Application on the Micro-hydropower generation Benefits of Agricultural Channels and the Water- Energy-Food nexus

Jen-Chieh Shih[1], Fu-Yuan Lin[2], Ming-Der Hong[2], Hong-Ru Lin[3], Jet-Chau Wen[4,5]

[1] Graduate School of Safety Health and Environmental Engineering, National Yunlin University of Science and Technology, 123, Section 3, University Road, Douliou, Yunlin 64002, Taiwan (R.O.C.)
[2] Irrigation and Engineering, Council of Agriculture, Executive Yuan, 37 Nan Hai Road, Taipei 10014, Taiwan (R.O.C.).
[3] Graduate School of Engineering Science and Technology, National Yunlin University of Science and Technology, 123, Section 3, University Road, Douliou, Yunlin 64002, Taiwan, (R.O.C.).
[4] Research Center for Soil and Water Resources and Natural Disaster Prevention (SWAN), National Yunlin University of Science and Technology, 123, Section 3, University Road, Douliou, Yunlin 64002, Taiwan
[5] Department and Graduate School of Safety Health and Environmental Engineering, National Yunlin University of Science and Technology, 123, Section 3, University Road, Douliou, Yunlin 64002, Taiwan (R.O.C.)

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Study Motivation

F Razavi et al. (2011) mentioned that the use of micro-hydropower in remote areas is the best choice, because it is not cost-effective to transmit electricity to remote and inconvenient areas, it involves high transmission costs and insufficient supply. Therefore, this study will use micro-hydropower applications in agricultural channels in order to generate energy.

Study Purpose

We study the benefits of adding micro-hydropower to agricultural irrigation systems by evaluating the mechanical efficiency, discharge and power generation profit in the channel and the feasibility of installing micro-hydropower in the irrigation channel.

Materials and Methods

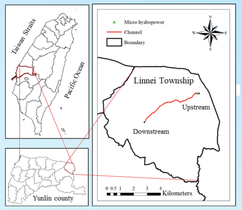
Field Site Description

The study area is located in Linnei Township, Yunlin County, Taiwan.

Linnei channel is for irrigation so discharge is stable.

The installation cost of the micro hydropower system is about 1.87 million.

a)



b)

Figure 1. a) Study area, b) Installation of the micro-hydropower on a)'s green triangle.

The measuring station is located 10 m upstream of the micro-hydropower (red triangle), and distance origin point is 116.9 m, bottom elevation is 102.41m.
The research uses the Teledyne StreamPro ADCP (Acoustic Doppler Current Profiler) to measure the water level and flow velocity in the measuring station.
In the field site to measure the water level, flow velocity and turbine speed.

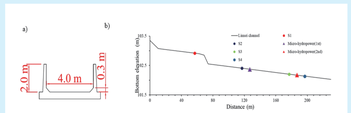


Figure 2. Sectional view of measurement location. (a) Measuring cross section (b) Longitudinal section of Linnei channel

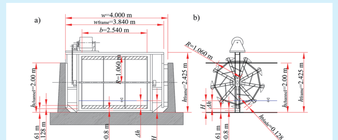


Figure 3. Cross-sectional view of the water turbine

1. The first turbine blade form

- The first turbine has nine sets of blades, which are airfoil blades

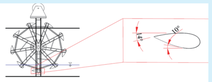


Figure 4. Side view of the first turbine.

2. The second turbine blade form

- The second turbine has 13 sets of blades, which are general blades

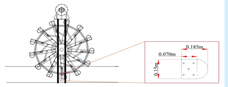


Figure 5. Side view and of the second turbine

Flow chart

Figure 6. Flow chart

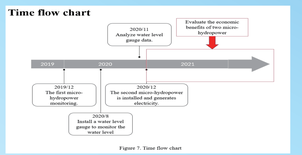


Figure 7. Time flow chart

Gauge monitoring

- We install water level gauges every 10 meters on the side of the channel, it is a total of ten water level gauges (UP01~05 and DN01~05). UP01~05 are located upstream of the first hydropower and DN01~05 are downstream.
- Mainly observe the changes of upstream and downstream water levels.

Figure 8. Installation water level gauge of Linnei channel

Field survey

1. Water level and discharge

- This study uses Teledyne StreamPro ADCP (Doppler flowmeter) to measure the velocity and water level of the channel

$$H = \frac{(h_1 \times w_1) + (h_2 \times w_2) + (h_3 \times w_3) + (h_4 \times w_4) + (h_5 \times w_5)}{w} \quad (1)$$

where w_i and h_i represent the channel width [m] and water level [m] respectively ; i represents the measurement point (i=1,2,3,4,5) , w_1=0.3 m 、w_2=1.1 m 、w_3=1.2 m 、w_4=1.1 m 、w_5=0.3 m 。

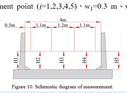


Figure 10. Schematic diagram of measurement.

After obtaining the channel water level (H), use formula to calculate the channel discharge ($Q_{channel}$):

$$Q_{channel} = (V_1 \times h_1 \times w_1) + (V_2 \times h_2 \times w_2) + (V_3 \times h_3 \times w_3) + (V_4 \times h_4 \times w_4) + (V_5 \times h_5 \times w_5) \quad (2)$$

Estimated hydraulic potential

- We use the rating curve to obtain velocity, and calculate the potential by equation (5), (6), (7),(8).

$$F = \rho Q_i V (\cos\theta_i - \cos\theta_2) \quad (5)$$
$$T = F \cdot R \quad (6)$$
$$P_{up} = T \cdot \omega \quad (7)$$
$$P(kW) = \rho Q g H = \frac{Q_i \times V^2}{2} \quad (8)$$

In equation (5),(6),(7),(8)
F : force [N] ;
Q_i : discharge push the water turbine blade (m^3/s)
ρ : density of water (1000 kg/m^3)
θ_i : included angle between inflow and flow direction
θ_2 : included angle between outflow and flow direction
T : torque [N·m]
R : radius of turbine
ω : rotary speed of water turbine (rad/s)
P_{up} : power generation of hydraulic potential (kW)
V : velocity of middle two parts of cross-section (m/s)

Mechanical efficiency

- Using the result of potential and the power generation of turbine output, we can get turbine efficiency η_t.
- Using the result of estimated power generation and theoretical power generation, we can get generator efficiency η_g.

$$\eta_t = \frac{\bar{P}_t}{P_{HP}} \quad (9)$$
$$\eta_g = \frac{P}{\bar{P}_g} \quad (10)$$

In equation (9), (10),
P_{HP} : realistic power generation (kW)
$\bar{P}_t$: power generation of turbine output (kW)
η_t : turbine efficiency
$\bar{P}_g$: theoretical power generation (equal to $\bar{P}_t$) (kW)
η_g : generator efficiency

Data collection

1. Water level of Linnei channel

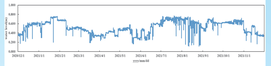


Figure 9. Time series of water level change of Linnei channel from Water Resources Department of Yunlin County Farmland Association

2. Economic benefit

- The price of electricity of hydropower generation is 3.1683 NTD/kWh and data source from Taiwan Power Company.
- The carbon reduction assessment method is based on the announcement of Bureau of Energy, MOEA (2019), the electric power emission factor is 0.509 and the price of carbon emissions is 3 NTU/ton.

2. Water level and discharge

- Plotting the rating curve between water level and discharge by exponential function regression.
- We obtain 45 measurements in total from December 1, 2020 to November 30, 2021 by Doppler current meter.

$$Q_{channel} = aH^c \quad (3)$$

In equation (3),
$Q_{channel}$: discharge in channel (m^3/s)
H: water level (m)
a, c: rating curve constant

3. Discharge and turbine speed

- We use the discharge(Q_i) and turbine speed , plot the characteristic curve by exponential function regression.

$$Q_i = b \cdot \Delta h \cdot V \quad (4)$$

In the equation (4),
Q_i: discharge push the turbine blade (m^3/s)
b : the length of turbine blade
Δh : the depth of turbine under the water (m)
V: velocity of cross section (m/s).

4. Turbine speed and power generation

- The speed ratio of turbine and generator is 1:10.8.
- We substitute generator speed into characteristic curves to estimate realistic power generation

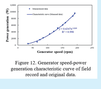


Figure 12. Generator speed-power generation characteristic curve of field record and original data.

Benefit Analysis

- **Internal rate of return:**

$$\sum_{t=1}^{n} \left[\frac{R_t - C_t}{(1+i)^t}\right] = 0 \quad (11)$$

In equation (11),(12),
R_t : profit of micro-power generation in year.
C_t : input cost
i : assumed discount rate is 5%.

- **Cost-Benefit ratio:**

$$\frac{B}{C} = \frac{\sum_{t=1}^{n} \frac{R_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{C_t}{(1+i)^t}} \quad (12)$$

- **Payback Period Method**

$$\sum_{t=1}^{t} C_t - C_0 = 0 \quad (13)$$

In equation (13),
C_t : profit of micro-hydropower generation in year

- **Carbon reduction**

Estimated carbon reduction = total power generation (kWh) × 0.509 (14)

Results and Discussion

Power generation calculation

- **First micro-hydropower**
- The generator input is 109,193 kWh and output is 79,286.4 kWh, and the generator efficiency is 72.6%.
- The turbine input is 139,787 kWh and output is 110,744.8 kWh, and turbine efficiency is 79%.

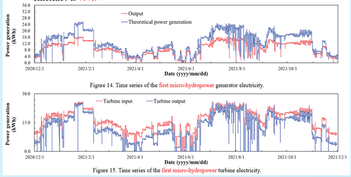


Figure 14. Time series of the first micro-hydropower generator electricity.

Figure 15. Time series of the first micro-hydropower turbine electricity.

- **Second micro-hydropower**
- The generator input is 98,128 kWh and output is 64,492 kWh, and the generator efficiency is 65.7%.
- The turbine input is 196,678 kWh and output is 98,034.8 kWh, and turbine efficiency is 50%.

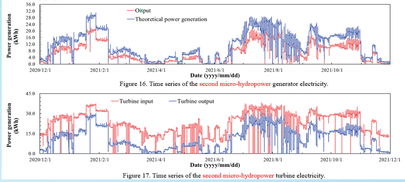


Figure 16. Time series of the second micro-hydropower generator electricity.

Figure 17. Time series of the second micro-hydropower turbine electricity.

Result of gauge monitoring

- The upstream impact range is 17.53 meters , while and the downstream impact range is 39.44 meters.
- Therefore, it is recommended to install the second turbine 80 meters away from the first micro-hydropower

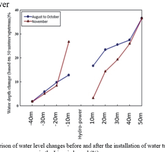


Figure 13. Comparison of water level changes before and after the installation of water turbines in the Linnei channel (%)

Result of benefit Analysis

1.Internal rate of return:

First turbine internal rate of return

$$= \sum_{t=1}^{n} \left[\frac{(79286 \times 3.1683) - 1871625}{(1+i)^t}\right] = 0 \ , i = 7\%$$

Second turbine internal rate of return

$$= \sum_{t=1}^{n} \left[\frac{(64492 \times 3.1683) - 1871625}{(1+i)^t}\right] = 0 \ , i = 0.2\%$$

2. Cost-Benefit ratio:

First turbine : $\sum_{t=1}^{n} \frac{251201.8}{(1+i)^t} \Big/ \left[1871625(\text{NTD}) + \frac{93581}{(1+i)^t}\right] = 0.87$

Second turbine : $\sum_{t=1}^{n} \frac{204330}{(1+i)^t} \Big/ \left[1871625(\text{NTD}) + \frac{93581}{(1+i)^t}\right] = 0.71$

3. Payback Period Method:

First turbine :

$$\sum_{t=1}^{t} 79286(kwh) \times 3.1683 - 93581(\text{NTD}) - 1871625, t = 11.9\ (years)$$

Second turbine :

$$\sum_{t=1}^{t} 64492(kwh) \times 3.1683 - 93581(\text{NTD}) - 1871625, t = 16.9\ (years)$$

4. Carbon reduction:

First turbine carbon reduction
= 79286 × 0.509 = 40356 kg

Second turbine carbon reduction
= 53792 × 0.509 = 27380 kg

Conclusion and Suggestion

1. Setting up micro-hydropower in the agricultural irrigation system, various economic benefit analyses show that this research has investment value.
2. After the installation of the micro-hydropower, the total channel flow has not decreased, which has a positive impact on the local economy.
3. Changing the turbine blades type has an impact on improving turbine efficiency.
4. According to the results, the second micro-hydropower efficiency is lower than first micro-hydropower. It may be due to the influence of the first micro-hydropower and the follow-up research needs to consider the installation distance.

Acknowledgements

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