

# A Case Study of Using Low-cost Siphon Equipment to Enhance Shorebird Foraging Habitats

## 利用低成本虹吸裝置改善岸鳥覓食棲地

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### Abstract

This study presents how to apply the siphon equipment, which is low-cost and low-carbon, to a dry salt pan in Taiwan to optimize foraging habitats for migrating shorebirds. The study area is situated in a subsidence zone with poor hydrological

facilities due to inadequate maintenance and long-term subsidence. Consequently, some salt pans have become completely dry or excessively flooded. As a key component, The siphon diversion equipment, was made by a 3-inch Polyvinyl Chloride (PVC) connecting pipes. Bird surveys were conducted before and after the water diversion. The results showed that during the experimental period from April 15 to April 21, 2022, the total volume of water diversion was approximately 2,788.5 m<sup>3</sup> in the Salt Pan 9-1 (area about 14 ha), providing suitable foraging habitats for migrating shorebirds. The siphon equipment was cost-effective, it cost only NT\$4,549 (around US\$150) in materials and took a single day for assembly. This case study shows comprehensive information on the environmental characteristics, fabrication process, operational procedures, and associated costs of the siphon water diversion equipment. The findings suggest that siphons can serve as a practical, low-cost, and environmentally friendly tool for habitat management under specific environmental conditions.

## 摘要

本研究描述一個低成本、低碳排的虹吸引水裝置，以其應用於嘉義布袋廢曬鹽田，用以改善遷徙鸕鶿的覓食棲地。研究地點位於一地層下陷、無引水設施，且面臨乾旱的鹽田。因鹽田剛好緊鄰潮溝，溝內水位高於鹽田底部，故運用虹吸原理進行引水。虹吸管根據重力和大氣壓力的物理原理來促進液體流動，本研究的虹吸水泵利用 3 吋的聚氯乙烯 (PVC) 水管組成。在引水前後進行鳥類調查。結果顯示 2022/4/15 - 4/21 試驗期間，在面積 14 ha 的 9-1 號鹽田引入水體積約為 2,788.5 m<sup>3</sup>，為遷徙鸕鶿提供適宜的覓食棲息地。該虹吸裝置成本為 4,549 新台幣（約 150 美元），材料費用和組裝時間為 1 天。本案例提供虹吸引水裝置的環境特性、製作方式、操作過程和相關成本的完整資訊。結果顯示在特定的環境條件下，虹吸可以是一種成本效益高、低碳的棲地管理工具。

Keywords: shorebird habitat, low-cost siphon equipment, water diversion

關鍵字：鸕鶿類棲地、低成本虹吸裝置、引水

## Introduction

The loss and degradation of natural habitats significantly threaten global biodiversity, particularly in coastal and near-coastal environments, which face severe development pressures (Halpern et al. 2019). The East Asian-Australasian Flyway, of which Taiwan is a part, has experienced some of the most rapid and extensive coastal habitat loss globally in recent decades (Murray et al. 2014; Duan et al. 2021). Consequently, waterbirds increasingly rely on artificial wetlands created or modified by human activities as alternative or supplementary habitats when natural habitats are reduced (Ma et al. 2004, 2010; Sebastián-González et al. 2010; Li et al. 2013; Fan et al. 2021). Appropriately improving habitats in suitable locations could alleviate the pressure on waterbirds' habitat loss.

Non-natural wetlands come in

different types, and their suitability or unsuitability for waterbirds can vary depending on their characteristics (e.g., depth, vegetation, surrounding land use) and location (e.g., geographic region, climate). However, once water becomes scarce or dries up entirely, these wetlands can no longer provide suitable habitats for waterbirds, or only a limited number of species can use them. Changes in water levels in the same wetland can also significantly influence the presence and abundance of different waterbird species or functional groups (e.g., waders, ducks, geese) using the wetland (Roshier et al. 2002; Ma et al. 2010; Gray et al. 2013; Wang et al. 2020). Therefore, when managing artificially created wetlands as waterbird habitats, adjusting water levels is often a crucial conservation measure (Cheek, 2009; Wang et al., 2020).

The United Nations Convention

on Biological Diversity's Kunming-Montreal Global Biodiversity Framework (GBF) includes restoring 30% of degraded global habitats as an important goal (access at <https://www.cbd.int/gbf/>). However, the actual implementation of the GBF's various goals faces global and local challenges, with the lack of funding being a major obstacle (Xu et al. 2021). Moreover, conservation actions that require large or long-term fossil fuel energy inputs and increase carbon emissions can conflict with addressing the global climate crisis. Thus, when designing habitat restoration measures, the optimal option within a suite of measures should be the least resource-intensive while avoiding increases in carbon emissions.

Since the Budai Salt Pans were abandoned in 2001, they have progressively evolved into a pivotal bird habitat in southwest Taiwan (Lin et al. 2023). Per the Taiwan New Year Bird Count, a citizen science project

initiated in 2004, the Budai Salt Pans are noted to harbor the highest concentration of waterbirds among over 170 sampling circles, each with a 3-kilometer radius, across Taiwan (Lin et al. 2023). Nevertheless, the hydrological infrastructure within these salt pans has been progressively deteriorating due to the combined effects of neglect post-closure and long-term subsidence (Wang et al. 2020). Consequently, several salt pans have completely dried up or maintained excessive water depth for prolonged periods, impairing their ability to facilitate water exchange.

This paper reports on a case study of the application of a low-cost, non-fossil fuel energy-based siphon diversion equipment in a dry salt pan, including the environmental conditions before its use, the design of the suction pump, and changes in species and numbers of waterbirds observed before and after its deployment.

## Methods

### Study Area

The study site is located along the southwest coast of Taiwan, spanning from 23°22'24.9"N to 23°18'39.1"N latitude and 120°08'57.9"E to 120°11'23.4"E longitude (Figure 1). The area is situated in a subsidence zone with an elevation lower than sea level ranging from -1.8 to -0.5 m (Kuo and Wang 2018). The region experienced an average annual of 1384 mm between 2018 and 2022, with the highest precipitation occurring from May to August, accounting for approximately 80% of the total annual rainfall (data collected from the Budai weather station of the Central Weather Bureau in Taiwan). The salt pans at the study site are characterized by a flat topography with predominantly muddy substrate, poor soil quality, and high salt content. During the rainy season (from May to October), the area accumulates water, while during the non-rainy season (from November

to April), parts of the area frequently experience drought due to evaporation and lack of water replenishment (Yeh and Tsao 2020).

### Siphon test

As a result of flood risk management measures implemented by the local authorities, the test site, Salt Pan 9-1 (Figure 1), frequently experiences several months of drought before the onset of the rainy season (Figure 2). For instance, the cumulative rainfall between January 1 and April 30 in 2021 and 2022 amounted to 34 mm and 343 mm, respectively. However, a significant rainfall event on April 23, 2022, accounted for 48% of the total rainfall from January 1 to April 30, 2022. During March and April, wintering waterfowl have typically departed the area, coinciding with the peak migration season for shorebirds. Therefore, increasing the water coverage of Salt Pan 9-1, which spans approximately 14 hectares, would be advantageous in providing suitable foraging habitats for

migrating shorebirds. The western side of Salt Pan 9-1 adjoins a tidal drainage system, and even during low tide, the water level remains higher than the flat areas of the salt pan, making it an ideal location for installing siphon diversion equipment. The equipment was installed on April 14, 2022, and pre-testing was conducted on April 15. The continuous water diversion started on April 16 at 10:00 a.m.

For this test, we selected 3-inch Polyvinyl Chloride (PVC) pipes considering the convenience of material handling and acquisition and the goal of maximizing water intake. Once the apparatus was installed, we used a Handheld 1-D electro-magnetic current meter (Model: AEM1-DA) designed for river use to measure the flow velocity at the outlet of the siphon tube. The water level in the drainage system used for water diversion remains relatively stable due to controlled water gate operations, resulting in minimal fluctuations during

regular times. Therefore, assuming that the water flow rate inside the siphon tube remains relatively stable during the experimental period. We conducted two measurements of the flow velocity of the siphon at the test site.

Subsequently, the flow rate was calculated using the formula  $Q = A \times V$ , where  $Q$  represents the flow rate in cubic meters per second ( $m^3/sec$ ),  $A$  denotes the cross-sectional area of the pipe in square meters ( $m^2$ ), and  $V$  represents the flow velocity in meters per second ( $m/sec$ ). The cross-sectional area of the pipe was calculated using the formula  $A = ID^2 \div 4 \times \pi$ , where  $ID$  stands for the pipe's internal diameter.

### Bird Survey

We adopted a before-and-after design to compare shorebirds' composition and behavioral differences at Salt Pan 9-1 before and after the water diversion. On April 8 and April 21, 2022, we conducted a complete count of the bird species and their quantities within

Salt Pan 9-1. Using a scan sampling method, we recorded the behavior of each observed bird at the moment of sighting to determine whether they were foraging. For example, probing of the bill into the water or mud by sandpipers, feeding on invertebrates by plovers, and foot-trembling behavior exhibited by plovers were considered valid foraging behaviors. We also utilized bird data collected on April 8, 2021, using the same methodology to present the composition and utilization patterns at Salt Pan 9-1 during two consecutive years of drought. Given that the primary objective of this experiment was to enhance the foraging function for sandpipers and plovers during their peak migration period, the comparison of species and quantities focused explicitly on Scolopacidae (sandpipers) and Charadriidae (plovers). We performed a chi-square test of homogeneity to determine if there was a significant difference in foraging proportions of the

sandpipers and plovers before and after the water diversion. Statistical analyses were performed with R packages (stats).

## Results

### Siphon Diversion Equipment

The siphon diversion equipment pump designed in this study is based on the environmental characteristics of the test site. Its main components and materials consisted of a 3-inch Polyvinyl Chloride (PVC) connecting pipe, extending from the water source to the drainage point. The water intake end was equipped with a 3-inch interface check valve that allowed water to enter but not exit, while the water outlet end was fitted with a 3-inch ball valve. At the highest point of the equipment, an extended fill pipe was connected to a 3-inch ball valve. Various connections and bends in the equipment incorporated a 3-inch PVC tee, three 45-degree bends, and a 90-degree bend, all made of PVC. The quantities and prices of the components

used in this experiment are presented in Table 1.

The purchased 4-meter-long 3-inch PVC pipe was cut into appropriate lengths for each section during assembly. After pre-assembly, the water intake section was positioned at the site, and necessary adjustments were made. Finally, solvent cement (PVC glue) was used to adhere to all connections securely. The installation of the siphon equipment was completed within a single day, and its proper functioning was confirmed (Figure 3).

At the commencement of the operation, ball valve B at the water outlet was kept closed while ball valve A was opened. Water was then introduced into the pipe until completely filled to serve as the siphon liquid, after which ball valve A was shut. This procedure ensured that the entire interior of the siphon pipe was filled with water. Following this, ball valve B was opened, permitting the liquid within the pipe to

flow out owing to atmospheric pressure. The resulting increase in internal pipe pressure triggered suction, causing the foot valve to open. Consequently, due to this elevated pressure, water from the channel was drawn into the siphon pipe, facilitating a continual water diversion.

#### Field test

Water diversion commenced on April 15, from 11:00 a.m. to 6:00 p.m. The continuous water diversion started on April 16 at 10:00 a.m. and lasted until early April 23. On that day, due to rainfall of 163.5mm in the Budai area, the water level within the salt pan rose by 10 cm, prompting the closure of the siphon pipe and ceasing its operation. During the water diversion period, there was a noticeable increase in the water coverage of Salt Pan 9-1 (Figure A1). In addition, we measured the flow velocity of the siphon at the test site. The average recorded velocity was 1.3 m/s. With a 3" PVC pipe diameter of 77 mm, the calculated average flow rates were

21.785 m<sup>3</sup>/h. From April 15 to April 21 (bird survey day), the total duration of water diversion was 128 hours, resulting in a total volume of 2788.5 m<sup>3</sup>. The surface area of Salt Pan 9-1 was approximately 140,000 square meters. Under the assumption of no leakage or evaporation, the total water diversion volume would lead to a water level rise of approximately 2 cm.

### Shorebird responses

There was a significant difference in the foraging proportions of sandpipers ( $\chi^2=254.6$ ,  $p<0.001$ ) and plovers ( $\chi^2=2178.5$ ,  $p<0.001$ ) before and after the water diversion. Before the diversion at Salt Pan 9-1 on April 8, 2022, eight sandpiper species and three plover species were recorded. Among the sandpipers, 575 (76%) were observed foraging, and 177 (24%) not foraging. For the plovers, 775 (29%) were observed foraging, while 1,936 (71%) were not foraging. On April 21, 2022 (seven days after the diversion on April

15, 2022), six sandpiper species and three plover species were recorded, and all individuals were observed foraging. The sandpipers accounted for 981, while the plovers accounted for 1,720 (Figure 4).

Before the diversion on April 8, 2022, the sandpiper species with more than 10% of the total population were ranked as follows: the Curlew sandpiper (44%), Red-necked stint (23%), and Broad-billed sandpiper (21%). Among the plovers, the Pacific golden plover (81%) and Mongolian plover (19%) were the two species representing more than 10% of the total population. After the diversion on April 21, 2022, the sandpipers with more than 10% of the total population were ranked as follows: the Broad-billed sandpiper (64%), Curlew sandpiper (13%), and Sharp-tailed sandpiper (10%). The Pacific golden plover (93%) was the only plover species representing more than 10% of the total population (Table 2).

In April, 2021, which experienced drier conditions compared to 2022, Salt Pan 9-1 recorded six sandpiper species, totaling 548 individuals. The majority consisted of 330 Curlew sandpipers and 114 Red-necked stints, accounting for 60% (328) of the observed sandpipers. Two plover species were observed with a total of 785 individuals, with the Pacific golden plover being the predominant species at 779. Only six Lesser sand plover individuals (0.8%) were observed foraging (Table 2). These findings indicate that Salt Pan 9-1 primarily serves as a resting site for plovers, especially the Pacific golden plover, under dry conditions.

## Discussion

This case study explores a salt pan habitat affected by drought, lacking water diversion structures. Despite limited funds, our management team identified a need for a foraging habitat for migrating shorebirds. We constructed siphon

equipment for 4,549 New Taiwan Dollars (around 150 USD) and assembled it in one day. This solution channeled water from nearby tidal drainage, creating a temporary foraging area for the birds. To our knowledge, this case represents the first documented instance in Taiwan of using a siphon for water management in a waterbird habitat. Our study details the habitat's characteristics, siphon construction, operation, costs, and the impact on sandpipers and plovers before and after the siphon's introduction.

Salt Pan 9-1 spans 14 hectares. When water was introduced, it mainly flowed to the southern and eastern lower areas of the pan. This increased wet or shallow water zones but mainly moistened the region. The very shallow water depth (less than 5 cm) allowed small sandpipers and plovers to forage easily. This change likely improved their foraging due to increased food availability within the salt pan, as studies suggest (Zhang et al. 2016; Wang and

Kuo 2018). The Pacific golden plover, for instance, typically rests during the day and feeds at night (Crawford and Herbert 2009). In past dry conditions, like on April 8, 2021, and April 8, 2022, Salt Pan 9-1 served as a daytime resting place for these birds. However, after the water diversion on April 21, 2022, there was a notable increase in foraging Pacific golden plovers (see Table 2). This change transformed Salt Pan 9-1 into a daytime feeding habitat.

Waterbirds exhibit remarkable mobility, and when suitable temporary habitats emerge within their primary distribution range or migration routes, they swiftly take advantage of the plentiful food sources, underscoring the significance of such stopover sites in their management (Roshier et al. 2002; Golet et al. 2018; Huang 2021). Nevertheless, it remains uncertain whether the rapid surge in food resources within Salt Pan 9-1 originates from the introduced water source or the rapid

proliferation of organisms. During the study period, sandpipers and plovers were at their peak migration season through the Budai Wetland. As a result, there were rapid fluctuations in bird species and occurrence numbers. Therefore, species composition may not be a good indicator to represent changes in food resources before and after water diversion.

Siphons have been long used for water management and irrigation due to their efficiency, low maintenance, and cost-effectiveness (Wichelns et al. 1997). For siphons to work, the water level at the inlet must be higher than the outlet. In our study, we designed the siphon tube with two closure methods: 1. Direct closure method: close ball valve B. This causes both valves A and B to shut and stops the water flow. The benefit is its ease of reuse by simply reopening valve B. The downside is valve B's potential location in muddy conditions, making it harder to access. 2. Air-entry method:

introduce air into the tube by opening valve A, which stops the siphon effect. This valve is nearer to roads, allowing quicker shutdowns in emergencies. However, before using the siphon again, it needs refilling. For equipment protection, close both valves during downtime. This keeps out organisms and reduces maintenance. To monitor water levels, a gauge can be added. This helps adjust water depths to attract various waterbirds. If the budget allows, adding more siphons can boost water diversion rates. While we used PVC for our siphon assembly, high-density polyethylene (HDPE) is also an option. HDPE joints are easier to assemble and disassemble, simplifying transportation and storage. Unlike PVC, which requires strong adhesive and is permanent, HDPE is more flexible. But, HDPE is significantly pricier than PVC.

The East Asian-Australasian Flyway, which includes Taiwan, has lost significant coastal habitats

recently. Taiwan's western coast alone has lost 60% of its natural mudflats in six decades (Wanjuan Chen, personal communication). This decline affects migratory waterbirds. As a solution, there has been a move towards wetland restoration and the use of artificial wetlands. While not perfect replacements, artificial wetlands can provide temporary refuges for these birds. Effective management of these habitats depends on understanding ecosystem needs, wildlife behaviors, and specific goals, especially in water level regulation (Gray et al. 2013). Practical challenges include budgetary and time constraints, while reducing carbon footprints remains crucial. Our study details an efficient water diversion technique for these artificial habitats.

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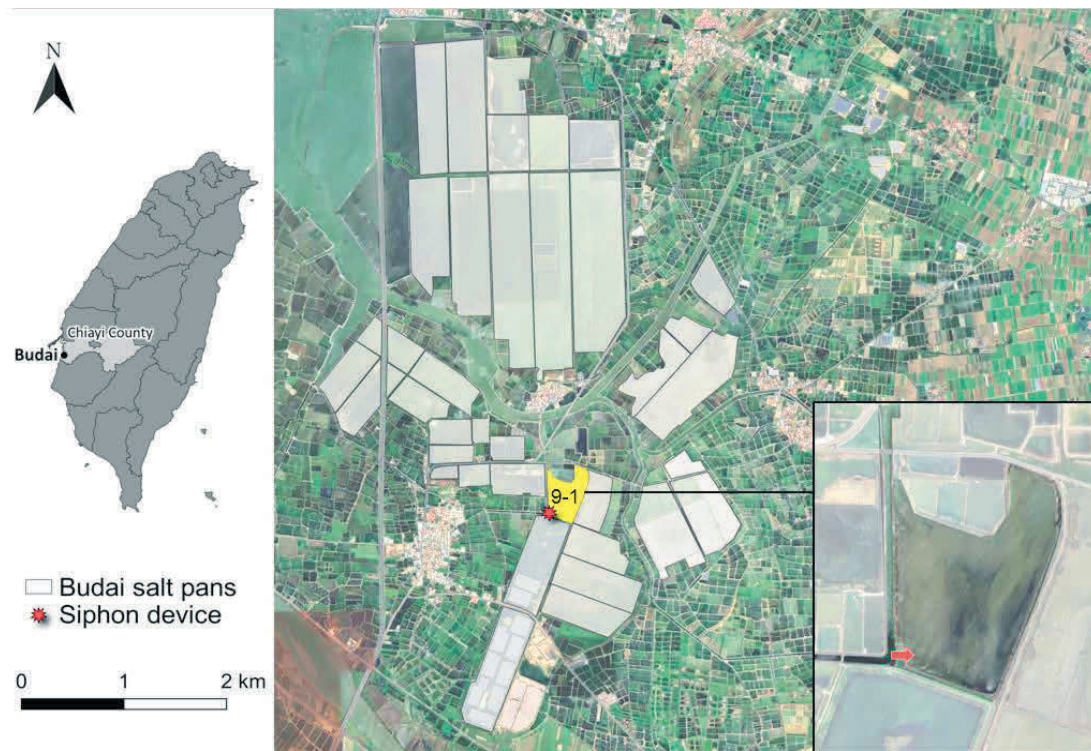


圖 1. 虹吸引水設施於布袋鹽田的設置地點 (Salt Pan 9-1)。

Figure 1. The location of the siphon equipment in Budai Salt Pans (Salt Pan 9-1).

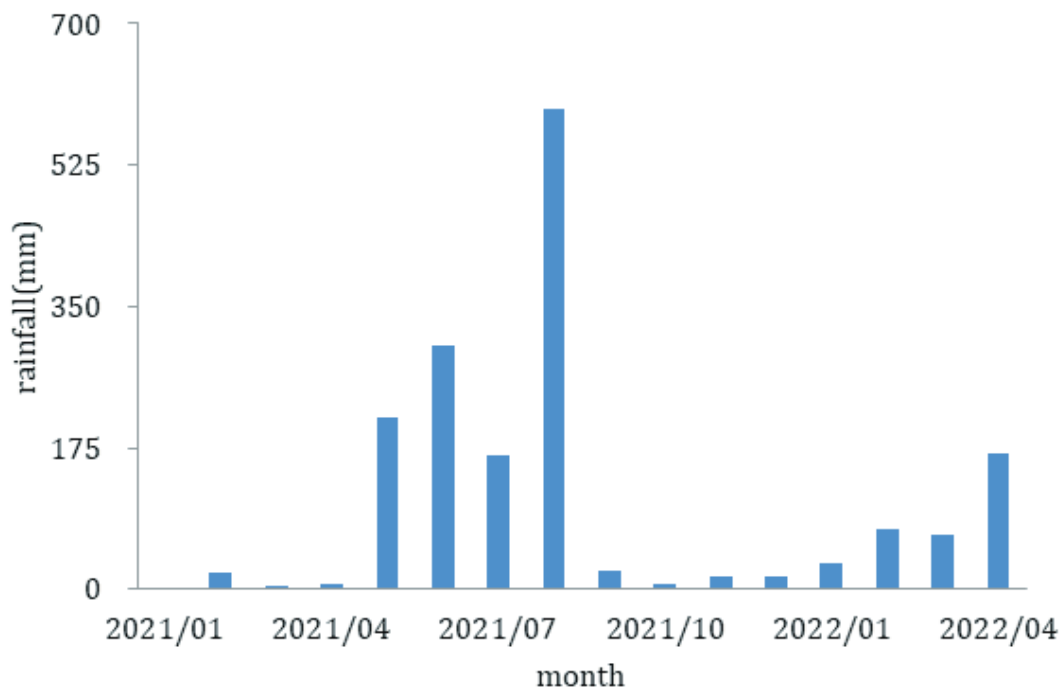


圖 2. 布袋氣象觀測站的月雨量 (2021/01-2022/04)。

Figure 2. The monthly rainfall of Budai weather station from January, 2021, to April, 2022.

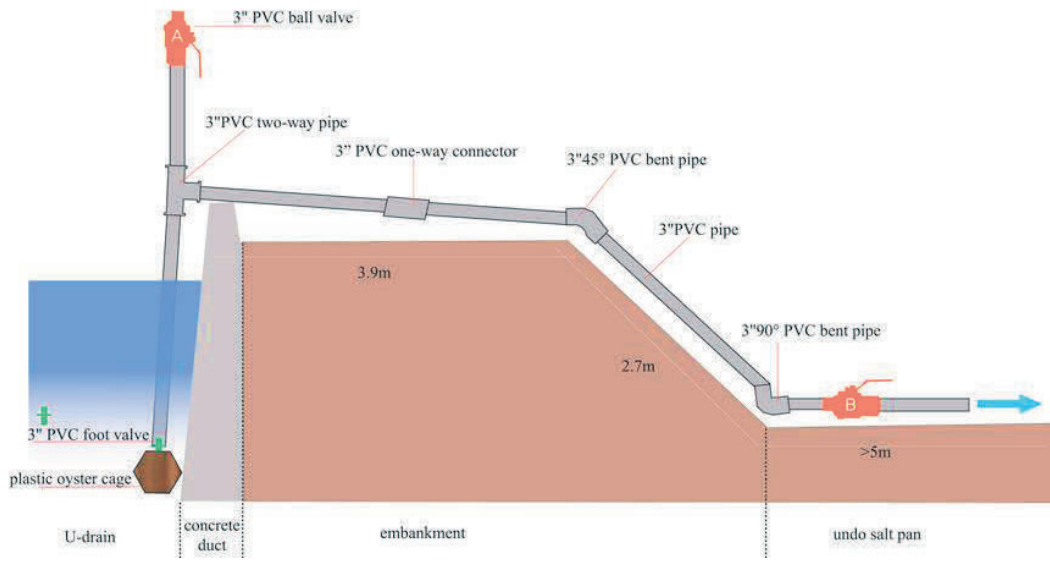


圖 3. 虹吸管設計圖與案場結構剖面示意圖。

Figure 3. The design of the siphon equipment and the schematic cross-sectional diagram of Salt Pan 9-1.



圖 4. Salt Pan 9-1 引水試驗前 (2021/04/08, 2022/04/08)、後 (2022/04/21) 鸕科與鴿科的數量變化。行為分為覓食與非覓食兩類。黑色線段代表引水當日 (2022/04/15)

Figure 4. The change in the number of Scolopacidae and Charadriidae before (April 8, 2021, and April 8, 2022) and after (April 21, 2022) the water diversion at Salt Pan 9-1. The behavior is divided into “foraging” and “non-foraging” categories. The black line represents the day of water diversion (April 15, 2022).

表 1. 本研究使用的虹吸引水設備組成零件的數量與價格 (新台幣)

Table 1. The quantity and cost (expressed in New Taiwan Dollars) of the siphon components utilized in this study.

Component	Unit price	Quantity
3-inches PVC pipe	400	4
3-inches two-way PVC pipe	210	1
3-inches 90-degree PVC bent pipe	128	1
3-inches 45-degree PVC bent pipe	104	4
3-inches PVC one-way connector	115	3
3-inches PVC ball valve	650	2
3-inches PVC foot valve	400	1
Plastic oyster cage	150	1

表 2. Salt Pan 9-1 引水試驗前 (2021/04/08, 2022/04/08)、後 (2022/04/21) 調查結果的鸕科與鴿科種類及數量。

Table 2. The species list and their number of Scolopacidae and Charadriidae in the survey results before (April 8, 2021 and April 8, 2022) and after (April 21, 2022) the water diversion at Salt Pan 9-1.

Date	Family	Scientific name	Common name	Foraging	Non-foraging
2021/4/8	Charadriidae	<i>Pluvialis fulva</i>	Pacific Golden-Plover	0	750
		<i>Charadrius mongolus</i>	Lesser Sand-Plover	6	29
	Scolopacidae	<i>Calidris ruficollis</i>	Red-necked Stint	94	20
		<i>Calidris alpina</i>	Dunlin	22	0
		<i>Tringa stagnatilis</i>	Marsh Sandpiper	46	0
		<i>Calidris acuminata</i>	Sharp-tailed Sandpiper	1	0
		<i>Tringa nebularia</i>	Common Greenshank	35	0
		<i>Calidris ferruginea</i>	Curlew Sandpiper	130	200
2022/4/8	Charadriidae	<i>Pluvialis fulva</i>	Pacific Golden-Plover	405	1800
		<i>Charadrius mongolus</i>	Lesser Sand-Plover	370	135
		<i>Charadrius alexandrinus</i>	Kentish Plover	0	1
	Scolopacidae	<i>Tringa stagnatilis</i>	Marsh Sandpiper	44	0
		<i>Calidris acuminata</i>	Sharp-tailed Sandpiper	10	0

		<i>Tringa totanus</i>	Common Redshank	1	0
		<i>Tringa nebularia</i>	Common Greenshank	14	2
		<i>Calidris ruficollis</i>	Red-necked Stint	73	100
		<i>Calidris alpina</i>	Dunlin	14	0
		<i>Calidris falcinellus</i>	Broad-billed Sandpiper	159	1
		<i>Calidris ferruginea</i>	Curlew Sandpiper	260	74
2022/4/21	Charadriidae	<i>Pluvialis fulva</i>	Pacific Golden-Plover	1613	0
		<i>Charadrius mongolus</i>	Lesser Sand-Plover	73	0
		<i>Charadrius alexandrinus</i>	Kentish Plover	34	0
	Scolopacidae	<i>Calidris falcinellus</i>	Broad-billed Sandpiper	627	0
		<i>Calidris ferruginea</i>	Curlew Sandpiper	132	0
		<i>Calidris acuminata</i>	Sharp-tailed Sandpiper	98	0
		<i>Calidris ruficollis</i>	Red-necked Stint	69	0
		<i>Tringa stagnatilis</i>	Marsh Sandpiper	38	0
		<i>Tringa nebularia</i>	Common Greenshank	17	0



附圖 1. Salt Pan 9-1 引水試驗期間的水域覆蓋度變化。(a) 2022/04/15: 引水試驗第 1 天。(b) 2022/04/21: 引水試驗第 7 天。

Figure A1. The change in water coverage during the water diversion period at Salt Pan 9-1. (a) April 15, 2022: the first day of the water diversion. (b) April 21, 2022: the seventh day of the water diversion.