speed of those water sources is approximately 0.5 - 2.0 m/s. Several research groups studied ways to harvest energy from the water flow. Akhyar Ibrahim and coworkers conducted a study in Indonesia regarding a water wheel that was made by hardwood with a diameter of 300 centimeters and 40 centimeters wide [6]. The wheel was installed in a river and it could bring water up to a height of 3 m from the water surface. The water was then sent into the system via bamboo pipe. As for streams, energy from the current and water velocity could be used to pump up the water. Peter Morgan designed the Spiral Tube Water Wheel Pump system with the diameter of 4 m which could pump water up to the level of 8 m [7]. The flow rate that could be used to pump the water was 3,697 L/hr. Duangtit and coworkers studied the performance of the vertical water wheel that achieved 1,500 L/hr with delivery head of 10 m [8]. Bunyat and coworkers also reported the efficiency of W.W.P. with inlet head of 3 m and achieved 15 m delivery head with the factor of water discharge of 33.47 - 77.24 % [9]. Morgan also created the spiral tube model with 20 m length and 25 mm diameter with total wheel diameter of 2 m. This model could provide 78 L/hr for every rotation of the W.W.P. [7].

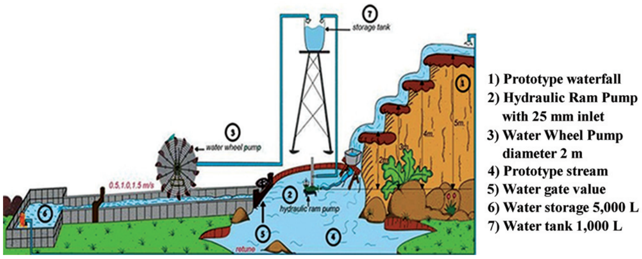
The system was developed from ancient rotor wheel technology. When the coiled tubes were applied to the rotor wheel, thus created the Water Wheel Pump system (W.W.P.) which could pump the water to higher level. When compared to the W.W.P. system with the H.R.P. system, it was found that the system could pump up more quantity of water with lower level of pumping ability.

The current situation and problems of the water pumping system which were previously described revealed both advantages and disadvantages of both W.W.P. and H.R.P. systems. The H.R.P. system had higher operational capability but could carry lower water quantity, which was the opposite to the W.W.P. system which could pump up more water with lower level of pumping ability. Both systems had common purpose which was to pump up water, moreover, both systems require the same energy from the water flow. The difference between both systems were body equipment, installation method, and operating system. After weighing the pros and cons between the two systems, it led to the main goal of this study. Integration of both the Hydraulic Ram Pump system and the Water Wheel Pump system to create a Hybrid Water Pump could reduce the disadvantages and enhance the advantages from both systems.

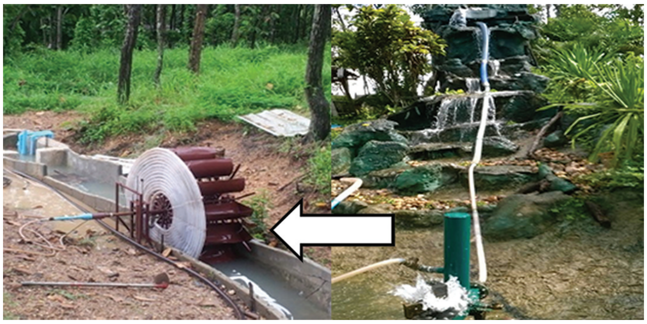
In this work, the performance of the systems were evaluated in terms of discharge, delivery head, and the Mechanical Efficiency from the natural water sources. The experiment could be applied to harvest the energy from the water that falls from high ground such as small weirs and small waterfalls and compared to the electric engine technology. The Water Hammer principle were applied to the H.R.P. system to pump up the water. The water that falls from high ground had energy which allowed the system to pump the water up to 1 - 2 times higher level than the level where the water fell from. The water sources that had water flow such as rivers, streams, and canals were experimented with W.W.P. system. This study examined the appropriate variables, conditions and technologies for pumping up the water in natural sources. The natural water sources and the pumping system used in the local area were designed and constructed prototype waterfalls with a height of 2 - 5 m with installed Hydraulic Ram Pump system to pump up the water to different levels. The researcher also made a prototype river with a size of 1 m wide, 10 meters long and with the adjustable water flow speed of 0.5 - 1.5 m/s. After that, the researcher installed a 2-m diameter W.W.P. system in the prototype river and conduct pumping experiment using various levels of water velocity. Height levels and water quantities including the system's performance were collected to determine the relation of various variables. The results of the experiment were used as the reference data for agricultural activities to save energy, reduce cost and pollution, and to use it as the guideline for communities in the countryside to be able to use pumping system that uses energy from natural sources or renewable energy for agricultural activities.

## Research Methodology

The H.R.P. and W.W.P. were installed at the prototype water sources which are shown in Figure 1. The overall total experiments for the prototype water sources evaluation were 510 experiments. The description of the experimental designed is described in Table 1. The H.R.P. experiment was set up with the prototype waterfall. During the experiment, H.R.P. with 25.4 mm inlet was tested with the waterfall of 4 tiers at 2, 3, 4, and 5 m with the inlet water flowrate of 100, 150 and 200 L/min. The evaluations were conducted with 10 replications for each condition with the total of 120 experiments. Figure 2 shows the method for verifying the water inlet flowrate at each supply head. The water from the waterfall entered the H.R.P., afterwards, the discharge and delivery head was measured. For the water pump evaluation, the 1,000 L water storage tank was installed at 10 m height. The height and size of the storage tank was common for agricultural usage because it provided the water pressure of 1 bar which was sufficient for farming and other applications.




(a) Hybrid water pump schematic diagram



(b) Pictures of Prototype Water Sources

**Figure 1** Hybrid water pump schematic diagram and pictures of prototype water sources


**Figure 2** Data collection of water inlet flowrate at various supply head, discharge volume and 10 m delivery head

The excess water from H.R.P. flowed through the prototype stream to the W.W.P. At the prototype stream, the water velocities were varied from 0.5, 1.0 and 1.5 m/s and the testing were conducted with 10 replications for each condition with the total of 30 experiments. W.W.P. had the diameter of 2 m, width of 40 cm, and during testing, the paddle was 30 cm beneath the water surface.

Hybrid Water Pump system was installed with the prototype water sources of waterfall and stream. The experiment was designed to evaluate the performance of the combined pumps to enhance the discharge volume and increase the delivery head. For the testing, the water flowrates were varied at 100, 150 and 200 L/min and dispensed from the prototype waterfall tier of 2, 3, 4, and 5 m. In addition, the velocities of the prototype stream were varied as 0.5, 1.0 and 1.5 m/s.

Therefore, the total experiments were varied for 36 conditions with 10 replications totalling 360 experiments. The reported outputs were delivery head and discharge volume at each delivery head. Then the pump efficiencies were calculated based on the discharge volume and input flowrate.

**Table 1** Experimental design with operating variables and performance output for prototype water source testing

| **Water sources Pump system** | **Inlet Variable** | **Performance Output** | **Remark** |
|---|---|---|---|
| Prototype waterfall/ Hydraulic Ram Pump | Supply head h = 2,3,4,5 m Inlet Flowrate q = 100, 150, 200 L/min | Discharge (Q) (L/min) Delivery head (H) (m) Mechanical efficiency (%) D'aubuisson's Efficiency (%) Rankine Efficiency (%) | Total 120 experiments |
| Prototype stream/ Water Wheel Pump | Velocity v = 0.5,1.0,1.5 m/s | Discharge (Q) (L/min) Delivery head (H) (m) Mechanical efficiency (%) | Total 30 experiments |
| Prototype waterfall and stream/ Hybrid Water Pump | Supply head h = 2,3, 4,5 m Inlet Flowrate = q = 100, 150, 200 L/min Velocity v = 0.5,1.0, 1.5 m/s | Discharge (Q) (L/min) Delivery head (H) (m) Mechanical efficiency (%) | Total 360 experiments |

## Results

### H.R.P. with prototype waterfall

The Hydraulic Ramp Pump experiment was set up with the prototype waterfall. The results for the discharge volume in Figure 3(a) revealed that with increasing supply head from 2 to 5 m, increasing amount of discharged was acquired from minimum of 1 L/min to maximum of 12 L/min. The range of accumulated discharge also varied based on supply head. With low impact energy at supply head of 2 m, the range of discharge was about 1 - 5 L/min. With higher impact energy at supply head of 5 m, wider range of discharge was observed at 1 - 12 L/min. However, increasing the inlet water flowrate from 100 to 200 L/min did not affect the amount of discharged. The maximum discharge accumulation was only about 10 % of the total flowrate (100 L/min). The amount of water was significantly lost and was not utilized because of the discharge flowrate with increased inlet flowrate.

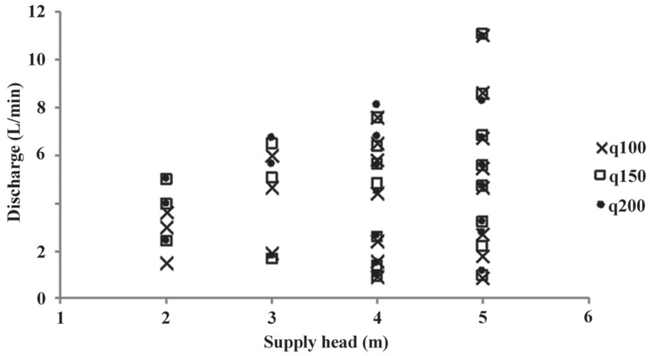
This observation was one of the disadvantage of the H.R.P. application that could not fully utilize the pump with high flowrate of waterfall. Therefore, in this work, hybrid system was then designed in the next part to minimize the disadvantage and improve the quantity of usable discharge flowrate.

With regards to the usable delivery head of the H.R.P., Figure 3(b) revealed similar trend as the discharge flowrate. The delivery head increased from approximately minimum of 3 m to maximum of 14 m with increasing supply head from 2 to 5 m. The range of the delivery head also widened as supply head increased. However, inlet flowrate did not have any effect on the height of the delivery head. So, in order to achieve higher delivery head, other type of pump must be integrated to fully utilized the loss water to facilitate the delivery head.

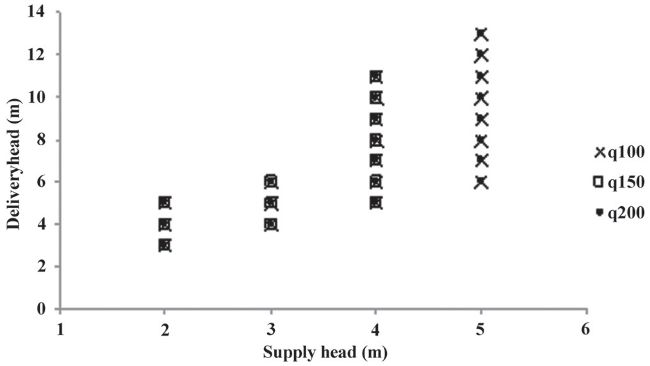
Figure 4 describes the pump efficiencies of H.R.P. From the water inlet flowrate of 100 L/min, it could be seen that the maximum height of the pumped water was 5 m which provided mechanical efficiency of 13.16 %. When the water inlet flowrate reached 150 and 200 L/min, the mechanical performance decreased, because the water trays had the maximum capacity for only 100 L/min. Therefore, when the water quantity was more than 100 L/min, the water overflowed the tray and mechanical performance decreased. Similar result trends were observed with the evaluation of Rankine and D'aubuisson's Efficiency. When compared with the efficiencies at the condition of 5 m and 100 L/min, the values of the 3 efficiencies were 13.16, 14.79, and 24.13 % for Mechanical, Rankine and D'aubuisson's Efficiency, respectively. Mechanical efficiency was calculated from the overall efficiency of water inlet and outlet. D'aubuisson's efficiency calculated the kinetic energy, potential and impact energy. In addition, Rankine calculated only the impact energy, therefore the value was lower than D'aubuisson efficiency. In addition, this result was similar to the result of the experiment conducted in a laboratory. Overall, for the system to start working, it depended on the water flow rate. If the flow rate was less than 100 L/min, the pumping system was not be able to start working. With the case of high flow rate, the water loss increased.

**W.W.P with prototype stream**

The Water Wheel Pump experiments were evaluated with the prototype stream. The results are shown in Figure 5 for the effect of water velocity with discharge, delivery head and mechanical efficiency. For W.W.P. experiment, only Mechanical Efficiency was relevant and calculated. W.W.P. did not have impact energy and therefore Rankine and D'aubuisson's Efficiency was not be applied. Figure 5(a) shows that at water velocity of 0.5 m/s, the discharge was recorded at 3 - 6 L/min of water. When the water velocity was doubled to 1.0 m/s, the discharge increased significantly to approximately 6 - 15 L/min. However, with increasing velocity to 1.5 m/s, the discharge did not increase prominently. It was observed that with high velocity stream, the paddle moved quickly, thus provided less time to bail a larger quantity of water. Therefore, the optimal water velocity was at 1.0 m/s. Higher velocity could not provide more discharge and resulted in higher quantity of water loss. Regarding the delivery head, water velocity of 0.5 m/s provided the delivery head of the pumped water at 3 - 8 m (Figure 5(b)). When the water velocity was increased to 1.0 and 1.5 m/s, the delivery head increased linearly. The range of the delivery head increased with higher velocity.




(a) H.R.P. Supply head and Discharge Relationship




(b) H.R.P. Supply head and Delivery head Relationship

**Figure 3** Relationship between supply head with discharge

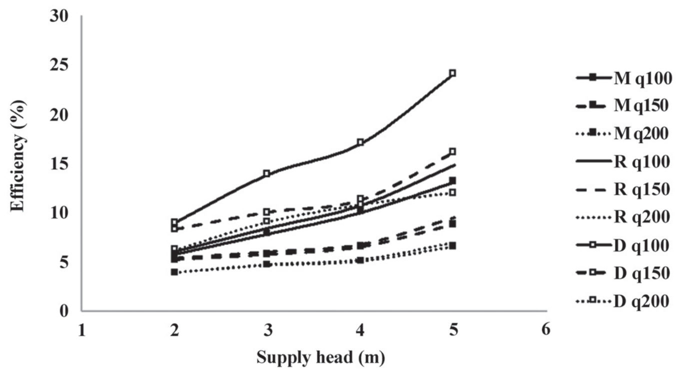
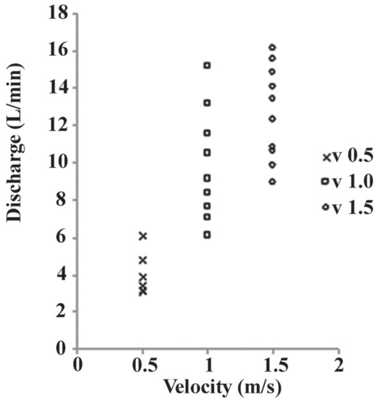
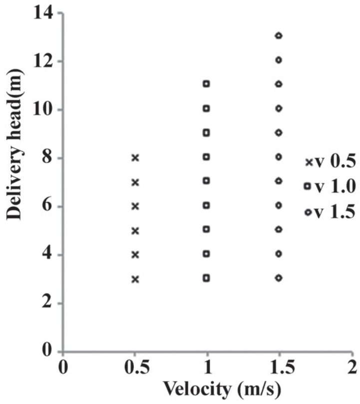


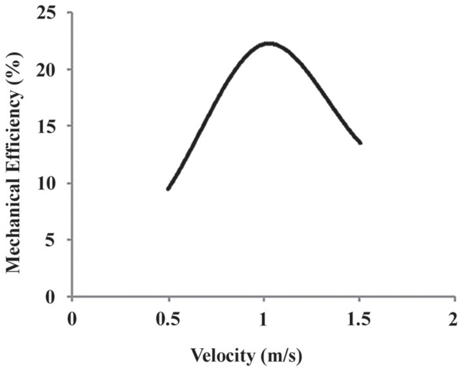

**Figure 4** Relationship between supply head with Mechanical Efficiency (M), Rankine Efficiency (R) and D'aubuisson's Efficiency (D) for H.R.P.




(a) W.W.P. Velocity and Discharge




(b) W.W.P. Velocity and Delivery head




(c) W.W.P. Velocity and Mechanical Efficiency

**Figure 5** Relationship between velocity with discharge

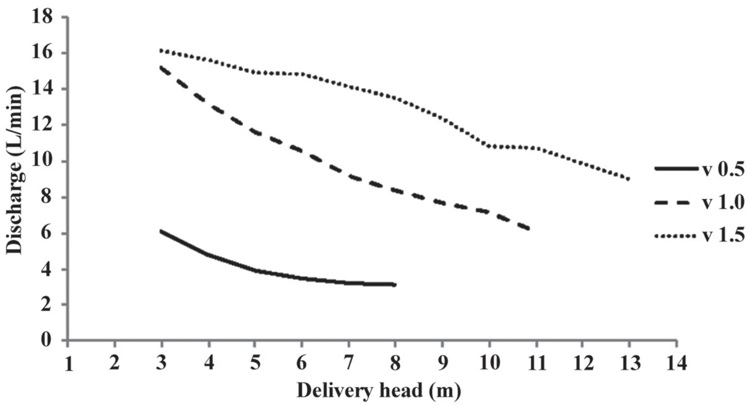



**Figure 6** Relationship between delivery head and discharge for W.W.P. with varying velocity

Mechanical efficiencies of the W.W.P. are shown in Figure 5(c) at the 8 - 23 % range. This was because the mechanism inside the spiral tube of the wheel employs the principle of air contraction and the movement of air mass and water mass [6]. The low speed of the wheel allowed the funnels to bail the water, but if the speed was too high, it provided less time for the funnel to bail the water. The observation was similar to the experiment of Thaveephorn Prayathep and Phuwanai Chaireun who designed and developed an undershot water wheel with a buoy [10].

From the varying inlet condition of W.W.P., the performance results revealed that delivery head was in the range of 3 - 13 m and the discharge was between 2 - 16 L/min. The W.W.P. had a mechanical efficiency in the range of 8 - 23 %. The relationship between of the results of the delivery head and discharge for the W.W.P. is displayed in Figure 6. The discharge values at condition velocity of 0.5 m/s were quite stable as the delivery head increased. However, with higher velocity, the water wheel had limited capability to uptake the same amount of discharge at low and high delivery head. Therefore, with higher delivery head, the discharge volume decreased. This was due to the pressure in the tube increased according to the velocity. When delivery head of the water increased, the level pressure decreased, hence the decrease of water discharge.

**H.W.P. with prototype waterfall and stream**

The Hybrid Water Pump (H.W.P.) system was installed with the prototype water sources of waterfall and stream. The goal of the hybrid system was to effectively utilize the natural water source with minimal water loss. The experiment was designed to evaluate the performance of the combined pumps to enhance the discharge volume and increase the delivery head. In the hybrid system, the H.R.P. with 25.4 mm inlet was installed at the prototype waterfall and then connected in series to the W.W.P installed at the prototype stream. The leftover water that was not uptake by the H.R.P. system was directed toward the stream to the W.W.P. Then, W.W.P. pumped the leftover water, therefore, fully utilizing the natural water sources. The performance results of H.W.P. are shown in Figure 7 - 9.

From the result of the hybrid water pump experiment, the condition with constant velocity of 0.5 m/s provide similar discharge amount range and delivery head range for the varying supply head irrespective of the inlet flowrate of 100, 150 or 200 L/min (Figure 7(a)). At 2 m supply head, the discharge range was at 2 - 12 L/min and at maximum of 5 m supply head, the discharge range was at 1 - 15 L/min. At the water quantity of 100 L/min and the water velocity of 0.5 m/s at the supply head of 2 and 3 m, the delivery head of the pumped water was at a height that came only from the W.W.P. Therefore, the result of the delivery head was the same at 8.3 m. At the supply head of 4 and 5 m, the result came only from the Hydraulic Ram Pump, which provided the delivery head at 11.3 and 13.3 m. However, when compared with the results from H.R.P. and W.W.P., the H.W.P. had greater discharge and delivery head combined. The delivery head of the water entering the system was higher and the overall discharged quantity of the pumped water was respectively increased due to the combined mechanism of the H.R.P. and the W.W.P.

The next sets of results were from the experiment with the water quantity of 150 L/min and the water velocity of 0.5 and 1.0 m/s. The result showed that when the supply entering the system was higher, the total quantity of discharged would slowly increase. The velocity of 1.0 m/s provided the total quantity of pumped water more than the velocity of 0.5 m/s. This was due to the speed of the W.W.P. at the velocity of 1.0 m/s higher than 0.5 m/s, hence the superior number of the total quantity. Furthermore, when both systems are combined, it provided the superior number of the total quantity than that of a single mechanism of the W.W.P.

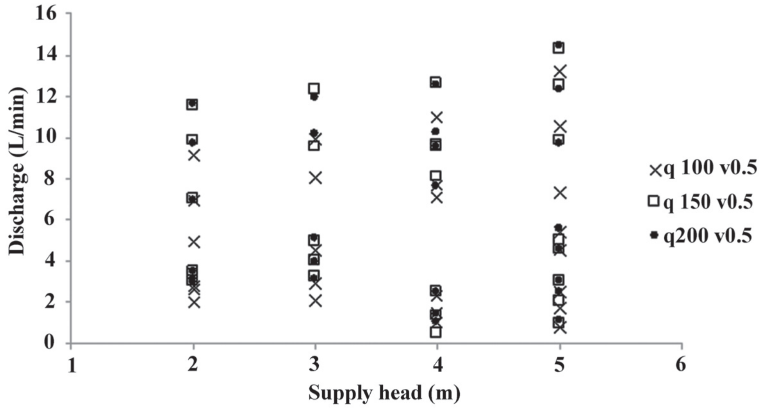
The result from the experiment at the velocity of 1.0 and 1.5 m/s showed that the quantity of discharged pumped water at low level inlet was relatively the same and would slowly increase to follow the supply level of the inlet water and the delivery head high level of the pumped water (Figure 7(b)). This was because the high speed of the W.W.P. provided little time to bail water and exhaust the air inside the funnels, hence the comparable water loss.

As for the experiment with water quantity from the prototype waterfall at 200 L/min and the water velocity of 1.5 m/s at the supply head of 2, 3, and 4 m, the result of the delivery head came only from the W.W.P., hence the height level of 13.4 m high. This was due to the fact that the H.R.P. could only pump up the water to the height level of 5.9, 7.7, and 11.8 m high with the same variables (Figure 8). However, when the supply head was changed to 5 m, the delivery head of the pumped water came only from the H.R.P. result instead, the result of the height level was 13.6 m. The result from the supply head of the water inlet of the H.R.P. at 5 m was relatively equal to the result of the previous experiments that had 200 L/min water quantity from the prototype waterfall and the velocity of 0.5, 1.0, and 1.5 m/s.

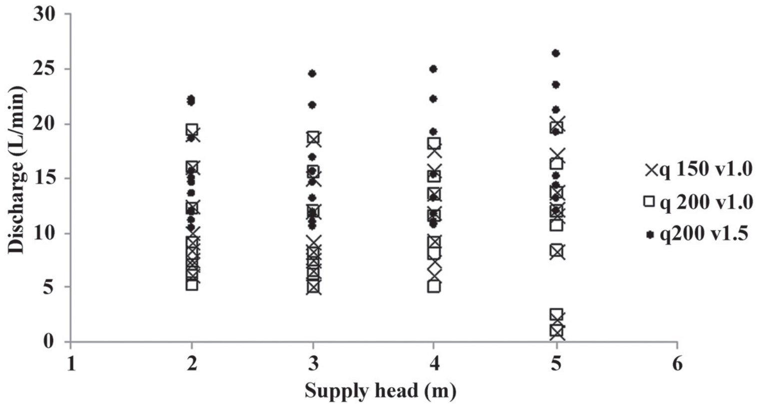
For the relationship between supply head and delivery head, the most influential parameter was the water velocity. The velocity of 1.5 m/s, provided the most stable maximum delivery head irrespective of the supply head. Thus, the mechanism of W.W.P. took over the hybrid system with higher velocity. At lower velocity, such as 0.5 m/s, the supply head of the water was greatly affected by the delivery head.

The mechanical efficiencies of H.W.P. for each water inlet condition are compared in Figure 9. The results clearly indicated that the optimal condition was the flowrate at 150 L/min and velocity at 1.0 m/s for all the supply head variation. This was because the flowrate of 150 L/min was the maximum flowrate for the H.R.P. inlet diameter of 25.4 mm. The higher flowrate at 200 L/min created excess water instead of higher usable discharge. In addition, the velocity at 1.0 m/s was optimal for the W.W.P. at diameter 2 m with 30 cm depth into the stream. With higher velocity, the paddle could not uptake more water and resulted in more unused water.

In summary, for the water inlet condition at low water velocity and low supply head, H.R.P. mechanism dominated the H.W.P. system with performance varying according to the supply head level. So, the results in Figure 9 indicates that for supply head of 2 - 3 m, the efficiency was higher than at the supply head of 4 - 5 m. However, with high flowrate and fast water velocity, the W.W.P. mechanism would dominate the H.R.P. irrespectively of the waterfall supply head and more unused water would occur, thus lower mechanical efficiency. Therefore, the condition of the natural waterfall would be very important in the design and size of the hybrid pump.




(a) H.W.P. Supply head and Discharge for velocity 0.5 m/s



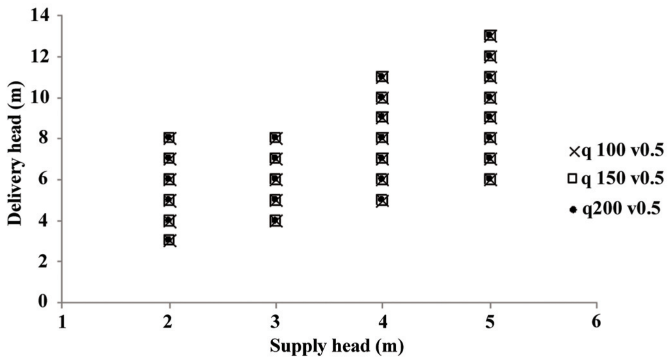

(b) H.W.P. Supply head and Discharge for velocity 1.0 and 1.5 m/s

**Figure 7** Relationship between supply head with discharge for H.W.P. at varying inlet flowrate and velocity

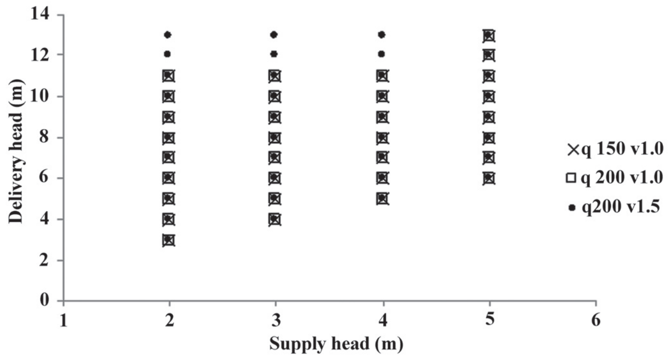
**Operating Condition and Performance Summary**

Overall, the natural water pump systems in this study were evaluated with a natural water source conditions of supply head at 2 - 5 m, inlet flowrate at 100 - 200 L/min, and water velocity at 0.5 - 1.5 m/s as indicated in Table 2. In these operating conditions, the 3 natural pump systems, H.R.P., W.W.P, and H.W.P., could similarly pump water up to the range of 3 - 13 m but with the maximum discharge of 13, 14, and 27 L/min, respectively.

The maximum mechanical efficiency for the 3 natural pump systems were 11, 15 and 26 %, respectively. It was revealed that the H.R.P. using the impact energy from the waterfall was the least efficient in pumping water and resulted in wide range of discharge at 1 - 13 L/min for the delivery head range of 3 - 13 m. Therefore, the H.R.P. could only be used in specific water conditions such as inlet flowrate greater than 100 L/min at supply head at least 2 m to achieve reasonable water storage. In contrast to H.R.P. dependent on inlet flowrate and supply head, the W.W.P. provided stable discharge in the narrow range of 10 - 14 L/min. At the low delivery head of 3 m, W.W.P. could provide discharge at 14 L/min which is more than H.R.P. discharge at 13 L/min. This was the characteristic advantage of W.W.P. Consequently, when H.R.P. and W.W.P were combined into a hybrid system (H.W.P.), the resulting performance for the delivery head was still in the range of 3 - 13 m but with the combined discharge up to the range of 12 - 27 L/min. Therefore, the hybrid system could fully utilize the water source energy of impact and flow velocity in yielding maximum discharge and delivery head. The parameters of the water source would mainly dictate the amount of discharge and height of delivery head.




(a) H.W.P. Supply head and Delivery head for velocity 0.5 m/s




(b) H.W.P. Supply head and Delivery head for velocity 1.0 and 1.5 m/s

**Figure 8** Relationship between supply head and delivery head for H.W.P. at varying inlet flowrate and velocity

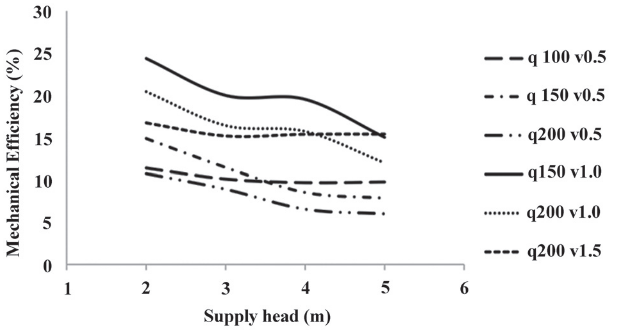



**Figure 9** Relationship between supply head and average mechanical efficiency for H.W.P. at varying inlet flowrate and velocity

**Table 2** Operating condition and performance for H.R.P., W.W.P., and H.W.P.

| **Pump** | **Water SourceCondition Range** | | | **Water Acquired Range** | | **Mechanical** |
|---|---|---|---|---|---|---|
| **System** | **h(m)** | **q(L/min)** | **v(m/s)** | **H(m)** | **Q(L/min)** | **Efficiency (%)** |
| H.R.P. | 2 - 5 | 100 - 200 | | 3 - 13 | 13 - 1 | 3 - 11 |
| W.W.P. | - | 100 - 200 | 0.5 - 1.5 | 3 - 13 | 14 - 10 | 9 - 15 |
| H.W.P. | 2 - 5 | 100 - 200 | 0.5 - 1.5 | 3 - 13 | 27 - 12 | 10 - 26 |

This work focused on 3 inlet parameters for water velocity, supply head and inlet flowrate. The noticeable result was at constant velocity, the amount of discharge range was similar even with varying supply head at 2 - 5 m. For example, at constant velocity of 0.5, 1.0, and 1.5 m/s, the amounts of discharge were in the range of 2 - 12, 5 - 20 and 10 - 25 L/min, respectively even with the different supply head. So, it could be concluded that the amount of discharge for the hybrid system was independent of the height of the waterfall supply head, and highly dependent on the water velocity of the stream. However, at the operating condition with higher velocity than 1.5 m/s, the water wheel was not able to uptake more water which resulted in no significant increase in the discharge. In addition, a clear correlation between the supply head and delivery head was also revealed. Higher supply head always yielded higher delivery head in any operating condition. Lastly, the inlet flowrate had an influence on the operability of the hybrid system. The H.W.P. could not operate with flowrate less than 100 L/min and with flowrate higher than 150 L/min the results of the water uptake were quite similar. So, the natural pumping system with Hydraulic Ram Pump inlet of 25.4 mm and Water Wheel Pump of 40 cm width could operate at the optimum water flowrate of 150 L/min and velocity of 1.5 m/s.

## Conclusion

The main goal for this research was to determine the appropriate technology for pumping water from the natural water sources such as waterfall and stream in the northern part of Thailand. The natural water sources would be used for farming and agriculture and would directly benefit the farmers and local communities. In this work, the operating conditions of the prototype water sources were within the range of height, water quantity and velocity of the conventional waterfalls and streams in the northern part of Thailand. The water pumping systems evaluation for the prototype water sources were focused on 3 types of natural water pumping systems which were Hydraulic Ram Pump (H.R.P), Water Wheel Pump (W.W.P.) and Hybrid Water Pump (H.W.P.) systems. The first system, H.R.P., operated by using the impact energy from the waterfall in various supply height however it was the least efficient in pumping water to achieve high discharge and delivery head. The second system, W.W.P. operated by using the water flow energy in the form of water velocity from rivers and streams. The flow energy induced the water wheel to rotate. The water wheel had the water coil to uptake the received water up to the water storage tank. The W.W.P. provided stable discharge in the narrow range. At the low delivery head of 3 m, W.W.P. could provide discharge of 14 L/min which is more than the H.R.P. discharge of 13 L/min. This was the characteristic advantage of W.W.P. In nature, waterfall is typically followed by river or stream. Therefore, combining H.R.P. and W.W.P. into the hybrid system, H.W.P., would utilized both water energies from impact and flow of the natural water sources. The resulting performance for the overall H.W.P. delivery head were 3 - 13 m but with the combined discharge up 12 - 27 L/min. The parameters of the water source were directly correlated to the amount of discharge and height of delivery head. The amount of discharge for the hybrid system was independent of the height of the waterfall supply head, and highly dependent on the water velocity of the stream. There was a clear correlation between the supply head and delivery head. Higher supply head always yielded higher delivery head in any operating condition. Lastly, the inlet flowrate had an influence on the operability of the hybrid system.

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