engineering proceedings

Proceeding Paper

Planning and Strategies for Expansion of Irrigation Services in Mountainous Areas: A Case Study of Nantou County in Taiwan †

Feng-Wen Chen [1,2], Yun-Wei Tan [1], Hsiu-Te Lin [1], Yu-Chien Cho [1], Ya-Ting Chang [1] and Li-Chi Chiang [3,*]

1 Resource Division, Agricultural Engineering Research Center, Taoyuan 32061, Taiwan; chenfw@aerc.org.tw (F.-W.C.); tan0710@aerc.org.tw (Y.-W.T.); linht@aerc.org.tw (H.-T.L.); uccho@aerc.org.tw (Y.-C.C.); kiki@aerc.org.tw (Y.-T.C.)
2 Department of Water Resources and Environmental Engineering, TamKang University, New Taipei City 251301, Taiwan
3 Department of Bioenvironmental Systems Engineering, National Taiwan University, Taipei 10617, Taiwan
* Correspondence: lchiang@ntu.edu.tw
† Presented at the 2024 IEEE 6th International Conference on Architecture, Construction, Environment and Hydraulics, Taichung, Taiwan, 6–8 December 2024.

Abstract: More than half of the cultivated land belongs to the Irrigation Association. Therefore, there have been no farmland consolidation, irrigation, and drainage projects. The cultivation in the non-irrigation area suffers from poor geographical conditions and a lack of water sources. A practical planning strategy is required for expanding irrigation services. The mountainous area of Nantou County, Taiwan, has 7477 ha of available land and 4656 ha of agricultural land outside the irrigation area. Rain and streams are the main water source. There are 82 ponds, 80% of which belong to the loam soil, and the rainfall from October to February is limited. The water requirement of crops is 1.5–3.1 mm/day. Wild streams, groundwater, and rainwater are the only potential water sources due to elevation and terrain. The potential runoff is estimated to be 0–0.927 cms (m^3/s) when using the SCS-CN method. Water supply and demand from October to April are limited, and the rainfall comprises 22% of the total water supply. Large reservoirs and water storage towers are required for flooding and in dry seasons. To address water storage challenges and stabilize the balance between water supply and demand, it is essential to construct additional ponds.

Keywords: irrigation service; water resource planning; water shortage area; irrigation association

Academic Editors: Teen-Hang Meen, Hsi-Hsien Yang and Cheng-Fu Yang

Published: 8 May 2025

Citation: Chen, F.-W.; Tan, Y.-W.; Lin, H.-T.; Cho, Y.-C.; Chang, Y.-T.; Chiang, L.-C. Planning and Strategies for Expansion of Irrigation Services in Mountainous Areas: A Case Study of Nantou County in Taiwan. *Eng. Proc.* **2025**, *91*, 17. https://doi.org/10.3390/engproc2025091017

1. Introduction

The agricultural land area in Taiwan expanded from 831,950 ha in 1946 to 919,680 ha in 1976. However, due to industrial and urban development, the area had declined to 790,078 ha by 2020. As of October 2020, 365,416 ha in 17 irrigation associations' districts was managed for irrigation water supply. Since then, the Ministry of Agriculture's Irrigation Agency has been responsible for coordinated irrigation management. Areas under its management are referred to as "irrigated service areas". Around 310,000 ha belongs to the Irrigation Agency, while 393,000 ha remains as non-irrigated service areas (Figure 1) [1]. In total, 393,000 ha of farmland previously required independent water for irrigation, and the Ministry of Agriculture has put its efforts into providing irrigation services.

More than 50% of Taiwan's arable land remains without formal irrigation services, encompassing multiple counties and municipalities. Such land needs appropriate water resource planning to ensure reliable access to water. Over the past several decades, numerous water source surveys and planning efforts have been conducted in these non-irrigated regions, with notable examples including the drought-irrigated zones of Nantou and the Bagua Mountain area in Changhua [2]; Xinshe region in Taichung [3,4]; Tongxiao region in Miaoli [5]; and Gaodiyang area in Longtan, Taoyuan [6]. The reports highlight the urgent need for stable water resource planning and assessment for the land.

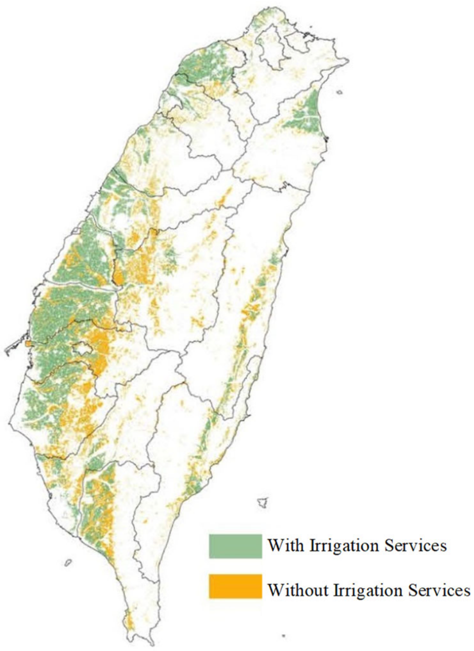

Figure 1. Distribution of agricultural areas in Taiwan.

Therefore, we proposed strategies for water resource planning in water-scarce mountainous regions in this study. We established a step-by-step strategy for expanding irrigation services and determined essential planning components for Zhongliao in Nantou County, Central Taiwan, as a case study. The strategy serves as a reference for similar regions facing challenges in water resource management and agricultural sustainability.

Expansion of Irrigation Services

Several implementation methods for expanding irrigation services in mountainous areas are as follows. Data, including hydrology, geomorphology, farmland, and crop information, were gathered. Then, a phased method based on factors such as farmland size, crop value, density, and farmer needs was formulated by determining the sequence for implementing irrigation services. Potential water sources, including rivers, groundwater, reclaimed water, and effective rainfall, were identified. Storage facilities, water quality, and supply capacity were evaluated after assessing water requirements for crops in the study area and estimating temporal and spatial variations in crop water demand. By conducting a demand analysis and irrigation expansion assessment, the sufficiency of water supply reliability was evaluated to provide irrigation services. Based on farmland size, crop type, and potential water sources, possible areas, scope, and feasibility for irrigation expansion were outlined. Finally, water engineering plans were developed to support the expanded service area for upgrading existing facilities, establishing new water intake points, designing water conveyance systems, arranging irrigation networks, selecting storage sites, and developing storage and field irrigation systems. Legal, technical, and economic feasibility were also studied using benefit–cost analyses.

2. Study Area

2.1. Geographic and Hydrological Characteristics of the Study Area

Zhongliao Township in Nantou County is located in the mountain regions of Central Taiwan. Nantou County is situated in Central Taiwan (Figure 2). The Zhongliao Township has an area of 4656 ha outside the irrigation service areas. The study area includes 18 villages, 2 major central government-managed rivers (Zhangping Creek and Pinglin Creek), and 6 county-managed drainage channels. The water systems in the study area are shown in Figure 3. The river flows into Zhangping Creek, Neicheng, Dongshi Kekeng, Houliao Creek, and Pinglin Creek. The water flows from these catchment areas to the west. There are 82 existing farm ponds in the area. Zhongliao Township has an elevation range of 200 to 1264 m above sea level, with a length of 13.7 km from east to west and a width of 11.5 km from north to south. The terrain gradually decreases from east to west. The hilly area accounts for about 143 km^2 (97.8%), and the flatland covers about 3 km^2 (2.2%). The land is higher to the north, east, and south. The dominant soil type is loamy clay (80.0%), followed by sandy clay loam (10.4%); sandy loam (1.7%); and other soil types, such as clay and fine sandy loam (2%).

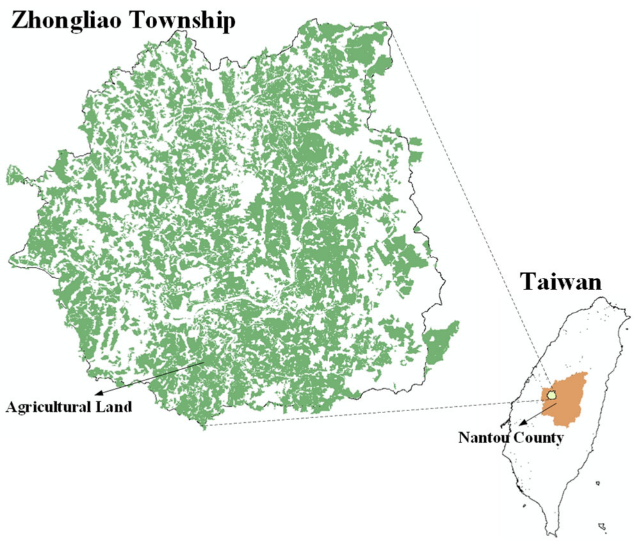

Figure 2. Study area and its agricultural land.

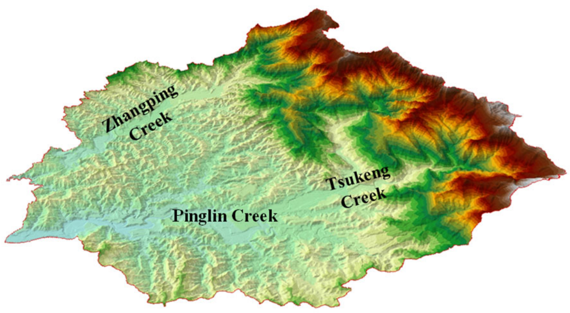

Figure 3. Terrain distribution of Zhongliao Township, Nantou County.

Rainfall data were obtained from the Zhongliao (C0H950) weather station during 2000–2022. The annual rainfall is 2248.5 mm, with the lowest monthly rainfall occurring in October (32.8 mm) and the highest in June (473.6 mm). The maximum daily rainfall is highest in August (140.1 mm), followed by July (127.1 mm), with the lowest in January (17 mm). The daily average rainfall is highest in June (15.8 mm), followed by August

(15.6 mm), while the rainfall from October to December is minimal, with October at 1.1 mm, and November and December both at 1.2 mm.

Due to a lack of irrigation sources, rice is not cultivated. The main crops are dryland crops (primarily long-term fruit trees, followed by short-term dryland crops), including bananas, longan, citrus, bamboo shoots, lychee, plums, pineapples, tea leaves, ginger, and coffee. The area and value of these crops are summarized in Figure 4. We selected bananas, longan, citrus, bamboo shoots, and tea leaves as representative crops in Zhongliao Township. The major water requirements for these crops are shown in Table 1.

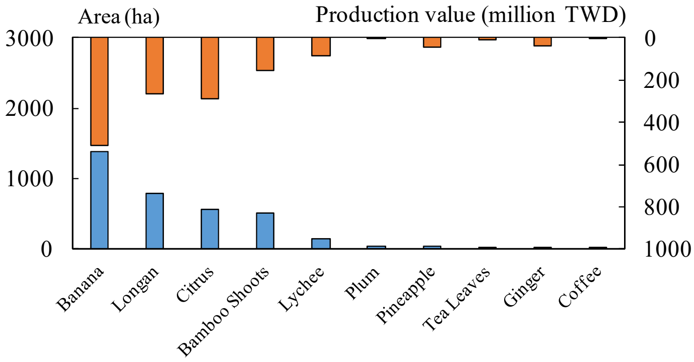

Figure 4. Spatial distribution of soil texture and bar chart of main crop planting area and value in Zhongliao Township.

Table 1. Main crop water requirements in Zhongliao Township by growing period.

Category	Banana	Longan	Citrus	Bamboo Shoots	Tea Leaves
January	•		•		•
February	•		•		•
March	•			•	•
April	•			•	•
May		•		•	•
June		•	•	•	•
July		•	•	•	•
August				•	•
September				•	•
October				•	•
November	•				•
December	•				•

Data source: [7–12].

2.2. Planning and Phased Implementation

The potential for improving water efficiency and stability in mountainous areas with water shortages is significant. By implementing appropriate irrigation facilities such as water intake, conveyance, and storage, or by upgrading existing facilities, water accessibility for farmers can be improved, thereby enhancing crop yield and quality. This contributes to securing farmers' rights and interests.

In this study, the scale and concentration of farmland, crop value, and farmers' willingness to participate were selected as factors impacting the irrigation of the area. Based on these factors, a phased implementation method was proposed for short-, medium-, and long-term implementation zones.

In the short-term implementation zone, areas with larger farmland, higher concentration, higher crop value, and greater farmer demand were prioritized. Focusing on updating or constructing water intake, conveyance, and storage infrastructure, detailed investigations and engineering plans were formulated for a stable water supply. In the medium-term implementation zone, large farmlands, crop value, and the farmer's demand were considered to update or build irrigation infrastructure. With storage towers and irrigation pipelines, higher water needs can be satisfied. In the long-term implementation zone, smaller scale, lower concentration, lower crop value, and lower farmer demand were considered. In the zone, the focus was placed on improving water storage and irrigation infrastructure for farmers with higher water demand, as well as conducting educational outreach and crop planning. Once the farmer's willingness increases, detailed engineering plans can be executed, as illustrated in Figure 5.

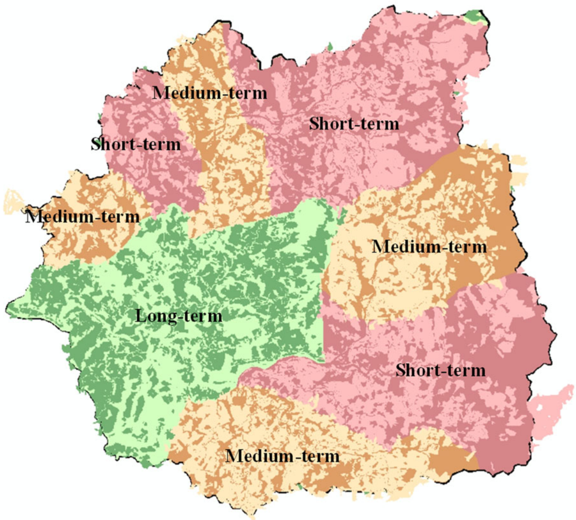

Figure 5. Results of regional division for short-term, mid-term, and long-term promotion.

3. Potential Water Sources and Supply Capacity

3.1. Assessment of Potential Surface Water

We estimated the potential water quantity based on the concept of runoff estimation from watershed precipitation. There are three methods for estimating runoff, namely the Rational Formula, the SCS method, and Manning's equation. The Rational Formula is appropriate for peak flow estimation, while Manning's equation is used for estimating channel design flow velocities. Since the potential runoff in each month was important, the SCS method was used in this study. The SCS method was developed by the U.S. Soil Conservation Service based on rainfall and runoff data from small watersheds to derive a series of related curves. The curve number equation is widely used in methods (1) and (2) [13,14]:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad (1)$$

$$CN = \frac{1000}{10 + S} \quad (2)$$

where S represents the watershed storage (inch), P is the rainfall (inch), and Q is the runoff (inch), with evaporation losses not accounted for in the equation. CN is a parameter determined by soil cover factors, soil moisture conditions, hydrological properties of the soil, and soil classification. The soil cover factor includes land-use types and farming practices. CN ranges from 60 to 90.

We calculated the runoff for the watershed of Keng Creek in the upper reaches of the Fusheng channel. The soil in Zhongliao Township is silty loam (SGS soil type C) and can be used as farmland with no protective measures and forest areas with good coverage. CN is assumed to be 70. The watershed area is approximately 1665 ha, and rainfall data from the Zhongliao weather station in 2018–2022 were calculated. The locations of the watershed and the rain gauge station are shown in Figure 6, and the runoff estimation results are shown in Figure 7. The average daily rainfall has two peak periods, from May to June and from July to September, with average daily rainfall ranging from 9.29 to 21.39 mm, with the highest in August. The flow from May to June ranges from 0.37 to 0.72 cms (m^3/s), and from July to August, the flow ranges from 0.19 to 0.93 cms (m^3/s), with the maximum flow in August.

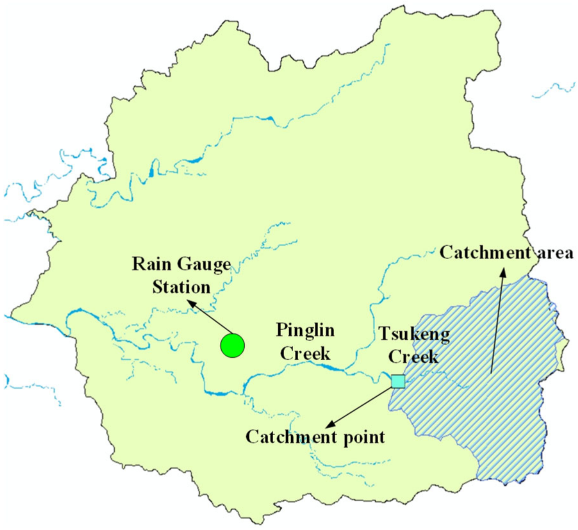

Figure 6. Fusheng channel Keng Creek and adjacent rain gauge station.

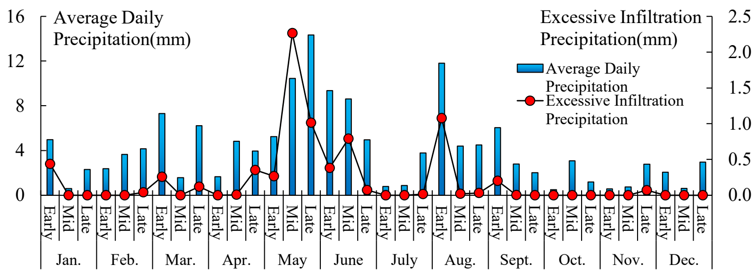

Figure 7. Average daily precipitation and excessive infiltration precipitation.

3.2. Precipitation Potential

Precipitation is the water source for irrigation, commonly referred to as effective precipitation. The definition of effective precipitation is the amount of rainfall during the crop growing season that can be utilized for irrigation, or the amount that is available for crop growth [15–18]. Refs. [19,20] pointed out that precipitation can substitute for irrigation water requirements, and this substitution is beneficial to agricultural management. The farmland in the Zhongliao irrigation area is located in a region with limited water resources, and rainfall is an important water source for dryland farming. We used the following analysis methods in this study.

For dryland crops, their water demand is lower than that of paddy crops, as they are less tolerant of waterlogging, making drainage in the fields important. Ref. [21] stated that the effective precipitation for dryland farming is the amount of precipitation that satisfies the crop's evapotranspiration. Ref. [20] explained that the water demand of dryland crops is generally based on the crop's water requirements. Therefore, the crop's water requirement serves as a threshold for calculating effective precipitation in dryland farming (3).

$$ER = \begin{cases} 0, & if\ R_s = 0 \\ R_s, & if\ R_s \leq ET_{crop} \\ ET_{crop}, & if\ R_s > ET_{crop} \end{cases} \quad (3)$$

where ET_{crop} represents crop water requirement (mm/day), and R_s represents actual daily precipitation.

A crop water requirement limit of 6 mm/day was set as the daily effective upper limit for calculating the effective precipitation in dryland. The analysis results based on daily rainfall data from the Zhongliao rain gauge station from 2018 to 2022 are shown in Figure 8. If dryland crops are planted in the irrigation area, the average annual effective precipitation available is approximately 493 mm/year, with a monthly average of 41.1 mm/month. The months with higher contributions of effective precipitation are from May to September, while in the other months, the precipitation is below the average. June has the highest effective precipitation at 82.1 mm/month, while October has the lowest at 9.9 mm/month. The utilization rate of effective precipitation is higher than the average (21.9%) from October to April of the following year, with January having the highest rate at 47.2%, and the lowest utilization rate in August at only 16.5%.

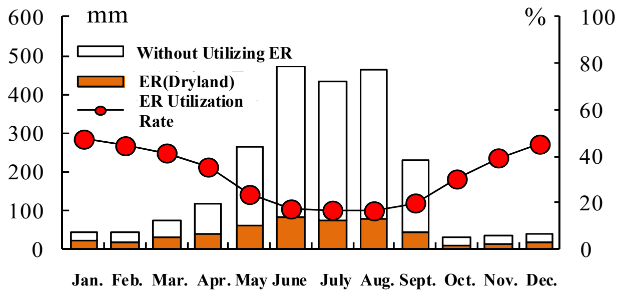

Figure 8. Effective precipitation and utilization potential for dryland crops.

3.3. Other Potential Water Resources

Potential water resources for crops include groundwater, effluent from water resource recycling centers, and seepage water in this study. Effluent from water resources and recycling centers is domestic wastewater (industrial wastewater is prohibited) and can be used as irrigation water. There are four water resource centers near Zhongliao Township, with wastewater treatment in Classes I and II. Three centers are located downstream in Zhongliao Township, and one is located upstream (8.6 km away from the town). Therefore, effluent recycling is a potential irrigation water source for the Zhongliao irrigation area but with challenges. Niaozuitan Artificial Lake and Sun Moon Lake have an effective capacity of 14.5 million m^3. The water is mainly used for domestic water supply, not for agricultural irrigation. Sun Moon Lake is a multi-purpose reservoir for power generation, tourism, domestic water supply, and irrigation, with an effective storage of 129.64 million m^3. Due to the distance of 5.5 km between the lake and the study area and the intervening mountains, its potential for utilization is limited. The seepage water intake for the Tianliao Irrigation Area is 3.5 km away from the study area. The elevation of the Tianliao Irrigation Area is 190 m, while the study area is at an elevation of 300 m, creating an elevation difference of 110 m. The difference poses a limitation for the development of seepage water. Groundwater is an important water source for agricultural irrigation. However, pumping groundwater is not appropriate. Based on the groundwater control zones designated by the Ministry of Economic Affairs, this area does not belong to the groundwater control zone. Therefore, groundwater is a potential backup water resource in the future.

4. Water Requirement Analysis

Crop Water Requirements

Estimating crop water requirements is significant in determining water supply in an irrigation area for crop growth. We used methods of the Food and Agriculture Organization (FAO) and the International Commission on Irrigation and Drainage (ICID) to estimate crop evapotranspiration (ET_{crop}). First, the reference crop evapotranspiration (ET_{o}) was estimated, and then the crop coefficient (K_{c}) value was determined based on the crop cultivation type, planting time, growth stages, and growth cycle. ET_{crop} was estimated using (4) [22]. ET_{o} was calculated using the Penman–Monteith method (5) [23].

$$ET_{\text{crop}} = K_{\text{c}} \times ET_{\text{o}} \tag{4}$$

$$ET_{\text{o}} = \frac{0.408 \times \Delta \times (R_{\text{n}} - S) + \gamma \times \frac{900}{T+273} \times U_2 \times (e_a - e_d)}{\Delta + \gamma(1 + 0.34 \times U_2)} \tag{5}$$

$$\Delta = \frac{2504 \times exp\left[\frac{17.27 \times T}{T+237.3}\right]}{(T + 237.3)^2} \tag{6}$$

where ET_{o} represents reference crop evapotranspiration (mm/day), R_n represents solar radiation (MJ/m^2/day), γ represents humidity constant (Kpa/°C), U_2 represents wind speed at a height of 2 m above the ground (m/s), T represents temperature (°C), e_{a}-e_{d} represents difference in saturation vapor pressure (Kpa), S represents soil heat flux (MJ/m^2/day), and Δ represents slope of the saturation vapor pressure curve (Kpa/°C).

FAO has recommended different K_{c} values for different growth stages of various crops. For the major crops in the study area, such as longan, bamboo shoots, bananas, and citrus, the collected and summarized K_{c} values are as follows. Longan and citrus have 0.83 and 0.85. The K_{c} of bamboo shoots and bananas is 1.9. and 1.1.

Meteorological data from the Sun Moon Lake station in 2018–2022 were used to estimate crop evapotranspiration. The crop coefficients of the crops and their estimated water requirements are shown in Figure 9. Bamboo shoots have the highest evapotranspiration, ranging from 3.35 to 6.99 mm/day, followed by bananas at 1.94 to 4.05 mm/day. Longan and citrus have water requirements of 1.46 to 3.06 mm/day and 1.5 to 3.13 mm/day, respectively.

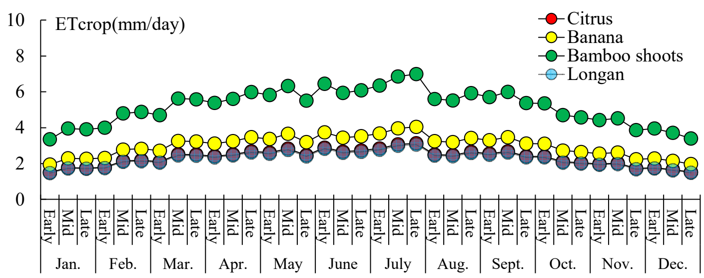

Figure 9. Distribution of crop water requirements for major crops in the study area.

5. Reliability Analysis of Water Supply and Demand

5.1. Exceedance Probability Method

The exceedance probability method is used to determine the value of hydrological data in a certain probability condition. It is commonly applied to rainfall, flow, and meteorological data to serve as a reference for related decision-making or planning. Ref. [24] defined the probability of an event occurring above a certain variable value as the exceedance probability. Let the probability density function of a hydrological variable, x, be (x). The probability of the event occurring between any value, x, and $x + dx$ is expressed as (x)dx. If x is plotted on the horizontal axis and frequency on the vertical axis, the exceedance probability (x) for values above x is the area under the curve from x to infinity (7). The non-occurrence probability above x is expressed as (8). The exceedance probability method used in this study modifies the vertical axis from frequency to exceedance probability to simplify the interpretation of hydrological quantities and their corresponding exceedance probabilities. A flow exceedance probability curve is then plotted to estimate the probability of a flow value exceeding a certain threshold.

$$W(x) = \int_{x}^{\infty} f(x)dx \quad (7)$$

$$S(x) = \int_{-\infty}^{x} f(x)dx = 1 - W(x) \quad (8)$$

where S represents catchment storage capacity (inch), P represents precipitation (inch), Q represents runoff (inch), and evapotranspiration is not considered in the equation.

5.2. Water Supply Rate

5.2.1. Irrigable Area and Water Supply Reliability

The irrigation water demand is derived from the water requirements of the four crops in Zhongliao Township: longan, citrus, bamboo shoots, and bananas. The actual water demand for each crop was calculated by multiplying the water requirement of each crop by its respective planting area. In the Fusheng channel catchment area, the catchment area is 1665 ha, with an estimated irrigable area of 18.49 ha. This area has the crop water requirement of the Fusheng channel, approximately ranging from 0.004 to 0.008 cms (m^3/s), with the lowest demand from late November to early February and the highest in mid- to late July.

The flow rate estimated by the SCS method for the Fusheng channel catchment area was estimated to balance between supply and demand (Figure 10). Surface water flow rates from early January, mid-February to early March, and May through late September met the crop water demand, achieving a water supply of 100%. However, in other months, surface water was lacking for the crop water demand, with deficits ranging from 0.004 to 0.007 (m^3/s). The largest deficit of 0.007 (m^3/s) was observed in late April. From early October to mid-December, the surface water flow is scarce, resulting in a reliability of 0% and indicating a period of severe water shortage.

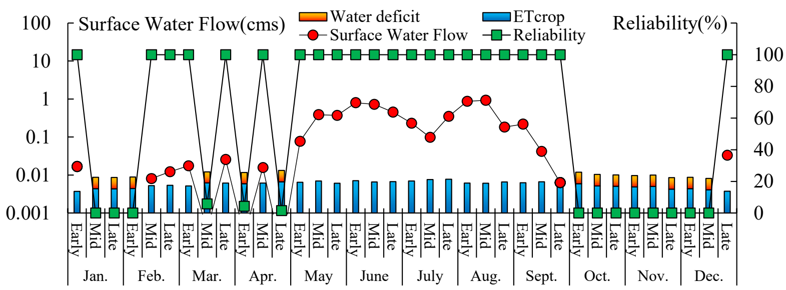

Figure 10. Reliability analysis of crop water demand and surface water flow.

5.2.2. Rainfall, Crop Water Requirement, and Water Supply

Effective rainfall, as a supplementary source for crop water supply, reduces dependence on surface water resources (Table 2). Without effective rainfall, the annual water demand for longan ranges from 49.8 to 91.3 mm, with July showing the highest demand (91.29 mm). When effective rainfall is included, the annual water demand for longan decreases to 0–56 mm, with June demand reduced from 80.7 to 0 mm, and the highest demand shifting to October (56 mm).

Table 2. Monthly water demands of different crops with and without accounting for effective rainfall.

Month	Longan		Citrus		Banana		Bamboo Shoots	
	*	**	*	**	*	**	*	**
Jan.	50.7	29.9	51.9	31.1	67.2	46.4	116.1	95.3
Feb.	55.5	35.9	56.9	37.3	73.6	54.0	127.1	107.5
Mar.	71.9	40.8	73.7	42.6	95.3	64.2	164.6	133.5
Apr.	74.2	32.7	76.0	34.5	98.3	56.8	169.8	128.3
May	79.5	17.5	81.4	19.4	105.4	43.4	182.0	120.0
June	80.7	0.0	82.7	0.6	107.0	24.9	184.8	102.7
July	91.3	18.4	93.5	20.6	121.0	48.1	209.0	136.1
Aug.	77.0	0.5	78.9	2.4	102.1	25.6	176.4	99.9
Sept.	74.6	28.8	76.4	30.6	98.9	53.1	170.7	124.9
Oct.	65.9	56.0	67.5	57.6	87.3	77.4	150.9	141.0
Nov.	55.9	41.9	57.3	43.3	74.1	60.1	128.0	114.0
Dec.	49.8	32.8	51.0	34.0	66.0	49.0	114.1	97.1

Unit: mm. Note: * Without accounting for effective rainfall; ** accounting for effective rainfall.

The annual water demand for citrus is 51–93.5 mm, with the peak demand in July (93.5 mm). Effective rainfall reduces the annual demand to 0.6–57.6 mm, with the highest remaining demand in October (57.6 mm). For bananas, the water demand without effective rainfall is 66–121 mm annually, peaking in July (121 mm). With effective rainfall, the demand decreases to 24.9–77.44 mm annually, with the highest demand in October. Bamboo shoots, without effective rainfall, have an annual water demand of 114.1–209 mm, with a peak in July. Effective rainfall reduces this demand to 95.3–136.1 mm annually.

Monthly crop water demand under effective rainfall, surface river flow from the Fusheng irrigation area watershed (Cukeng Stream), and irrigation water demand are shown in Figure 11. Surface water flow ranges from 0 to 0.659 (m^3/s). Without effective rainfall, regional crop water demand ranges from 0.004 to 0.008 (m^3/s), with the highest demand in July (0.0075 (m^3/s)) and the greatest water deficit in October and November (0.005 (m^3/s)), when surface water flow is nearly absent, resulting in the lowest reliability in these months at 0%. With effective rainfall, regional crop water demand reduces to 0.001–0.005 (m^3/s). The maximum deficit remains in October and November at 0.005 and 0.004 (m^3/s), respectively, with the lowest reliability still observed in July at 0%. However, including effective rainfall improves reliability in April, raising it from 86.09% to 13.91%.

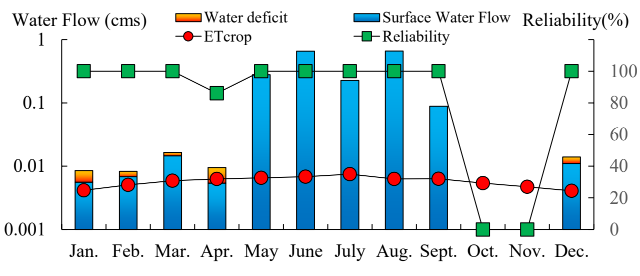

Figure 11. Crop water demand and surface water flow reliability analysis.

6. Irrigation Service Strategies and Feasibility Assessment

6.1. Planning

To improve the irrigation facilities for farmland outside the irrigation district, we evaluated and planned water supply and its solutions for the study area. The potential plans include updating and improving existing facilities, establishing new water intake points, planning water conveyance projects, designing irrigation system layouts, selecting locations for water storage sites, planning water storage facilities and regulation systems, and subsidizing field irrigation systems. Plans were made based on survey results, with overlaying hydrological maps and boundary maps to assess the proximity to available water sources in each subregion. In the terrain, appropriate planning of water storage facilities and irrigation system layout was conducted.

6.2. Review of Regulations and Procedures

Regulations and procedures related to land-use permits for related facilities, Irrigation Act, Water Act, Geology Act, Soil and Water Conservation Act, and Environmental Impact Assessment Act are categorized for land acquisition, land-use categories, application for river public land, application for water infrastructure construction, geological safety assessment, environmental impact assessment, and soil and water conservation.

6.3. Feasibility of Plans

The feasibility assessment of the engineering plans includes the evaluation of water supply reliability, storage capacity and ability, technical feasibility, cost estimation, land acquisition feasibility (including the feasibility of acquiring both public and private lands), benefit–cost ratio analysis, and project evaluation (including water source legality, supply cost analysis, annual benefits analysis, and funding strategies). Based on factors such as urgency, demand, and benefits, recommendations for phased and prioritized implementation plans can be proposed.

For water supply, an assessment must be conducted for the available irrigated area considering alternatives and backup water conditions and the variation between irrigation water supply and crop water demand. The evaluation of storage capacity and ability requires on-site investigation, integration of land ownership data, and pipeline planning to identify suitable storage facility sites. The technical feasibility of the engineering plans requires an on-site survey to propose relevant connection schemes and assess the advantages and disadvantages of the engineering techniques in each plan. The benefit–cost ratio analysis is used to assess the economic feasibility of the various water supply engineering plans.

6.4. Review and Recommendations

The current models for expanding irrigation services in Taiwan are as follows.

6.4.1. Model I

After the government conducts a feasibility assessment, funds are allocated sequentially for the construction of shared infrastructure with high costs. The funds are to assist local areas with the construction or upgrading of water extraction, storage, and transportation facilities for irrigation purposes. Upon completion, the infrastructure is handed over to local governments or community organizations for operation and management.

6.4.2. Model II

The government subsidizes farmers to install pipeline water-saving or smart irrigation systems on their farmland. This model focuses on the provision of subsidies for end-use irrigation equipment, such as water extraction facilities, storage facilities, or water-efficient irrigation pipeline systems for dryland farming areas owned by farmers. The farmers are responsible for the management and maintenance of these facilities on their own.

7. Conclusions

Water resources are critical in agriculture. In Taiwan, about half of the farmland still lacks a stable water supply, particularly in areas where the hydrological and geomorphological conditions are more challenging than those in regions with established irrigation management services. Therefore, if authorities set guidelines for investigation, planning, and design based on different locations or conditions, the implementation of expanded irrigation services can be accelerated across Taiwan, reducing discrepancies in planning quality among different regions and effectively achieving timely expansion of irrigation services. Then, agricultural production can be increased, the farmers' production conditions can be stabilized, and agricultural water supply infrastructures can be constructed. The water supply and demand planning for irrigation in typical water-scarce mountainous areas can be made based on the results of this study. The result also provides a reference for other countries or regions facing similar issues.

Author Contributions: Conceptualization: F.-W.C. and L.-C.C.; Methodology: F.-W.C. and Y.-W.T.; Software: Y.-W.T.; Data Collection: Y.-C.C. and Y.-T.C.; Validation: L.-C.C. and Y.-W.T.; Formal analysis: F.-W.C.; Investigation: H.-T.L. and Y.-C.C.; Data curation: Y.-C.C. and Y.-W.T.; Writing—original draft preparation: F.-W.C. and Y.-W.T.; Writing—review and editing: L.-C.C.; Visualization: Y.-W.T.; Supervision: L.-C.C. and Y.-W.T.; Project administration: F.-W.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are available in this manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Chen, F.W. Facing the Challenges of the Water Scarcity Crisis—Strategies for Water Resources Management in Taiwan. *Agric. World* **2021**, *456*, 6–18.
2. Nantou County Government. *Performance Evaluation Report for Phase I Project of Bagua Mountain Facility Ex-pansion*; Nantou County Government: Nantou, Taiwan, 2014. (In Chinese)
3. AERC (Agricultural Engineering Research Center). *Evaluation and Planning on Agricultural Excess Water Utilization of Bai-len Canal in Taichung County*; AERC-Research Report; AERC (Agricultural Engineering Research Center): Taoyuan, Taiwan, 2005.
4. AERC (Agricultural Engineering Research Center). *Assessment and Planning of Expanding Baileng Canal Irrigation Area in Xinshe District, Xiecheng Village, Touko Mountain Area*; AERC-Research Report; AERC (Agricultural Engineering Research Center): Taoyuan, Taiwan, 2020.
5. CRRB (Central Region Resource Branch, Water Resources Agency of the Ministry of Economic Affairs). *Review of Water Source Utilization in Tongxiao Area*; CRRB (Central Region Resource Branch, Water Resources Agency of the Ministry of Economic Affairs): Taichung City, Taiwan, 2006.
6. DWRT (Department of Water Resources). *Investigation and Planning of Irrigation Canals, and Development of Subsequent Maintenance and Management Measures in High Yang and Low Yang Irrigation Areas*; DWRT (Department of Water Resources): Taoyuan, Taiwan, 2018.
7. Huang, H.C. *Taiwan Farmers' Almanac, Revised 3rd Edition, Volume II: Perennial Fruit Trees.Banana*; Council of Agriculture, Executive Yuan: Taipei, Taiwan, 2005; pp. 9–18.
8. TARI (Taiwan Agricultural Research Institute, Ministry of Agriculture). *Good Agricultural Practice for Longan (TGAP)*; TARI (Taiwan Agricultural Research Institute, Ministry of Agriculture): Taichung City, Taiwan, 2020.
9. NCU (National Chiayi University). *Good Agricultural Practice for Citrus (TGAP)*; NCU (National Chiayi University): Chiayi, Taiwan, 2020.
10. LKAFT (Liu-Kung Agriculture Foundation). *Cultivation and Management of Green Bamboo Shoot*; LKAFT (Liu-Kung Agriculture Foundation): Taipei, Taiwan, 1996.
11. TDARES (Taoyuan District Agricultural Research and Extension Station, Ministry of Agriculture). *Good Agricultural Practice for Bamboo Shoots (TGAP)*; TDARES (Taoyuan District Agricultural Research and Extension Station, Ministry of Agriculture): Taoyuan, Taiwan, 2007.
12. TBRS (Tea and Beverage Research Station, Ministry of Agriculture). *Good Agricultural Practice for Tea (TGAP)*; TBRS (Tea and Beverage Research Station, Ministry of Agriculture): Taoyuan, Taiwan, 2007.

13. USDA SCS (USDA-Soil Conservation Service). *National Engineering Handbook. Section 4. Hydrology*; USDA-SCS: Washington, DC, USA, 1985.
14. Ponce, V.; Hawkins, R. Runoff Curve Number: Has It Reached Maturity. *J. Hydrol. Eng.* **1996**, *1*, 11–19. [CrossRef]
15. Hayes, G.I.; Buell, J.H. *Water and Our Forests: Trees Also Need Water at the Right Time and Place, Yearbook of Agriculture*; USDA: Washington, DC, USA, 1955; pp. 219–228.
16. USDA. *Irrigation Water Requirements, Technical Release 21*; USDA Soil Conservation Service: Washington, DC, USA, 1967.
17. Obreza, T.A.; Pitts, D.J. Effective Rainfall in Poorly Drained Microirrigated CitrusOrchards. *Soil Sci. Soc. Am. J.* **2002**, *66*, 212–221. [CrossRef]
18. Rahman, M.M.; Islam, M.O.; Hasanuzzaman, M. Study of Effective Rainfall for Irrigated Agriculture in South-Eastern Part of Bangladesh. *World J. Agric. Sci.* **2008**, *4*, 453–457.
19. Chen, S. A study on Water Management and Effective Rainfall in the Taoyuan Region of Taiwan. Ph.D. Dissertation, Hokkaido University, Sapporo, Japan, 1989.
20. Chen, F.W. Assessing Climate Change on Effective Rainfall for Agricultural Water Management. Ph.D. Dissertation, Department of Bioenvironmental Systems Engineering, National Taiwan University, Taipei, Taiwan, 2013.
21. Liu, Z.D.; Duan, A.W.; Xiao, J.F.; Liu, Z.G. Research Progress on Calculation Methods of Effective Rainfall in Growing Period on Dry Crop. *J. Irrig. Drain.* **2007**, *26*, 27–30.
22. Kassam, A.; Smith, M. *FAO Methodologies on Crop Water Use and Crop Water Productivity*; Expert meeting on crop water productivity. Paper No. CWP-M07; FAO: Rome, Italy, 2001.
23. Doorenbos, J.; Pruitt, W.O. *Guidelines for Predicting Crop Water Requirements*; FAO Irrigation and Drainage Paper 24; FAO: Rome, Italy, 1973.
24. So, M. *Applied Hydrology*; Department of Soil and Water Conservation, National Chung Hsing University: Taichung, Taiwan, 1992. (In Chinese)