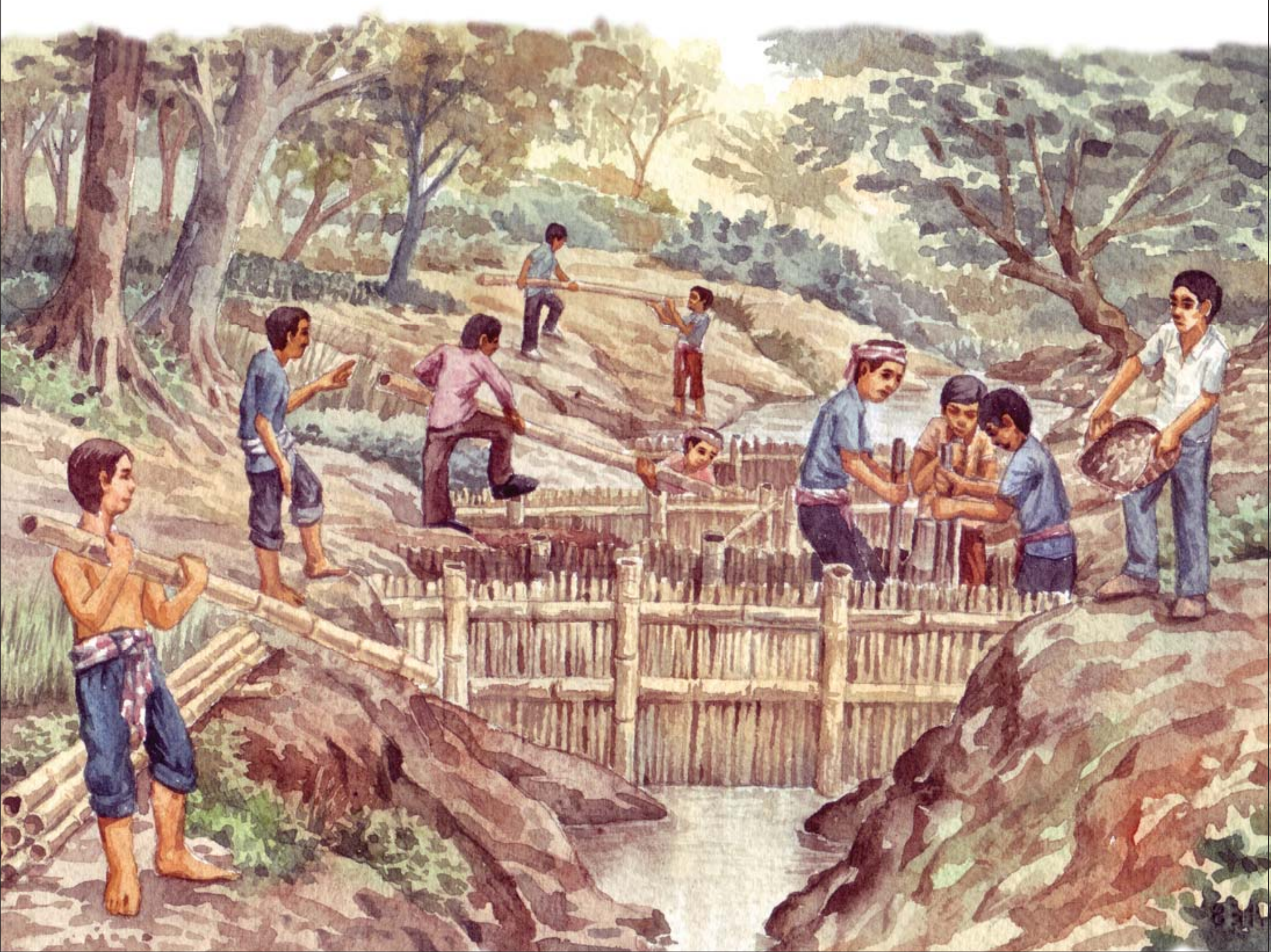
มูลนิธิแม่ฟ้าหลวง ในพระบรมราชูปถัมภ์
Mae Fah Luang Foundation under Royal Patronage

THE MAE FAH LUANG DEVELOPMENT MANUAL

Irrigation Management



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INTRODUCTION

THE IMPORTANCE OF WATER AND WATER MANAGEMENT

"...It is important that there be water for consumption, for household use, and for agriculture. Where there is water, there is life. You can live without electricity, but without water, though you have electricity, there is no life..."

Excerpt from speech by
His Majesty the King
at Chitralada Villa on March 17, 1986

His Majesty the King has emphasized water resource development and management for consumption and farming, as water is vital to living standards and agriculture. It has a direct impact on people's economic well-being as well as national security. With an efficient and well-supplied irrigation system and other factors such as soil, seeds, and the appropriate knowledge base, the farming communities that are the foundation for national food security and livelihood can survive. They do not need to take loans, sell their land, move to big cities to find jobs, and split up their families. Soil and forest resources would not be ruined by chemicals, and farmers would not be forced to adopt shifting cultivation practices. Therefore, good water resource development and management are among the key solutions for resolving socio-economic problems at their root. If successful, they can restore to small farmers their human dignity, conserve water resources, soil, and forests, and further strengthen human and natural capital for sustainable well-being in the long term.

On April 8, 2008, in reference to the King's speech on the global issue and the importance of water resource management, Privy Councillor Dr. Kasem Wattanachai reiterated the fact that there are two major problems in the world: climate change and food security. Such problems are not for one nation to cope with, but for everyone on this planet. With an increasing average temperature worldwide, sea water becomes warmer and harms aquatic lives which are a key source of food for human beings. With rise in sea temperature, water evaporates faster, making it easier for small ocean storms to escalate into larger, more powerful systems.

If we do not prepare in advance, the damage could be critical. With sufficient preparation, the crisis could be turned into opportunity because we could store more rainfall water with the Kaem Ling detention basin (Thailand Water management concept). Furthermore, we should study the flow range into the ocean as well as the possible water barrier patterns into the Mekong River, the Chao Phraya River, the Mun River, and the Chi River. If we could do this, we would have better opportunities than other countries. Furthermore, with proper irrigation management, we could have three farming seasons a year. In summary, with efficient water management, Thailand would have sufficient water to support farmers and be treated as one of the greatest food producers in the world.

The Meteorological Department and Hydro and Agro Informatics Institute (HAII) of Thailand, both running under the Ministry of Science and Technology, have found that in 2003-2007, the rainfall level in Thailand was impressive but the water storage capacity was disappointing. According to HAII, the average rainfall volume in 2002, 2005, and 2006 in the northeast of Thailand was 228,833 million cubic metres. However, only 6,134 million cubic metres of the total rainfall (2.7%) were stored. As a result, the areas which were affected by flood during the rainy season also suffered from drought during the dry season.

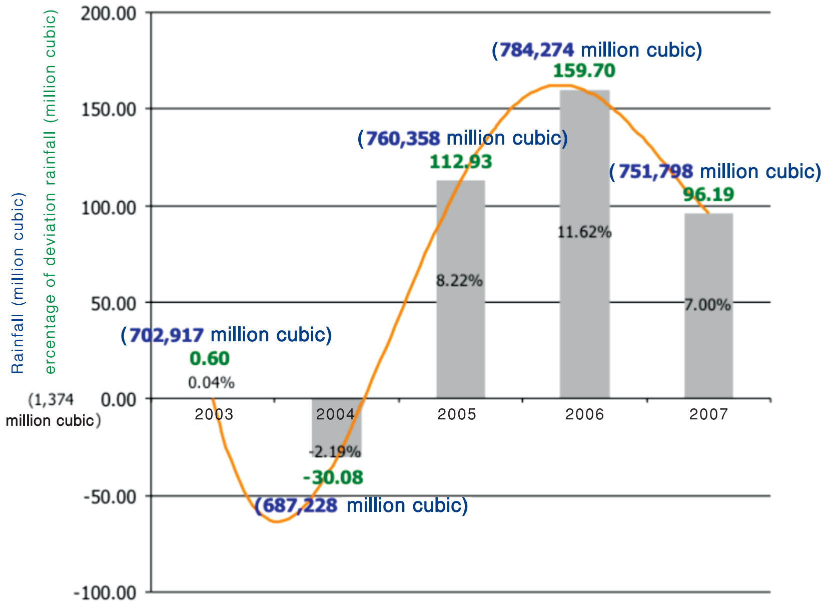

Table 1:

Rainfall volume and level in Thailand in 2003 - 2007

Source: Automatic weather station. Meteorological Department

Region	Rainfall (million cubic)	Rainwater Harvested (million cubic)	Percentage of Rainwater Harvested
Central and West	109,748	25,248	23
North	148,032	21,371	14.4
South	157,506	6,239	4.0
Northeast	228,883	6,134	2.7
East	61,657	644	1.0

Table 2:

Rainfall level and the average rainfall storage harvested in each region of Thailand in 2002, 2005, and 2006

Source: Hydro and Agro Informatics Institute (HAD), Ministry of Science and Technology

Irrigation Management according to the Mae Fah Luang Foundation

Although Thailand has abundant sources of water, many cities in the country are still facing water shortages due to a lack of appropriate knowledge and inefficient irrigation management within the community. To be specific, local people do not know what to do when there is erosion; when the public irrigation management system stops; or when the bureaucracy fails to provide an integrated water management system. A government agency might construct a reservoir within a community without irrigation ditches because that comes under another department's jurisdiction. In many cases, the irrigation project manager or legal framework even prevents the local communities from managing the water resource themselves. When an irrigation canal becomes shallow or blocked by debris, the community cannot fix it because it's illegal. The responsible government agency, meanwhile, also might not be able to take action due to their busy routine. As a consequence, nobody actually benefits from the reservoir, resulting in a loss of opportunity for the community to increase productivity. One example is Sakoen village, Yot, Sakoen village, Yot subdistrict, Song Khwae district, which has a large reservoir with capacity of 1.2 million cubic metres, large enough to irrigate a rice farming area of at least 1,090 rai[1]. However, with non-functional irrigation canals, the local people lost the opportunity to increase their productivity for a period of at least 10 years. If you translate that into financial value, calculating rice at 10 baht per kilogram, at 400 kilograms per rai over 10 years, the community lost an estimated 43.6 million baht. Considering that there are a large number of other non-functioning reservoirs throughout the country, the loss incurred is tremendous.

The Mae Fah Luang Foundation's water management model is based on field work conducted according to the royal initiatives of Their Majesties the King and Queen, as well as HRH Princess Srinagarindra, the Princess Mother. All of them focus on "understanding and accessing" the community's existing assets and potential, the government's past support and infrastructure, local wisdom as well as the community's attitude. All these elements are taken into account before a development plan is initiated to fulfil the community's needs and maximize their potential. The purpose of the concept is help the community maximise their benefits without any negative environmental impact. All in all, the essence of the royal principles is a fully integrated development system which takes into account all possible impacts that might be imposed.

The irrigation management process according to the Mae Fah Luang Model involves a survey of water demand for consumption and agriculture, available natural sources of water, storage capacity, water supply, distribution system, and the local water management framework. This data will be analysed in order to formulate an appropriate solution. The most important part of the process is community participation; the local people need to be engaged throughout the process, from the water system survey to finalising a solution for a water system that meets the local needs. This participation empowers them with knowledge on water system, pinpoints the causes of water shortages and guides them towards a solution. So as to be practical for the local people, the approach and processes have to be simple, cost-effective and practical, so as to be less dependent on external support.

In the compilation of this manual, all team members, including fieldworkers, data providers, interviewers, content analysts and writers, compilers, proofreaders and editors, have adhered to His Majesty the King's principles of good teaching or knowledge transfer: 1) to teach or

[1] One rai of rice field requires 1,100 cubic metres of water for one growing cycle

transfer pure knowledge without inserting personal biases or beliefs, and 2) to teach or transfer knowledge to the best of his/her ability, without fear of being overshadowed by his/her students (Kanok Wongtrangan, June 12, 2010).

This handbook provides a practical guideline based on years of experience. However, successful learning occurs when theory is put into practice with careful and thorough consideration. The outcome from this practice, either good or bad, can be a great lesson that further improves the quality of work. Should operational problems arise that cannot be solved with this technical manual, a review of the socio-economic environment of the target area has to be conducted, and solutions devised through the use of logic and reason, based on the common benefit of the people as the underlying principle.

In conclusion, despite the principles and methodology provided in this manual, practitioners who take action and lead individuals or communities in water management endeavours need to have the proper qualifications of a social development worker[2].

Editorial Team

[2] Further details can be found in the Mae Fah Luang Foundation's Development Manual series: Building a Development Team in the Target Area.

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(01)
WATER SYSTEM SURVEY

1. Preparation prior to water system survey

1.1 Survey tools

1.1.1 Map with the scale of 1:50,000, 1:10,000, or 1:4,000. Available at the Royal Thai Survey Department or Royal Irrigation Department, Department of Lands, or any provincial forestry office.

1.1.2 Global positioning system device (GPS)

1.1.3 Measuring tape

1.1.4 Camera

1.1.5 Pen

1.1.6 Notebook or field notebook

1.1.7 Calculator

1.1.8 Computer (should be a portable computer for convenience)

1.1.9 Mapping software (if any) such as MapSource, ArcGIS, etc.

1.1.10 Internet connection

1.1.11 Vehicle for entering the site

1.2 Collecting topographic data

Collecting basic topographical data of the area helps determine the scope of the target survey area, the availability and quality of water sources, and the estimated timing needed for the survey, based on the data and maps from the Royal Irrigation Department and Meteorological Department. The following data needs to be collected:

1.2.1 Scope of the site: To be clearly demarcated on the map

1.2.2 Scope of the catchment basin[3]: Determined by drainage divide[4]

1.2.3 Watercourse: Surveying the watercourse - usually shown as blue lines on geographical map - indicates the feasibility of the water development program. A higher number of watercourses indicates a better chance for a successful water development program, while a low number of watercourses indicates a limited chance of success.

1.2.4 Altitude from sea Level: This refers to the contour line of the site showing the highest and the lowest points of the area. Streams on steep slopes will discharge water faster than gentle slopes, so the information will help in designing the best weir or reservoir and irrigation system for the target area to suit the local topographical conditions.

1.2.5 Rainfall volume: Collect statistics of the rainfall volume going as far back as possible to estimate the volume of water at surface level[5] and the average rainfall of the area.

1.2.6 Transport route: Knowledge of the transport route of the target are, including the distance from the entry/exit points, will help you plan your trips to the site. If the location is far from the main road, a temporary shelter should be prepared mid-way to save travelling time.

1.2.7 Landmarks: It is also necessary to know several landmarks in the area such as villages, temples, and schools that can be used as reference on the map, as well as meeting points for project coordinators, community surveys, or temporary offices or accommodation to coordinate with other agencies.

[3] The area surrounding a drainage divide. Catchment basin is an area of land that collects rain water which flows down from the main stream in the area.

[4] A line on the top of the mountain which parts the rainfall into streams and rivers.

[5] The water surface level in streams from the end of the rainy season until the beginning of the next rainy season

1.3. Survey Team Composition

1.3.1 Water survey experts[6]: The water survey experts should possess the knowledge and ability to perform a water survey and have extensive planning and management experience. He/She must be able to offer advice on water system maintenance, water usage efficiency, and possess the ability to transfer the knowledge to the local communities. The development team may find such a qualified expert from the Royal Irrigation Department or Department of Water Resources.

1.3.2 Community leaders or local representatives: This includes sub-district headmen, village headmen, or members or representatives of the Subdistrict Administrative Organizations (SAO). The local team members receive information on the project and coordinate with the locals. There should be at least 2 local members on the team, so they can discuss and verify the collected data together.

1.3.3 Personnel from water-management agencies or practitioners in charge of the area: The personnel should come from main governmental agencies such as Royal Irrigation Department, Land Development Department, Royal Forest Department or local administrative organizations such as Subdistrict Administrative Organizations (SAO), Municipality Office (particularly civil engineers). At least one representative from these organizations should participate in the program to establish a mutual understanding of the project.

1.3.4 Local residents who are familiar with the local routes and watercourse: These local residents are responsible for escorting the team to appropriate water sources. There should be at least 2 locals so that both of them can discuss and verify the data together.

1.3.5 Local volunteer: One local volunteer should be responsible for cutting down the grass or bushes that block the survey routes.

[6] Refers to government officials' level in the Royal Irrigation Department which is equivalent to the rank of 6-7

1.3.6 Program staff: One program staff who should be able to use GPS devices and pinpoint reference points on the corresponding map. His/Her responsibility is to monitor the survey team and collect relevant typographical data such as dry season water, water sources, reservoirs, and current water supply systems as part of the assessment of water sources.

1.4. Establishing Survey Plan

After an initial preparation, the team is advised to establish the water survey plan by considering the following factors:

1.4.1 Survey time: The suitable time for water survey is from the end of rainy season until the beginning of the next rainy season. This enables the survey team to gather precise information on actual stream flow volume from the water source without intervention by additional rainfall.

1.4.2 Zones: Target survey areas should be zoned according to individual headwaters or tributaries

1.4.3 Surveying order: Survey should be firstly conducted in locations where streams have a year-long water flow or greatest water volume, then at streams with less water volume. For example, start with streams that have a 9-month flow period followed by those with a 6-months flow duration.

After completing the survey plan, the team should discuss the data and the survey plan with the local people who need to review the data and confirm the appropriateness of the survey plan. The most important part of this process is to ensure that the villagers understand the purpose and value of the survey and approve or even participate in the initiative. With a complete data preparation, the team should arrange the survey date and time with the locals before launching an actual assessment.

2. Conducting water system survey

The survey methods under Mae Fah Luang Foundation's principles are categorized into 2 groups: Survey approach for areas with an existing water supply system, and for areas without. Both categories can also be further divided by the purpose into 1) consumption-oriented or 2) agriculture-oriented. Water for consumption has to focus more on hygiene than for agriculture. The location and structure of both types of water storage are also different and thus different survey approaches are required.

2.1 Surveying methodology for areas with an existing water system

The field team needs to gather data on all available water resources in the area, including reservoir, water tanks, and local water storages. The team should also assess the water distribution system, water supply system, and the existing irrigation system to analyse the cause of water shortages. If the problem is caused by ineffective system, the team should decide whether to have it fixed or reconstructed, taking cost-effectiveness into account. However, if the problem is due to insufficient resources compared to the current demand, the team should consider exploring new water resources.

2.1.1 Consumption-oriented water survey consists of the following steps:

Examine current water sources

1) Examine the condition of the existing community water reservoir.
2) Examine the condition of the water distribution system as well as the public water provision. The survey team should do that by reviewing water pipes and plumbing fittings. If they are found damaged, decide whether they can be fixed.
3) Examine water storages in the community such as water tanks. Identify the total number of available tanks as well as the total capacity.

4) Measure water volume discharged[7] into the local water storage.

5) Examine the community water supply. This refers to an assessment of water distribution system from the local storage into households. The survey team should review water pipes and plumbing fittings. If they are found damaged, decide whether they can be fixed.

6) Identify whether the current water system serves purposes other than consumption. If so, then how much, such as how many agricultural fields receive water that has been supplied by consumption-oriented storage tanks?

7) Identify the existing community water management framework and examine its nature.

Diagnose problems

8) After completing the initial survey, the team should identify the cause of consumption water shortages in the community.

- If the analysis points out that the water storage is sufficient but the supply does not meet the local demands, the team should discuss the cause with the local residents and the local committee. Some of the possible root causes are excessive water usage, water committee is too lenient, poor discipline in water usage. When the cause has been pinpointed establish a solution with the community members.
- If the analysis points out that the water storage is insufficient, then further surveys should be carried out with the local participation. The new data will be used to develop new water sources, and build a new water system that suits the local geographical constraints and water demand.

[7] See "Measuring water resources withdrawal" on page 21

2.1.2 Agriculture-oriented water survey consists of the following steps:

Examine current water sources

1) Measure the actual volume of all water in dams or reservoirs. Check the conditions of the reservoirs; whether there is any sediment blocking the distribution channel or if any fixing is required.
2) Examine the condition of the irrigation system for agriculture. This includes the condition of water ditch, and whether any repairs are needed. The distribution point should be reviewed to see whether it allows efficient water distribution to all targetted agricultural fields.
3) Review the existing water distribution system to determine how much it covers — how many rai, how many plots, how many farms, and find the ratio to the total available water storage. This will help determine whether to repair the existing reservoir and distribution system to expand coverage of agricultural land, or to build a new reservoir in the same area.
4) Examine existing local water administration/management schemes, if any.

2.2. Surveying methodology for areas without an existing water system

If the community does not have a water system, the objective of the survey is to assess the feasibility of constructing a new water supply. The following steps should be taken:

2.2.1 Examine the catchment area: Use a GPS device to measure the altitude, location and scope of the catchment area.

2.2.2 Record data on the map: Mark relevant reference points on the map to determine the boundary of the catchment area.

2.2.3 Zoning: The survey team should investigate the catchments by topographical order, starting with

1) Areas on the same mountain slope
2) Areas adjacent to target area
3) Areas which share the same headwaters or tributaries

2.2.4 Examine the feasibility to establish a new water system by taking the following factors into account:

1) Which sources of water can be diverted into the local storage system
2) The total volume of water at each source
3) The potential coverage of target areas for the available water supply from each source.

3. Post Water System Survey

3.1 Planning the construction of the water system

After collecting all data, the survey team should validate the data before finalising the construction plan by considering the following:

3.1.1. In which areas should a new water system be constructed?

3.1.2. In which areas should the existing water system be repaired, and how?

3.1.3. What kind of distribution system should be adopted - canal or pipe system?

3.2. Factors to consider when constructing a new water system

3.2.1. Target areas to benefit from the water supply should correspond to available water sources. For instance, if Village A's demand is 100 rai and the Source B can only supply 50 rai, the team has to find an additional source to supply the other 50 rai.

3.2.2. Water supply should be evenly distributed to all stakeholders. Farmers whose lands are at the end of the distribution system should also benefit from the water supply.

3.2.3. Water should be harvested or stored above the entry to the reservoir to ensure that discharged water is replaced. This can be done by building conservation check dams and forestation to maintain a balance between water consumption and conservation. The concept of sustainable water management should be instilled from the beginning of the project.

3.2.4. Apart from establishing the water consumption rules within the community, it is also advisable to encourage the community to establish regulations for the conservation and maintenance of the system for an integrated and sustainable water management program.

(02)
MEASURING WATER RESOURCES WITHDRAWAL

1. Definition and objectives of water withdrawal measurement

Water resources withdrawal is defined by calculating the amount of water discharge at a certain location to determine the amount of water available e.g. the total capacity of a reservoir, or the amount of water that flows through a stream or creek. The data is crucial in determining an appropriate irrigation structure, and help practitioners statistically assess the success of the program by comparing the water volumes before and after a development initiative.

Water withdrawal can be measured using three different tools: buoy, V-notch check and measuring container. Each tool has different applications.

The choice of tool depends on the expanse of water to be measured:

1.1 For streams over 1.5 m wide and over 30 cm deep, use the buoy.

1.2 For streams less than 1.5 m wide and less than 30 cm deep, use the V-notch check.

1.3 For a very small streams with small trickles of water where it is impossible to use any large measuring equipment, use a measuring container.

These three tools can be made from local materials such as bamboo or plastic buckets. The method is simple, and can be taught to others easily.

2. Measuring water withdrawal with a buoy

2.1 Equipment

2.1.1 Measuring rod or ruler

2.1.2 Clock with timer

2.1.3 Metal measuring tape

2.1.4 Notebook

2.1.5 Pen

2.1.6 Buoy: There are three types of buoy used in this approach;

1) Floating buoy: This type of buoy can be made of any locally available materials. When floated, however, the buoy should be partially submerged, so as to prevent inaccuracy due to the effect of wind. The buoy method is the simplest and most convenient method of measuring water assets.

   Here are samples of floating buoys:

   - Processed wood, cut into 4 in cubes, and tested for proper buoyancy.
   - Plastic containers such as a half-filled water bottle so that it is partially submerged when dropped into the stream.
   - Dry logs found in the area, and tested for buoyancy.

2) Submerged buoy: This type of buoy can be made by tying two objects together; one that floats and another that sinks to weigh down the floating object. The sunken object must be bigger than the floating one. A balance has to be found between the two; if the sunken object is too heavy, the floating one will also sink. The anchor line which ties the two objects together must be 0.6 of the depth of the water. For example, if the river is 1 metre deep, the line must be 60 centimetres long.

3) Upright buoy: This type of buoy is made up of a vertical object such as a bamboo tube or a wooden stick weighted on the end to keep the buoy upright.

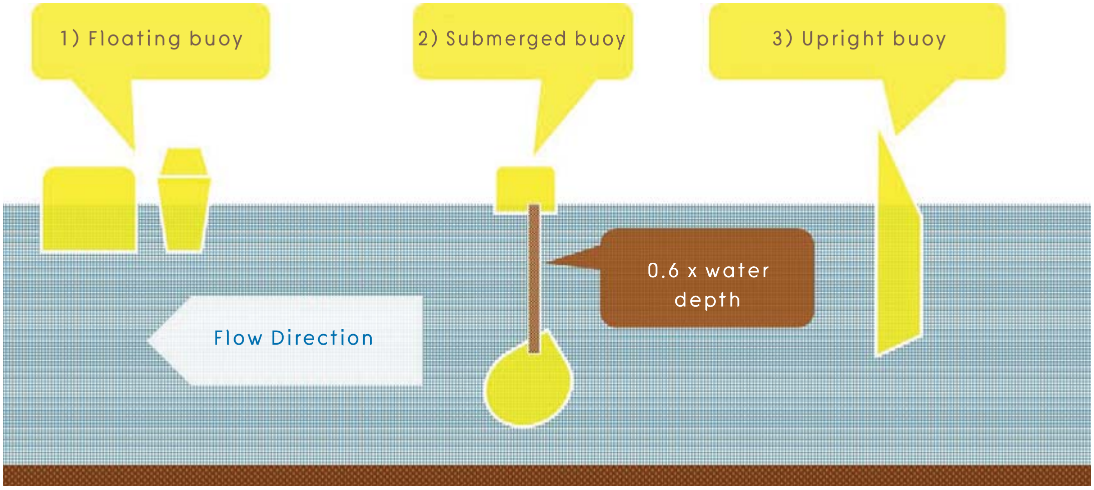


Figure 1:
Three types of buoy

2.2 Calculation method

Calculating water withdrawal with buoys means measuring the downstream velocity and multiplying it with the cross section of the stream which is targeted for measurement. The following equation is used:

$$Q = A \times V$$

Q refers to water discharged (in litres or cubic metre/second)

A refers to the cross-section of the stream (in square metre)

V refers to velocity of water (in metre/second)

2.2.1 Calculating the cross-section area (or A)

1) Select the area in which water discharge needs to be measured. The suitable area should have the following attributes:

- The stretch of water must be straight.
- The streambed must be stable and even. There should be no weeds on either bank since this may affect the accuracy of the measurement.
- The length of the stream should be not less than 20 metres to achieve the most accurate timing figure, and for convenience in taking multiple measurements to find the average value.

Figure 2:
Using a metal measuring tape to calculate the cross-section of a river.

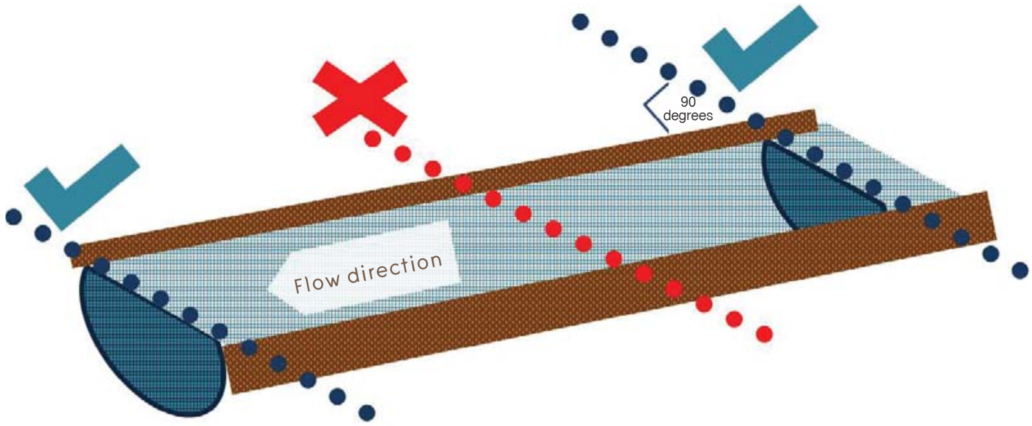


Figure 3:
The correct angle of measuring
the width of the stream

2) Place a measuring tape across the stream at a right angle to the river bank.

3) Evenly divide the tape into four equal lengths and mark them with a pencil. The finer the scale, the more accurate the result.

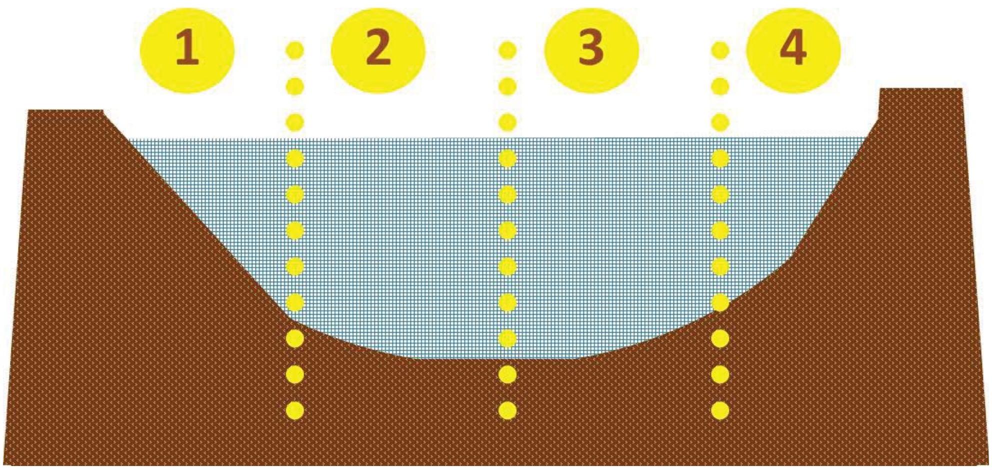


Figure 4:
The figure shows how to mark the measuring tape into equal sections.

4) Vertically anchor a metal rod, ruler or a bamboo stake into the stream at the marked points, perpendicular to the water surface.

5) Use a measuring device with the units in metre, centimetre, and millimetre to measure the depth of streambed at different points. The depth should be measured from the streambed to the water surface.

Figure 5:
Anchoring wooden rods to measure the depth of stream.

6) Record the following data:

- Name of the stream
- GPS reference points and height above sea level
- Date, time, and location of the survey
- Distance between each point as well as the depth of the stream at each point. Draw a cross-section image of the stream to enter each data item.

7) Calculate the total cross-section area of the stream by:

- Calculate the cross-section of areas nearest to the bank which resembles a triangle (areas 1 and 4 in illustration) using the formula to find the area of a right triangle (1/2 x base x height). The result should be expressed in m^2.

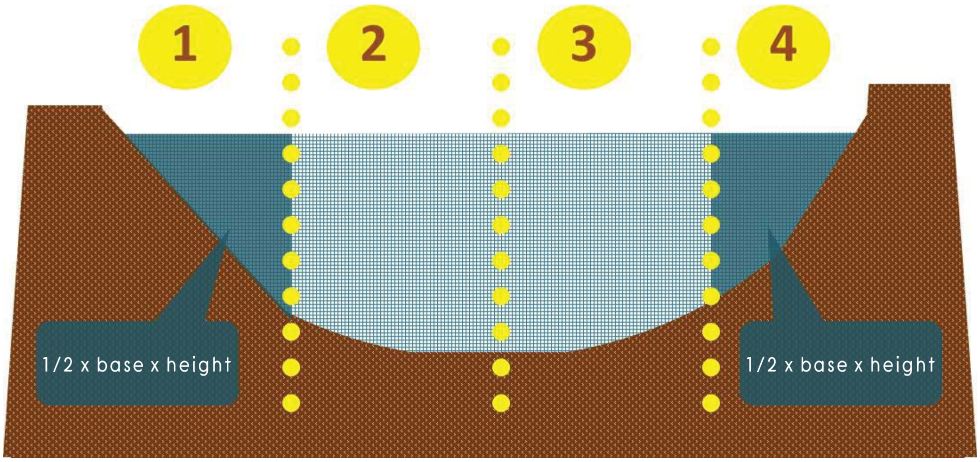


Figure 6:
Calculating the cross-section areas
nearest the stream bank

- Calculating the cross-section of other sections (areas 2 and 3). Use the formula for finding the area of a quadrangle.

$$\frac{\text{Sum of top and bottom width}}{2} \times \frac{\text{sum of depth of both sides}}{2}$$

The result should also be expressed in m^2.

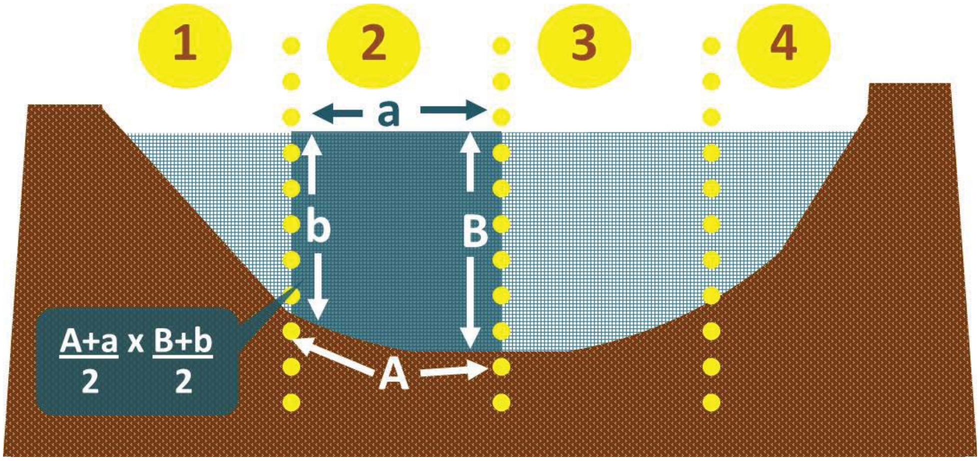


Figure 7:
Calculating the cross-section area using
the formula for finding the area of a quadrangle

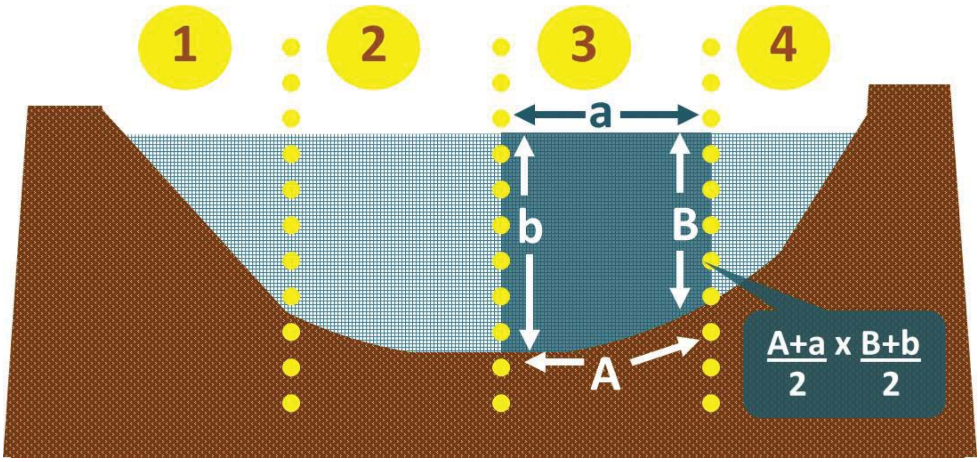


Figure 8:
Calculating the cross-section area using
the formula for calculating the area of a quadrangle

8) Combine the value of each sub-cross section to find the total cross-section area of the stream. In the illustration, we combine 4 sub-cross-sections (Area 1, 2, 3, and 4) to find the total cross-section area of the stream. The result is expressed in m^2 and is equivalent to value A in the equation.

A = Section 1 + Section 2 + Section 3 + Section 4

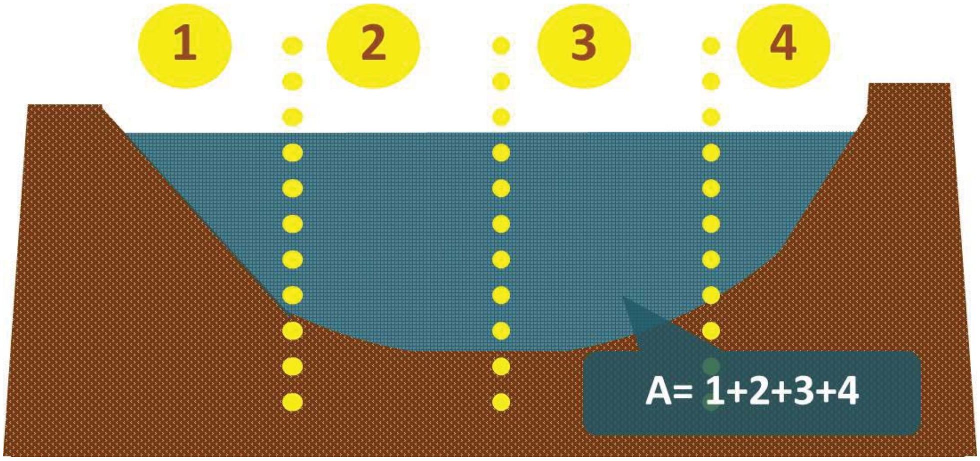


Figure 9:
Combining all sub-cross-section area to calculate
the total cross-section area of the stream.

2.2.2 Finding the water velocity (V)

1) Define the start line which should be 20 metres upstream from the cross-section area (value A).

2) Define the buoys' release points. There should be at least 3 points; one near the left bank, one in the middle of the stream, and one near the right bank. If the stream is wider than 4 metres, then 4-6 release points are recommended.

3) Float the buoy at the defined point, by releasing it not less than 2 metres upstream from the start of timing point to allow the buoy to catch the current.

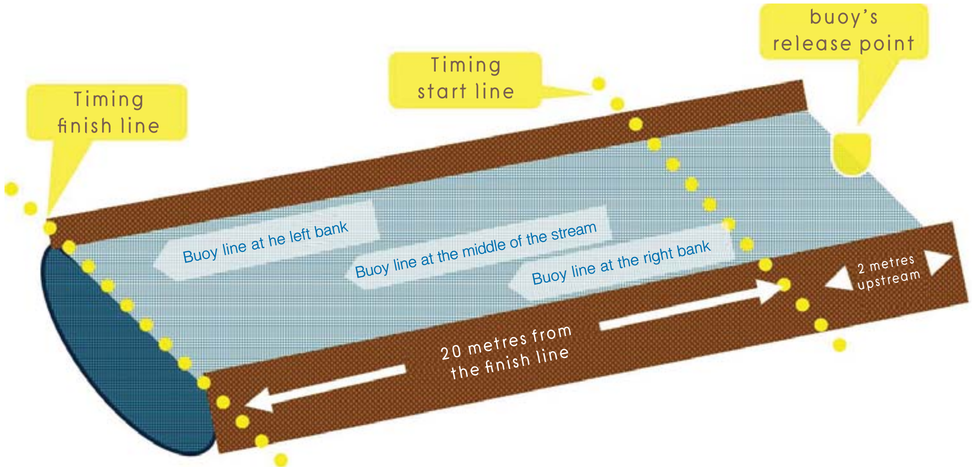


Figure 10:
The figure shows a start of timing line
and buoy's release point

4) Start timing when the buoy reaches the start line and stop when the buoy reaches the cross-section area (Value A). Record the time and bring the buoy back to the start line to re-float it again at different release point.

5) Combine the timing of each release and divide the sum with the total number of releases to calculate the average velocity in downstream direction (V). The equation should be as follows.

$$\text{Avg V} = \frac{\text{(Velocity at line1+Velocity at line2+Velocity at line3}}{3}$$

When the average V is obtained, calculate the V using the following formula:

$$\text{(m/sec)} = \frac{\text{(Distance between start line and finish line (m)}}{\text{Average V(sec)}}$$

2.2.3 Multiply Q (volume of water flow) by coefficient8

Before applying Q in other equations, it is important to multiply Q with the corresponding coefficient. Each type of buoy has a different coefficient as follows:

1) For floating buoy: multiply Q by 0.85
2) For submerged buoy and vertical buoy: multiply Avg V by the respective coefficients in the table below, and apply the V to to the equation.

d/D	0	0.5	0.75	0.9
Coefficient values	0.85	0.92	0.95	1

Table 3:
Coefficient values

2.3 Example of how to calculate water withdrawal with buoy

A stream has the cross-section area (A) of 1.43 square metres and the average water velocity (V) is 0.25 metre/second.

$$Q = A \times V$$

$A = 1.43\ m^2$ $\quad V = 0.25\ m/sec$

Therefore $Q = 1.43 \times 0.25 = 0.3575\ m^3/sec$

The result should be multiplied by the coefficient of flow on the water surface, the bank and mid-stream which equals to 0.85. This is the value for calculating with the floating buoy because water velocity on the surface is higher.

Q = 0.3575 x 0.85 m^3/sec

Q = 0.3038 m^3/sec

(Use 4 decimal points for better accuracy)

If you want to know how much water flows through this point per day, use this equation:

60 (sec) x 60 (min) x 24 (hr) x 0.3038

The water discharge of this stream = 26,248.32 m^3/day.

Remark: The values in this calculation apply only on the time and date of survey. If measured other time, the result will be different depending on the rainfall volume, temperature, and condition of the watershed forest.

2.4 Notes on calculating water withdrawal using floating buoy

2.4.1 If there is any incident that affects the velocity timing, such as if the buoy gets stuck at the bank, or gets caught in an eddy or veers off-course by strong winds, the timing needs to be redone.

2.4.2 If one of the velocity readouts appears to be significantly different from the others, such readout may be deleted.

2.4.3 The floating buoys approach is not appropriate on a rainy or windy day because the A and V values will be distorted.

3. Measuring water withdrawal with V-Notch check

3.1 Equipment

3.1.1 One plywood plank 50 cm (width) x 120 cm (length) x 1 cm (thickness)

3.1.2 One hardwood plank 2 cm (width) x 120 cm (length) x 2 cm (thickness)

3.1.3 Two bamboo stakes (each 50 cm long)

3.1.4 Saw

3.1.5 Oil finish or hardwood oil

3.1.6 GPS tracker

3.1.7 Camera

3.1.8 Notebook

3.1.9 Pen

3.1.10 Oil paint

3.1.11 Hoe

3.1.12 Machete

3.1.13 Ruler with the minimum length of 45 cm

3.1.14 Plastic sheet

3.2 Assembling a V-notch check

3.2.1 Draw a V shape 60 cm wide x 30 cm deep on the top centre of a plywood plank. To do this, measure 30 cm from the top outer edges of the plank, leaving 60 cm area in the middle of the wood which represents the top width of V. Determine the centre point of the V and measure in 30 cm to mark the V notch. Draw 2 lines from the notch upward to create V arms.

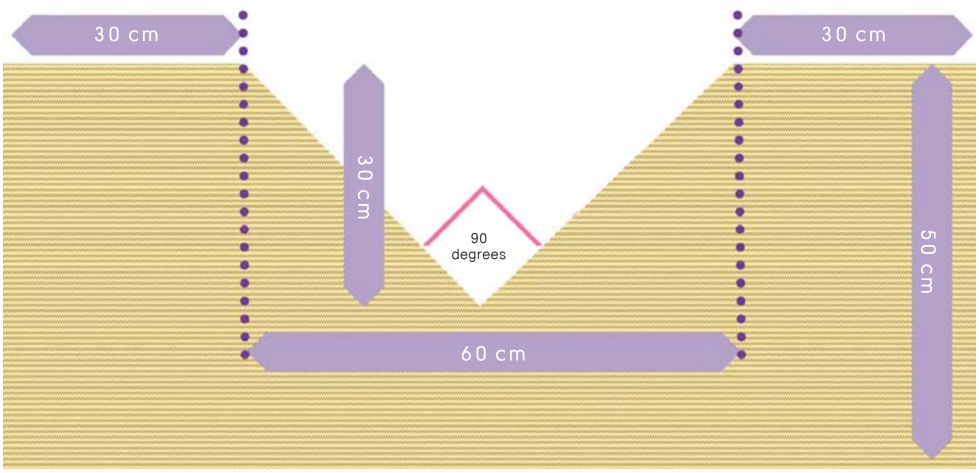


Figure 11:
V-Notch size

3.2.2 Saw the wood along the drawn line, making sure the saw cuts the wood at a 45-degree angle. This is to ensure a sharp edge that allows water to flow through the notch easily. A blunt cut will slow down the water or push it higher, making it difficult to read the value.

Figure 12:
Cut plywood at 45 degrees

Figure 13:
The appearance of an appropriate cutting edge

3.2.3 Nail the hardwood plank 2 cm (width) x 120 cm (length) x 2 cm (thickness) along the top of the V-notch check. This is to ensure that the V-notch plank does not bend, and can also be used as a handle for convenience. The plank can also be reinforced with an additional bamboo frame.

Figure 14:
Strengthening a V-notch plank

Figure 15:
Reinforcing a V-notch plank with bamboo and nails

Figure 16:
V-notch check plank with a completed handlebar

3.2.4 Apply oil or wood finish to protect the wood and keep it durable

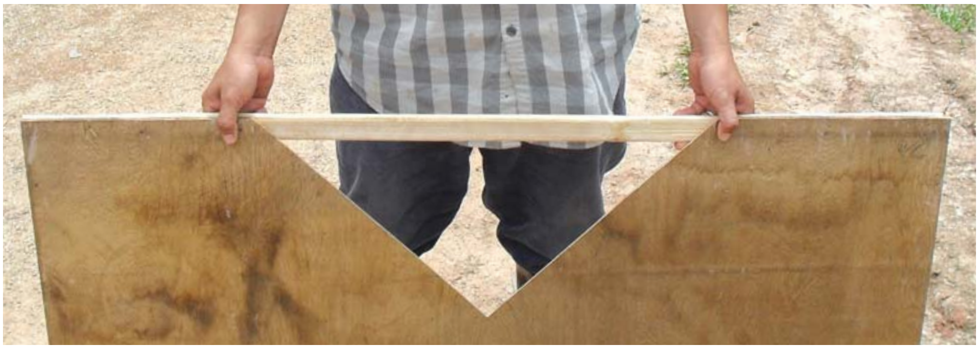


Figure 17:
A completed V-notch plank (front view)

Figure 18:
A completed V-notch plank (back view)

3.3 Measuring the water level

3.3.1 Select an area with an even streambed. There should be no rocks on the bottom because the V-notch plank needs to be placed right on the bed, allowing no water to seep underneath the plank.

3.3.2 Place the V-notch plank across the stream direction, keeping the top of the V-notch plank parallel with the surface of the water.

Figure 19:
Placing the V-notch plank perpendicular
to the streambed

3.3.3 Seal the gaps between the V-notch plank and the banks on both sides to prevent water from seeping through. This can be done by using soil, a plastic sheet, or any available objects such as plants and banana leaves. The purpose is to direct the water to flow through the V notch only.

Figure 20:
A V-notch plank being installed to completely block the water flow

3.3.4 Wait until the water runs through the V-notch and rises until the downstream surface becomes stable and is at the same level as the upstream surface.

Figure 21:
After installing the V-notch plank,
wait until the water level on both side are even.

3.3.5 Place a ruler vertically against the V-notch. Make sure that the 0 scale is at the notch of the V and the ruler does not tiltto either side for the best accuracy. Read the value on the ruler where it touches the water surface. The result should be in cm and mm.

Figure 22:
Place a ruler against the V-notch.
Make sure that the 0 scale is at the notch of the V shape.

3.3.6 Remove the ruler and re-measure the stream height at least three more times. Record the results and compare them with each other. Choose the most concurrent value.

3.3.7 Record GPS reference point of the measuring location and mark it with paint; name the measuring point for reference and future re-measurement.

3.4 Calculating Water Discharge

Once the height is collected, compare the value with the water discharge value through V-notch in the table. Use that value to rationalize the water discharge per day.

Height (cm)	Water Discharge (m^3/sec)	Water Discharge (litre/sec)	Height (cm)	Water Discharge (m^3/sec)	Water Discharge (litre/sec)	Height (cm)	Water Discharge (m^3/sec)	Water Discharge (litre/sec)
1	0.00000587	0.0059	12.5	0.00324339	3.2434	24	0.01656731	16.5673
1.5	0.00001618	0.0162	13	0.00357752	3.5775	24.5	0.01741372	17.4437
2	0.00003321	0.0332	13.5	0.0039315	3.9315	25	0.01834737	18.3474
2.5	0.00005802	0.058	14	0.0043057	4.3057	25.5	0.01927854	19.2785
3	0.00009152	0.0915	14.5	0.0047005	4.7005	26	0.02023751	20.2375
3.5	0.00013455	0.1346	15	0.00511625	5.1163	26.5	0.02122455	21.2245
4	0.00018788	0.1879	15.5	0.00555332	5.5533	27	0.02223992	22.2399
4.5	0.00025221	0.2522	16	0.00601207	6.0121	27.5	0.02328389	23.2839
5	0.00032821	0.3282	16.5	0.00649282	6.4928	28	0.02435672	24.3567
5.5	0.00041651	0.4165	17	0.00699594	6.9959	28.5	0.02545868	25.4587
6	0.00051773	0.5177	17.5	0.00752175	7.5218	29	0.02659003	26.59
6.5	0.00063242	0.6324	18	0.00807059	8.0706	29.5	0.02775101	27.751
7	0.00076115	0.7611	18.5	0.00864277	8.6428	30	0.02894189	28.9419
7.5	0.00090443	0.9044	19	0.00923863	9.2386	30.5	0.03016292	30.1629
8	0.00106279	1.0628	19.5	0.00985849	9.8585	31	0.03141435	31.4143
8.5	0.00123672	1.2367	20	0.01050265	10.5026	31.5	0.03269642	32.6964
9	0.00142669	1.4267	20.5	0.01117142	11.1714	32	0.03400938	34.0094
9.5	0.00163318	1.6332	21	0.01186512	11.8651	32.5	0.03535348	35.3535
10	0.00185662	1.8566	21.5	0.01258404	12.584	33	0.03672896	36.729
10.5	0.00209748	2.0975	22	0.01332848	13.3285	33.5	0.03813606	38.1361
11	0.00235616	2.3562	22.5	0.01409873	14.0987	34	0.03957501	39.575
11.5	0.00263311	2.6331	23	0.0148951	14.8951	34.5	0.04104607	41.0461
12	0.00292871	2.9287	23.5	0.01571786	15.7179	35	0.04254945	42.5494
35	0.04254945	42.5494	46.5	0.08656776	86.5678	58	0.15041591	150.4159
35.5	0.04408539	44.0854	47	0.08891365	88.9137	58.5	0.15367862	153.6786
36	0.04565413	45.6541	47.5	0.09129728	91.2973	59	0.15698343	156.9834
36.5	0.04725589	47.2559	48	0.09371884	93.7188	59.5	0.16033052	160.3305
37	0.04889091	48.8909	48.5	0.09617853	96.1785	60	0.16372007	163.7201
37.5	0.05055941	50.5594	49	0.09867656	98.6766	60.5	0.16715225	167.1523
38	0.05226161	52.2616	49.5	0.10121312	101.2131	61	0.17062725	170.6272
38.5	0.05399774	53.9977	50	0.1037884	103.7884	61.5	0.17414523	174.1452
39	0.05576803	55.768	50.5	0.1064026	106.4026	62	0.17770638	177.7064
39.5	0.05757269	57.5727	51	0.10905592	109.0559	62.5	0.18131087	181.3109
40	0.05941195	59.4119	51.5	0.11174854	111.7485	63	0.18495887	184.9589
40.5	0.06128601	61.286	52	0.11448067	114.4807	63.5	0.18865056	188.6506
41	0.0631951	63.1951	52.5	0.11725248	117.2525	64	0.19238612	192.3861
41.5	0.06513944	65.1394	53	0.12006418	120.0642	64.5	0.1961657	196.1657
42	0.06711924	67.1192	53.5	0.12291595	122.916	65	0.1999895	199.9895
42.5	0.06913471	69.1347	54	0.12580798	125.808			
43	0.07118606	71.1861	54.5	0.12874046	128.7405			
43.5	0.0732735	73.2735	55	0.13171357	131.7136			
44	0.07539725	75.3972	55.5	0.1347275	134.7275			
44.5	0.0775575	77.5575	56	0.13778244	137.7824			
45	0.07975448	79.7545	56.5	0.14087856	140.8786			
45.5	0.08198838	81.9884	57	0.14401606	144.0161			
46	0.0842594	84.2594	57.5	0.14719512	147.1951			

Results calculated from the following equation:

$$Q = (8/15) \times Cd \times (2g)^{1/2} \tan(\theta/2) \times H^{5/2}$$

$$Cd = 0.6$$

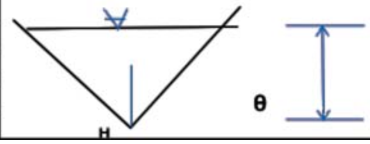


Figure 4:

Table of Water Discharge through the V-notch

Example: According to the Table of Water Discharge through the V-notch, If the height value at point A is 8.4cm, the water discharge should be 1.2367 litres/sec or 106,850.88 litres per day, which is the closest value to the recorded height.

Remark: The values in this calculation apply only on the time and date of measurement only. If measured other time, the result will be different depending on the rainfall volume, temperature, and condition of the watershed forest.

4. Measuring Water Withdrawal with a Measuring Container

4.1 Equipment

4.1.1 A measuring container with a clear volume specification

4.1.2 PVC pipe

4.1.3 GPS tracker

4.1.4 Camera

4.1.5 Notebook

4.1.6 Pen

4.1.7 Oil paint

4.1.8 Hoe

4.1.9 Machete

4.2 Calculating Water Discharge

4.2.1 Create an earthen dyke that completely blocks the stream. Wait until the water infiltrates into the dyke

4.2.2 Dig a hole in the constructed dyke and place a bamboo tube or PVC pipe of appropriate size through it

4.2.3 Collect the water discharged through the pipe by using a container with a clear volume indicator such as a plastic jug or a bucket

4.2.4 Start the stopwatch when the water flows into the container and stop it when the container is completely filled. Record the time in a notebook.

Figure 23:
Collecting water discharged through the pipe

Figure 23:
Collecting water discharged through the pipe

Figure 25:
Timing the flow of water into the container

4.2.5 Time the water discharge again at least three times and find the average value. For example, if the discharge is tested three times and it takes 11.42, 11.67 and 11.53 seconds to completely fill the container respectively, the average time of discharge should be calculated by summing all the three values and divide it by the numbers of measurements. The formula for above sample may look like the following:

$$\frac{11.42 + 11.67 + 11.53}{3 \text{ (number of measurements)}} = 11.54 \text{ seconds}$$

4.2.6 Calculate the water discharge per second by dividing the capacity of the container by the average time of discharge. The result should be expressed in litre/sec. To find the water discharge in litre/min, multiply it with 60 (60 seconds = 1 minute). If you need the value per day, multiply the litre/min value by 60 (60 minutes = 1 hours) and 24 (24 hours = 1 day).

Example: If the container has a capacity of 5 litres and the average time of discharge is 11.54 seconds,

In 11.54 seconds the stream discharges 5 litres of water

In 60 seconds, the Water Discharge $= \frac{5 \times 60}{11.54}$ = 25.996 litres/min

Or 25.996 x 60 x 24 = 37,434.24 litres/day

Remark: The values in this calculation apply only on the time and date of measurement only. If measured at another time, the result will be different depending on the rainfall volume, temperature, and condition of the watershed forest.

(03)
WEIR CONSTRUCTION

1. Definition and Roles of Weirs

A weir is a construction built across a stream or a river to obstruct the flow and raise the level of water and let it overflow into a distribution system. The water is conveyed through canals and distributed for agricultural purposes according to seasonal demands, while excess water will spill over the construtcted weir along its natural course downstream. It is necessary to construct a weir on a high terrain to ensure proper delivery of water into the irrigation system, and its length should be sufficient to allow water to safely spill over during the rainy season without overflowing the banks upstream. Generally, weirs are not very high and are trapezoid in shape (Pramot Maiklat, November 28, 2011).

2. Types of weirs

There are four types of weirs that have been engaged under the programmes initiated by the Mae Fah Luang Foundation. They are defined by the construction materials as 1) check dam or conservation weir 2) gabion weir, 3) masonry weir, and 4) reinforced concrete weir. When weir construction is needed, the key factors that the Foundation takes into account are topographic constraints and the output efficiency to the local communities. The details on requirements for four types of weirs can be read in the following table.

	Check dam	Gabion weir	Masonry weir	Reinforced concrete weir
Bottom slope of the stream	Less than 30 degrees	Less than 20 degrees	10-20 degrees	5-10 degrees
Width of water course	1-5 metres	Less than 20 metres	3-10 metres	Less than 10 metres
Streambed characteristics	All kind of streambed	Rocks and pebbles	bedrock	bedrock
Construction materials	Natural materials such as bamboo, rocks and gravel. Suitable for areas with access to these materials.	Natural materials such as rocks and gravel. Suitable for areas with access to these materials.	Natural materials such as rocks and gravel. Suitable for areas with access to these materials.	Steel wire and concrete
Accessibility	Construction relies on natural materials found in the area. Accessibility to the site is not important. A weir can be constructed anywhere that is deemed necessary and beneficial.	Construction relies on imported supplies. The area must have an access to roads for raw material transportation and future maintenance work.		
Cost	Less than 250 baht/ metre	Less than 12,600 baht/metre or 1,400 baht/sq metre.	Less than 7,500 baht/metre or 2,500 baht/sq metre.	Expensive, and should the refore be constructed only when necessary.
Workforce capacity	1 weir/1 day/ 8 persons	1 weir (5x1.5 m)/ 10 persons/ 20 days	1 weir (5x1.2 m)/ 10 persons/ 10 days	1 weir (5x1.2 m)/ 10 persons/ 10 days

Table 5:

Different requirements for each type of weir

3. Check dam or conservation weir

"...Weirs can be constructed out of low-cost materials available in the local area, such as riprap or discarded rocks covered with nets and placed across the stream at intervals to retain water and soil sediment. The retained water will infiltrate the stream bed and banks, increasing the moisture content in the soil on both sides of the stream. Then you can grow firebreak plants, fast-growing plants, and evergreen plants to gradually rehabilitate the watershed area ..."

Excerpt from His Majesty the King's speech
at Mae La Noi District, Mae Hong Son, on March 1, 1978

"...Weirs should be constructed upstream to decelerate the flow of water and store water to keep the watershed area moist ..."

Excerpt from His Majesty the King's speech
at Doi Ang Khang, Fang District, Chiang Mai, on March 11, 1989

Aware of the importance of forests, His Majesty the King has introduced several royal initiatives to develop and restore forests by utilising local resources that provide mutual and optimal benefits. One of the tools advised by His Majesty the King is the check dam or conservation weir which blocks the flow of water near the source, decelerating the flow and allowing the water to infiltrate the soil as much as possible. This results in a lush natural forest cover and, on steep slopes, also prevents soil and sediments from being flushed away and collecting downstream. The trapped sediment and lush forest cover will help reduce soil erosion and reduce the co-efficient of water runoff. This means check dams can serve as a flood prevention and drought relief tool, benefiting farms and residential areas downstream. In summary, check dams not only help to preserve soil and water but also prevent many complications caused by degraded soil, water, and forests.

Although check dams are very beneficial, to optimize the effect, it is necessary to conduct a careful stream survey, focussing on the stream size, depth and capacity. If a stream has a great capacity, then the more check dams built, the better. However, the topography must be taken into account. Where slopes are steep, the check dams should be closely spaced, or at least 10-20 metres apart. On a gentle incline, however, where the stream is wide or deep enough to retain a large amount of water, the check dams should be placed at least 50 metres apart in order to store a large quantity of water. In the area of 93,515 rai of the Doi Tung Development Project under royal initiative, there are approximately 2,000 check dams, or one to every 45 rai approximately.

Check dams may have different characteristics in each area, depending on the available construction materials. In most cases, they are not relatively large and resemble a trapezoid shape. The gradient of the check dam downstream is less than those further upstream. All the weirs constructed by the Mae Fah Luang Foundation were made with low-cost materials which were easily obtained in the area such as sticks, leaves, bamboo, wood, sand, and gravel. The frame of the weir is made of overlapping panels of bamboo or wood in the desired shape, then filled with rocks, sand, and gravel for reinforcement.

Figure 26:
A check dam or conservation weir

3.1. Construction planning

3.1.1. Team Composition

1) Site supervisor: this person is responsible for mentoring the team and giving advice from first-hand experience. A supervisor can be recruited from local construction sites or hired from a private or public company with extensive experiences in irrigation construction or domestic construction. A site supervisor should have the following qualifications:
    - Has the ability to construct a weir and is able to perform other construction tasks
    - Understands the structure and formats of different types of weirs, and is able to read architectural drawings
    - Possesses the knowledge of how to overlay the rocks, and can transfer this knowledge to other workers

2) General labour: while the numbers of general labour is not limited, their scope of work is to perform a variety of construction tasks such as bamboo cutting, dirt loading, and rock dumping. Local people can be recruited as general workers. Not only does this provide job opportunities to the local people but also teaches them skills in weir construction, maintenance and management which will be needed in the future when the weirs are finally handed over to the community.

3.1.2. Materials and equipment

1) Materials
    - Bamboo
    - Soil found in proximity to the site
    - Rocks found in proximity to the site
    - Nails (1.5”, 3”, and 4”)
    - Wire
    - Plastic sheets

2) Equipment

- Steel measuring tape - to measure the site area (width, length, and height) in order to calculate the quantity of bamboo stakes needed.
- Knives - to cut bamboo
- Hoes - for digging soil
- Clamshell baskets to carry soil
- Wooden soil compactor - to manually compact the soil
- Hammers - to nail the bamboo stakes

3.2. Check dam construction process

3.2.1. Site preparation

The stream area below the check dam should be wider than the area where the check dam is constructed to be able to store water and collect sediment. Remove weeds and debris (wood and rocks) from the construction area.

3.2.2. Weir structure

The structure of a check dam can be divided into 4 components, in order of construction: 1) Brace 2) Post 3) Joist and 4) Rafter.

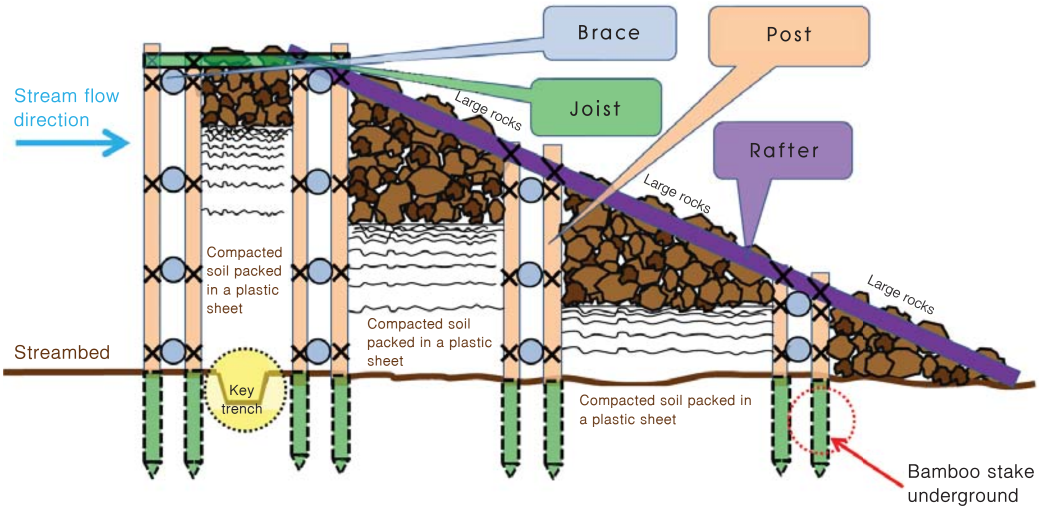


Figure 27:
Components of a check dam (Linear-section)

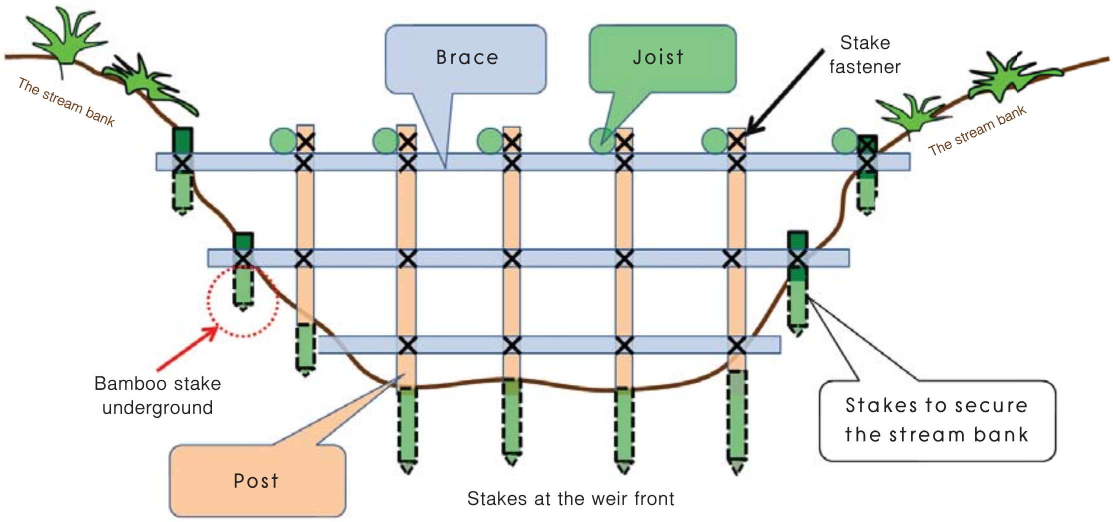


Figure 28:
Components of an Economy weir (Cross-section)

Steps in the construction of a check dam:

1) **Determine the placement of braces:** This can be done by finding two parallel spots on both sides of the stream banks. The easiest way to find them is to stand in the middle of the stream, facing upstream. Spread your arms across the stream and mark the spots where the hands point to as the brace placement.

2) **Place the braces:** Dig a trough at least 50 cm into the bank. Place bamboo poles across the stream, keeping the ends of the bamboo poles within the trough. Repeat the process 1 metre from the first set.

Figure 29:
Digging a trough to place the braces.

Figure 30:
Placing the brace 1 metre apart

3) **Securing the braces:** Drill a hole in both ends of the bamboo poles. Select a bamboo stakes with a diameter of around 3-5 cm and sharpen one end. Firmly fix the smaller stake into the ground to secure the poles. Secure the drilled bamboo with the post using a hammer and nails, then tie with wire. Repeat the process with all other braces.

Figure 31:
Securing the braces

4) **Placing the posts:** select bamboo stakes with the diameter of 5 cm and sharpen one end. Align the posts against the outer side of the fixed brace 0.5-1 metre apart. Hammer the post into the ground as hard as possible. Secure the posts and the braces with 3”-4” nails. Tie them up again with wire to reinforce the strength.

Figure 32:
Hammering posts into the ground

Figure 33:
Securing the posts and braces together

Figure 34:
Tieing the posts to the braces with wire

5) **Placing the joists:** Joists are bamboo stakes with a minimum diameter of 10 cm Cut the joists into the length corresponding to the distance between posts in rows 1 and 2. Drill a hole in both ends of the bamboo stake. Make sure that the hole fits the diameter of the posts perfectly. Be careful to drill the hole in the node to prevent the bamboo from cracking. When the holes are drilled, place the joist over the posts, making sure that the top part of posts slip into the drilled slot. This procedure secures the braces in different rows together and maintains the frame during earth fill procedure.

Figure 35:
Placing joists over the posts

6) **Placing the rafters:** Select bamboo tubes with at a minimum diameter of 5 cm Cut it to the length that covers the whole frame, starting with the 2nd row until the last row. Firmly fix the rafter into the ground. Reinforce its strength with nails and wire at every point it crosses the frame.

Figure 36:
Placing rafters

Figure 37:
Placing rafters

7) **Putting up the walls:** Cover the frame with wooden laths. If the material is not available in the area, cut bamboo tubes vertically into half and put them up as a wall. These laths should be aligned with the posts and firmly fixed into the ground. Wooden laths result a more durable weir.

Figure 38:
Cutting the bamboo tubes into half and use them as laths

Figure 39:
Fixing the laths into the ground

Figure 40:
Fixing the laths into the ground

Figure 41:
Putting up walls made of wooden laths

3.2.3 Digging a core trench

Remove unwanted debris and sediments from the weir bed. Dig a trench along the inner wall of the weir 20-30 cm wide and 30-50 cm deep.

Figure 42:
Digging a core trench

3.2.4 Lining a plastic film

Cut the plastic sheet into the size that would cover the length of the crest line. Spread the plastic sheet and line it along the crest line, core trench as well as the inner walls.

Figure 43:
Installing the plastic sheet lining

Figure 44:
Installing the plastic sheet lining

3.2.5 Soil filling: Fill the plastic sheet with soil dug from nearby areas. The soil should not be taken from an area too close to the weir. If that cannot be avoided, then the dig should be at least 1 metre higher than the crest. Fill the soil into each frame box one layer at a time. Make sure to compact each soil layer hard enough until it almost fills up the weir, leaving a space of 20-30 cm from the crest. Top with large rocks to prevent erosion.

Figure 45:
Digging soil to fill the weir. The soil dig area should be at least 1 metre higher than the crest

Figure 46:
Earthfill procedure

Figure 47:
Compacting the soil

Figure 48:
Spare a space of 20-30 cm height from the crest
and fill it with large rocks

3.2.6. Covering with rocks or bamboo: Top the earthfill with rocks found in the area until the laths cannot be seen. If it is impossible to find rocks, use bamboo as an alternative. A rock cover should make the weir considerably more durable compared to a bamboo cover.

Figure 49:
Topping the soil with large rocks

Figure 50:
Check dam with rock cover

Figure 51:
Check dam with a combination rock
and bamboo cover

Figure 52:
Check dam with bamboo cover

4. Gabion weir

Gabion weir is a type of weir that utilises a series of gabion boxes as the core component. A gabion box is made of different sizes of wire-mesh and filled with rocks and gravel.

The gabion box used by the Mae Fah Luang Foundation is a zinc-coated wire-mesh with the diameter of 2 mm. The box itself is 0.5 metre high, 1 metre wide and 2 metres long. Inside, there is a diaphragm that divides the storage into 2 compartments to maintain the box shape. Compared to the original square gabion box, the rectangular gabion basket has proved to be of higher flexibility and applicability.

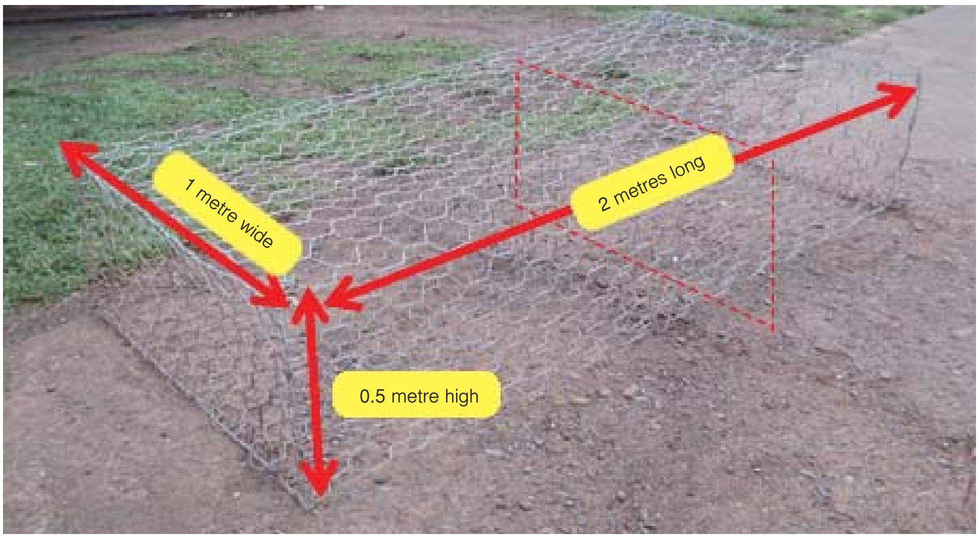


Figure 53:
An assembled gabion box ready for use

4.1. Construction plan for gabion weir

After completing the preliminary site survey and weir design to ensure the weir suits the typographic conditions, a construction plan should be initiated by taking the following issues into account:

4.1.1 Team Composition

1) Site supervisor: this person is responsible for mentoring the team and giving advice according to his experience. A supervisor can be recruited from local construction sites or hired from a private or public company with extensive experiences in irrigation construction or domestic construction. A site supervisor should have the following qualifications:

- A minimum of three years of experience in construction supervision
- The ability to supervise the construction process
- An understanding of the structure and different types of weirs, and able to read architectural drawings
- The ability to perform construction tasks
- Possesses the know-how on gabion box assembly and the ability to transfer the knowledge to other workers
- The ability to adapt the placement of the gabion boxes to to suit different typographic constraints.

2) General technician: either one or two per project, depending on the workload and urgency. This technician is responsible for performing tasks instructed by the supervisor and delegating jobs to general labourers. A technician should have an experience as a construction worker. This position can also be recruited from the villagers or people who are working as construction workers.

3) General labour: While the numbers of general labour is not limited, their scope of work is to perform a variety of construction tasks such as gabion aligning, gabion assembling, rock filling. Local people can be recruited as general workers. Not only does this provides them with job opportunities but also teaches them skills needed in weir construction, maintenance and management, particularly when the weir is handed over to the community.

4.1.2 Materials and equipment

1) Materials

- Gabion boxes, the quantity depends on the design
- Geo textile, the size depends on the weir size
- Galvanized wire
- Anneal wire no 12
- Nails (1.5”, 2.5”, 3”, and 4”)
- Bamboo stakes or wood, the size of the weir crest with the width of 1.5-2 inches
- Plywood board to hold construction blueprint, 1.20x2.40 metres long
- Softwood
- Cement
- Sand
- Crowbar
- Pickaxe
- Hammer
- Hoe
- Spade
- Clamshell baskets
- Shovel
- Crushed rocks
- Large rocks, 20-30 cm in diameter
- Steel pipes, size corresponding to the design of the water distribution plan

2) Equipment

- Lineman pliers - to assemble the gabion
- Pincers - to assemble the gabion
- Steel wire cutter, size 50 cm
- Steel measuring tape (30 m) for large area measurement
- Portable steel measuring tape (5 m) - for small area measurement
- Wood Saw

- Steel Saw
- Concrete trowel
- Concrete bucket
- Water level
- Plumb bob
- Camera
- Notebook

** The quantity of the materials and equipment depends on the size of the weir and available labour. **

4.1.3 Site preparation: Follow these steps

1) Remove weeds and debris at the site.

2) Divert the water flow using one of the following methods:

- Water diversion utilising pipes: Block the water flow and insert pipes to create a temporary water passage. The pipe ends should be placed over the weir in the downstream direction. This is the easiest and most convenient method, suitable for a small stream.

Figure 54:
Water diversion with pipes

Figure 55:
Water diversion with pipes

- **Water diversion utilising a bypass channel:** Suitable for a medium size stream, this method utilises a manually or mechanically dug channel which diverts the water to other direction. Once the construction is complete, close the bypass channel and fill in the bypass channel with soil as compact as possible. Allow the water to run through the constructed weir. For a very large stream, both pipes and bypass can be utilised simultaneously.

Figure 56:
Water diversion with a bypass channel

- **Diversion utilising an earth dike:** A simple earth dike can be constructed to block half of the natural water course. This half should cover a small gate that helps drain sand when weir construction started and turns in to spillway when the construction of the other half begins. This method is suitable for large streams.

Figure 57:
Diversion utilising earth dike

Gabion weir is different from other types of weirs. The site does not need to be completely dry because no construction components are anchored on the streambed.

3) Once the diversion is complete and the site is dry, start the site preparation as suitable for the design. The important part of site preparation is soil compaction. This is necessary for the stability of the weir.

Figure 58:
Preparing the site with heavy machinry

Figure 59:
Manual site preparation

4.2. Constructing a gabion weir

4.2.1 Determine the position of the a cut-off trench. For gabion weirs, trench can be placed at any of the following three positions:

1) Centre line: The width of the cut-off trench depends on the crest width. Generally, a trench is 2 metres wide, equivalent to the width of a gabion box placed in parallel to the stream direction. Centre position proves to yield a high impermeability. For a small stream, the trench can be 1 metre wide, equivalent to the width of a gabion box placed across the stream.

Figure 60:
Digging a cut-off trench at the centre of the weir

2) Front and rear toes: The distance between the cut-off trench in the front and rear toe depends on the weir design. However, each cut-off should be 1 metre wide and 0.5 metre deep and well keyed to mount a gabion box. This is to ensure that the top of the gabion box is at the same level as the streambed. If well keyed, the box improves the stability of the foundation and prevents seepage underneath the structure.

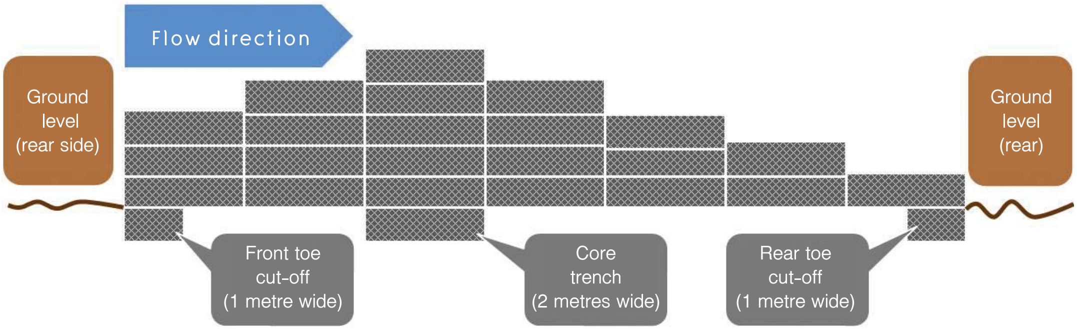


Figure 61:
The cut-off trench at the front and rear toe

3) **Full length:** Cut-off trench can fully extend to cover the entire weir. For a very small weir, the core trench should be cut out along the entire weir. A full length core trench offers a stronger and durable and weir than the cut-offs along the centre line or at the front and rear toes. However, this type of core trench is not recommended for a large-sized weir because it is time and labour consuming.

4.2.2 **Siting a core trench:** The best way to site a core trench is to dig deep down to the hard soil or the subsoil level. This is necessary to prevent seepage underneath the weir and strengthen the weir's foundation. Dig the core trench along the crest line. Clean up the area by removing debris, fine particles of soil and dirt.

4.2.3 **Setting up gabion boxes:** Once the core trench is excavated, set up the gabion boxes immediately by following the instructions below:

1) Unwind the mesh and fold it up into a box shape.

Figure 62:
Unwinding the mesh

Figure 63:
Unwinding the mesh

Figure 64:
Folding the mesh into a box

2) Lace the four vertical edges of the gabion, utilising pincers and provided lace wires. Double tie each edge with a black wire to strengthen the box (Figure 65-70).

Figure 65:
Lacing the edge of a gabion box
using pincers

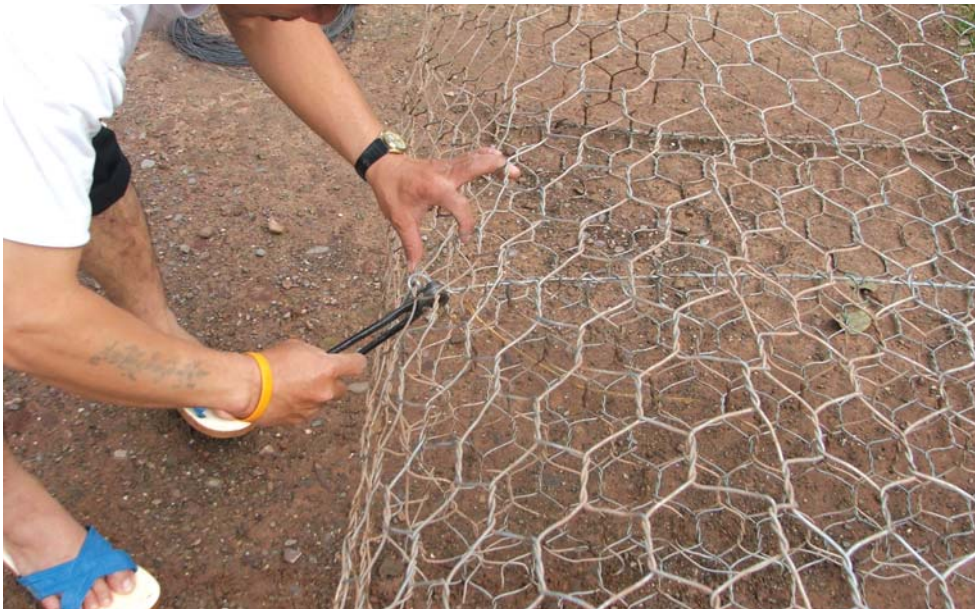


Figure 66:
Lacing the edge

Figure 67:
Double lacing each edge to retain the shape and strengthen the box

Figure 68:
Lacing the edge of a gabion box

Figure 69:
Lacing the edge of a gabion box

Figure 70:
Double lacing each edge to retain the shape and strengthen the box

3) After assembling each gabion box, join the baskets together. The finished gabion boxes should have the same length as the crest. To join each gabion box, do the following steps:

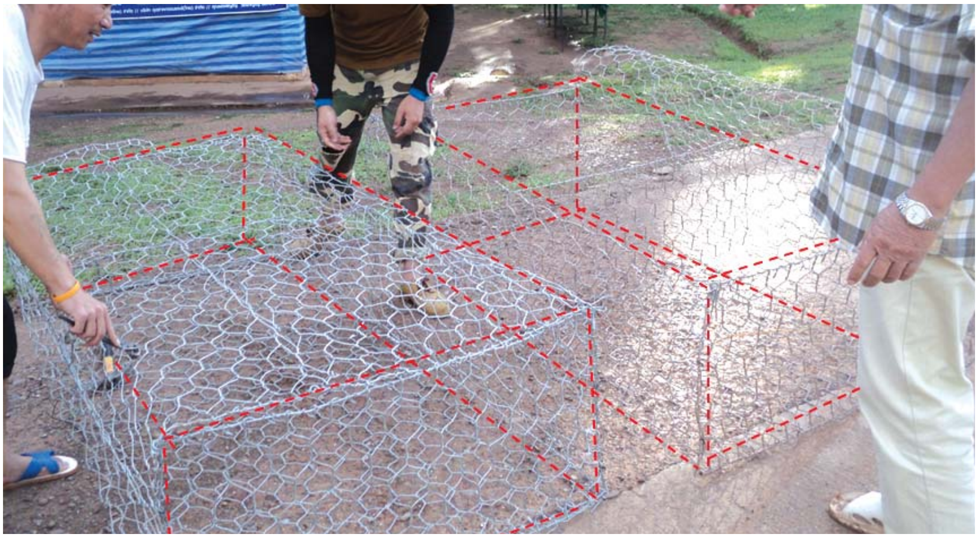


Figure 71:
Placing the gabion boxes together

1. Cut annealing wire (no.12) into 1 metre lengths.

Figure 72:
Cutting annealing wire (no.12) into 1 metre lengths.

2. Turn the end of the wire into a hook to join two boxes.

Figure 73:
The end of the wire being turned into a hook

3. Join the edges of two gabion boxes with the hook and begin lacing.

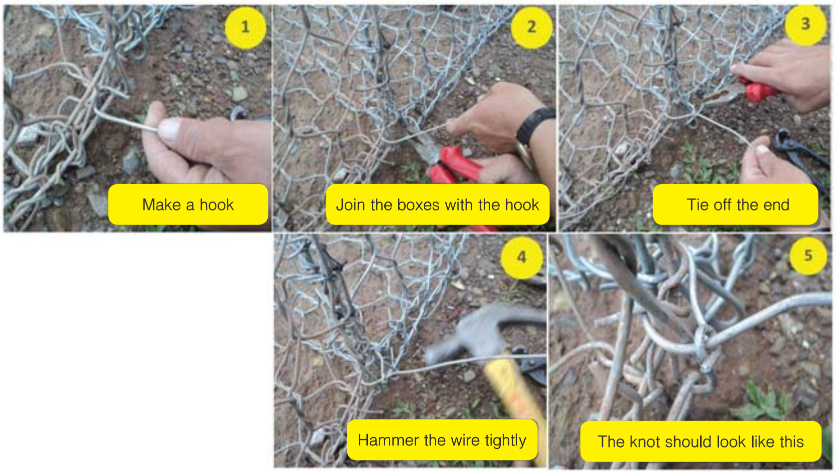


Figure 74-78:
Joining two gabion boxes together

4. Lace around the edges being joined in an upward direction for 15 cm. Use triple tie each turn.

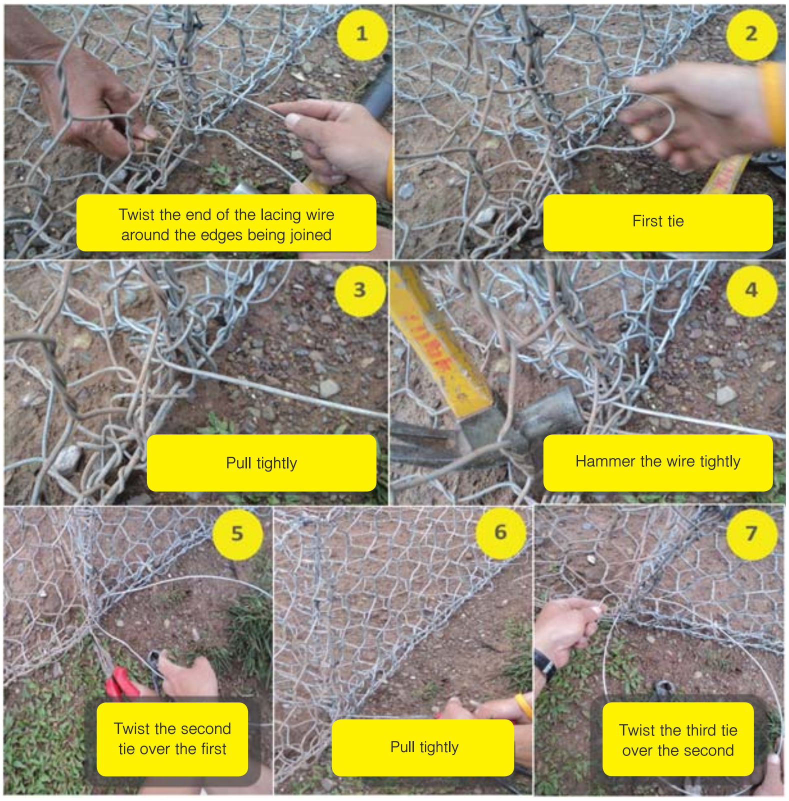


Figure 79-85:
Staff lacing the joined edges

5. If the wire is not long enough, lengthen it with a new wire. Continue the twist upward until the edges are completely secured.

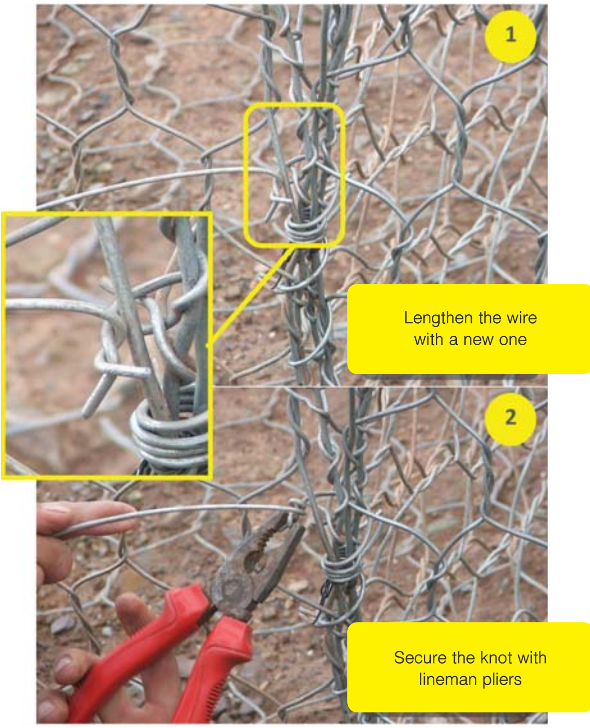


Figure 86-87:
Lengthened wire

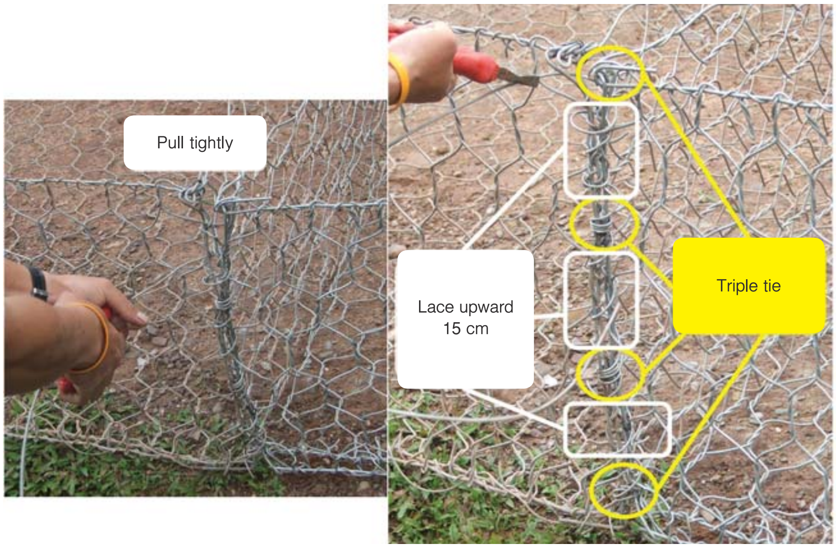


Figure 88-89:
Continued lacing

Continue the lacing with all sides, corner, and joints of the gabion until the gabions are securely joined.

4) Continue the lacing until all edges are secured. Cut off the end of the wire or turn them to the inside of the gabion on completion.

Securely connect all sides of the gabion boxes with wire.
Once completed, the boxes are ready for placement.

Figure 90-91:
Completing the lacing process

4.2.4 Placing geo textile

Geo textile has a special quality; it allows the passage of water, but not soil or gravel. It is therefore a useful material perfect for weir construction. Geo textile placement should be done once a gabion construction is complete. The process of geotextile placement is as follows:

1) If the core trench is not wide, it is preferable to lace a layer of geo textile with the gabion boxes and place the whole gabion structure into the core trench. This method yields a better security between the geo textile and the gabion structure.

Figure 92:
Anchoring a layer of geo textile under the gabion boxes and placing them into the core trench

2) For a larger core trench, place a layer of geo textile onto the core trench, followed by the gabion boxes. Securely assemble the boxes on the layer in accordance to the design.

Figure 93:
Assembling the gabion boxes on the geo textile layer.

4.2.5 **Bracing the top edges of the gabion boxes,** utilising long, straight and durable bamboo stakes. Securely tie the stakes along the top edges of the boxes. If bamboo stakes are not available, any wood sticks would do as long as they are straight and have the same size as the bamboo stakes. Bracing the top inner lines of the gabion boxes prevents deformation during rockfill. It also evens out the top face of the boxes and facilitates the lacing of the next layer of the gabion structure.

Figure 94:
Bracing the top face of the gabion boxes

4.2.6 **Rockfilling the gabion boxes.** The rocks must be bigger than the mesh openings. Make sure that there are no empty spaces in the box.

4.2.7 **Placing brace wires inside the gabion box.** When a gabion box is half-filled, insert bracing wires at the centre of the basket to preserve the shape and prevent bulging by pulling the opposite sides (see Figure). Brace wires ensure that the structure has a flat surface and is ready for the placement of an overlying layer. To place brace wires, take the following steps:

Figure 95:
bracing wires at the centre of the basket

1) Divide each side of the box into three sections. At the midway point of each section, tie one end of the wire to the box.
2) Twist all the wires at the centre of the box to prevent them from loosening. Wrap around the adjacent side of the box with the wire for better attachment with another box. Pull the wire from all sides to tighten the braces.
3) Lace the wire around the jointed edge of two boxes to fasten them together.
4) Continue rockfilling until the rocks reach the top line of the opening. If the topmost gabion box has been completed, or the structure has reached the desired height, close the cover and tightly secure it with wires. If another layer is required, all four edges of the two layers should be precisely aligned and strongly laced to one another. If 3-4 sides of a gabion box are shared, it is important to lace all sides and corners of the boxes, utilising pliers and hammer. Once complete, reinforce the top inner lines with bamboo sticks before rockfilling to maintain the shape. Follow with the wire bracing and tension procedure to complete the whole construction process according to the design of the weir.

4.2.8 Placing gabion boxes in the prepared site

1) **If the site is dominated by large rocks,** simply place the gabion boxes in the available areas without clearing or breaking down the rocks. The gabions should be closely placed to the natural rocks. In other words, these stones become part of the weir and make it even more durable.

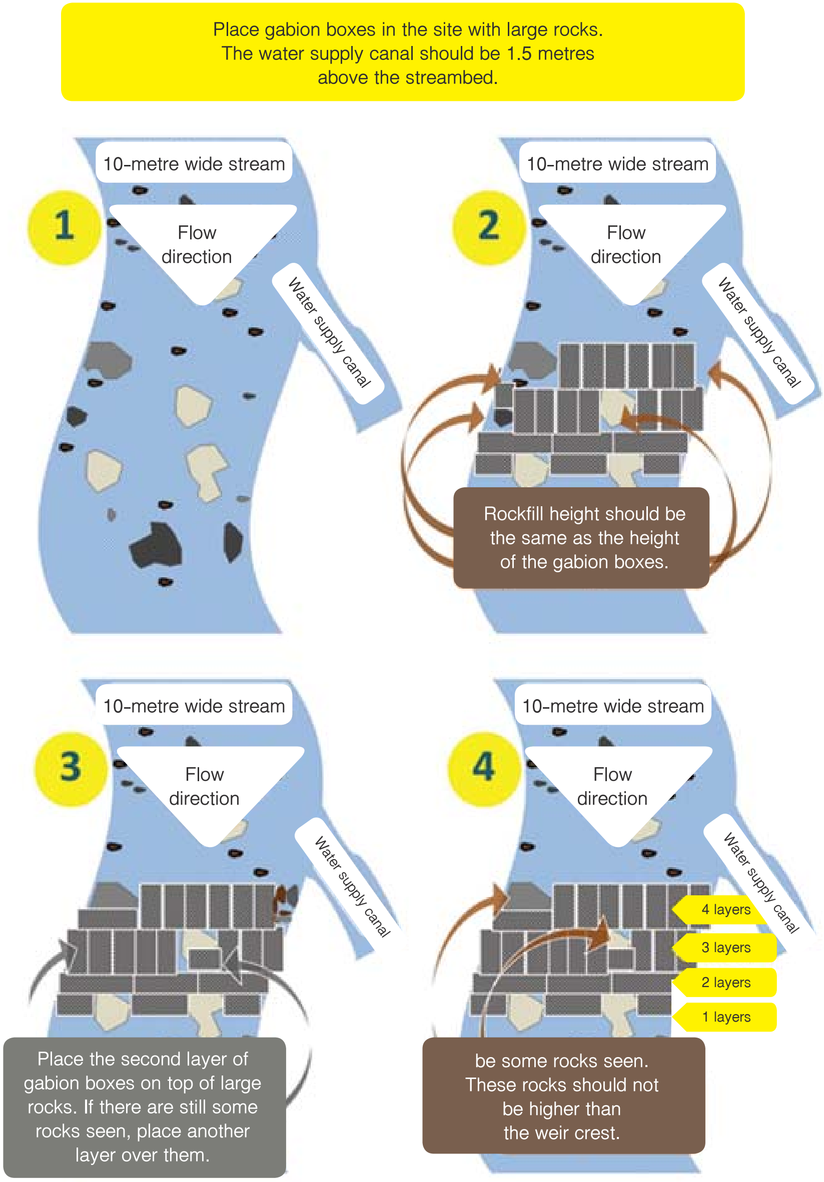


Figure 96:
Placement of gabion boxes in the site with large rocks

Figure 97-99:
Placement of gabion boxes in the site with large rocks

Figure 100-101:
Placement of gabion boxes in a site with large rocks

2) If the site is scattered with rocks, it is advised to tie the gabion boxes to the rocks to stabilise the structure. Cross-lace large rocks (minimum diameter of 40 cm) with the wire utilised in gabion assembling. Securely tie off the wire, leaving a tip of about 30 cm. Firmly attach the gabion to rocks, utilising the same wire. At least 6 rocks should be tied underneath each box.

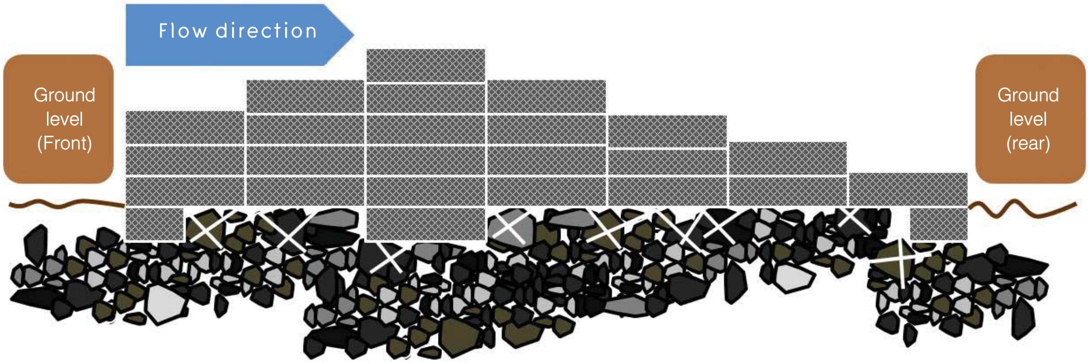


Figure 102:
Putting additional load to the gabion boxes with rocks

4.2.9 Placing seepage path (if necessary)

1) The seepage path should not be placed higher than 0.5 metre above the river bed. If it is too high, during the dry season it will be impossible to convey the water through the path. The pipes should be placed at the side of the weir to minimise the impact caused by the current, debris, and rocks. Once the seepage path is determined, cut the gabion box mesh corresponding to the size of the path.

2) Insert a pipe into the cut-out channel, tilting one end to the rear of the weir to facilitate the flow. Elbow joints can be added to adjust the height of the path corresponding to the water level at the front of the weir.

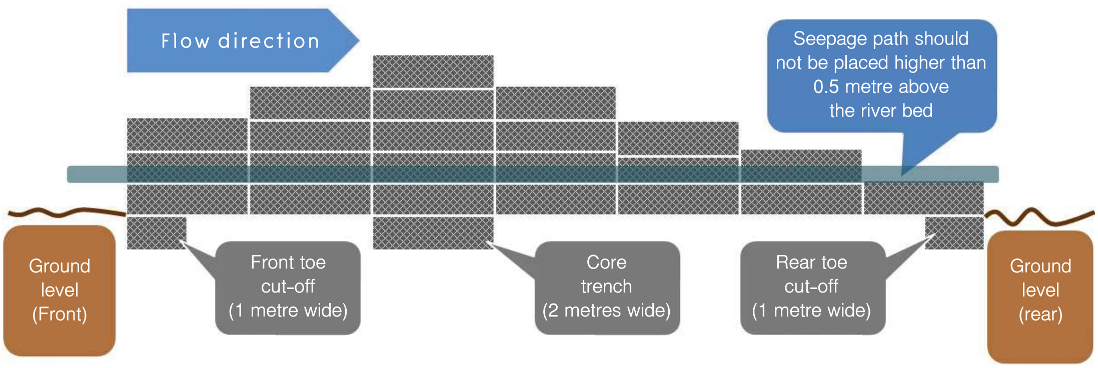


Figure 103:
Position of piping in the gabion weir (side view)

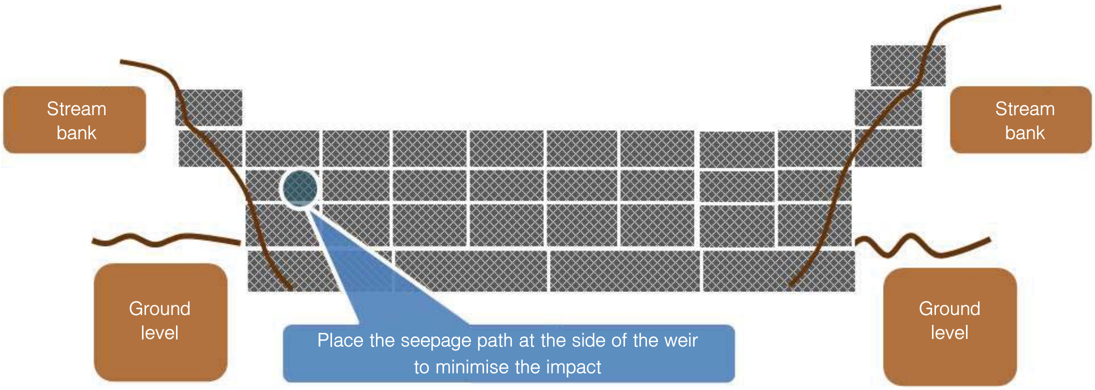


Figure 104:
Placement of seepage path (rear view)

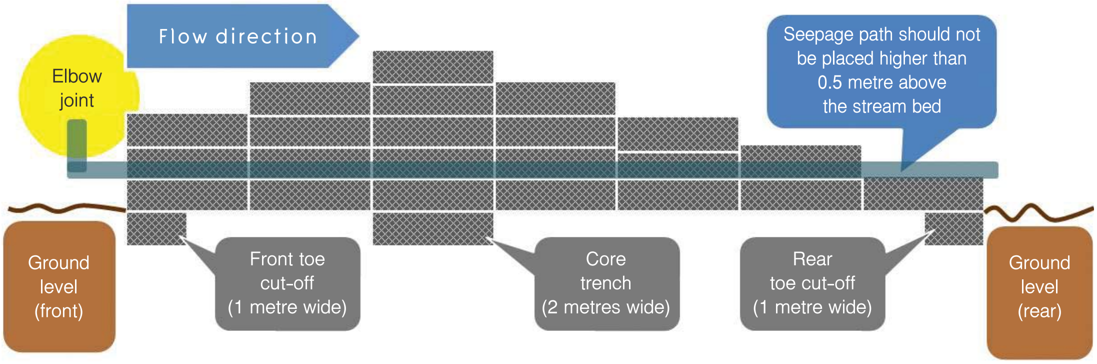


Figure 105:
Adding the elbow joint to adjust the level
of the seepage entry (side view)

3) After placement, tightly lace the pipe with the gabion boxes.

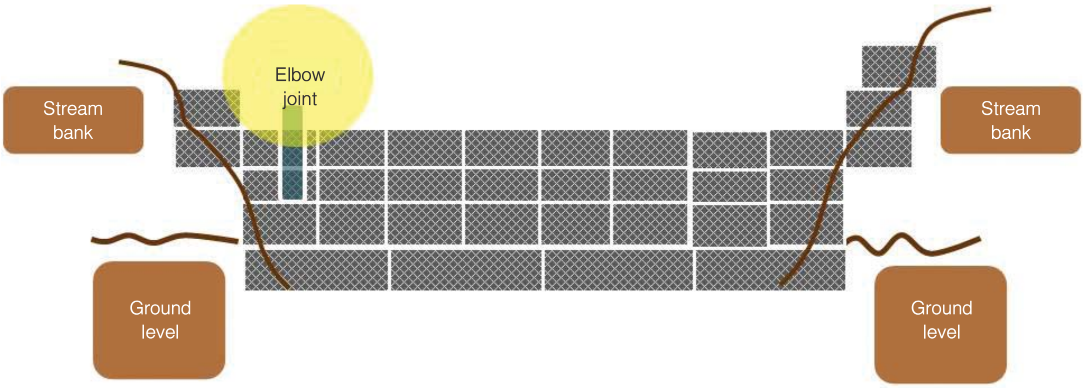


Figure 106:
Adding the elbow joint to adjust the level of the seepage entry (rear view)

4) Concrete lining of the pipe. Add a concrete layer of at least 10 cm along the pipe line for further durability. This also prevents the pipe from any movement caused by the water motion. Once the concrete is dry, fill up the gabions with rocks.

4.2.10 Concrete lining of gabions. The concrete should cover the top surface and four sides of the gabion boxes. Sluiceway should be formed according to the design.

Figure 107:
Gabions before concrete lining

Figure 108:
Gabions with partial concrete lining

Figure 109:
Gabions with full concrete lining

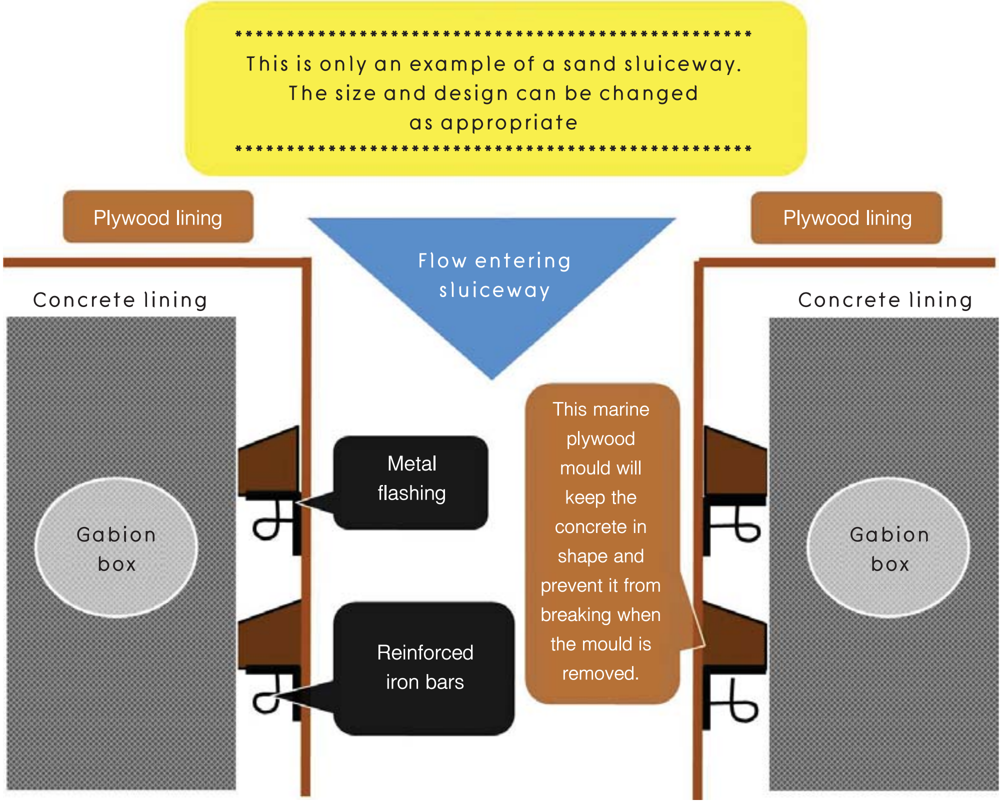


Figure 110:
Example of sluiceway design in a gabion weir

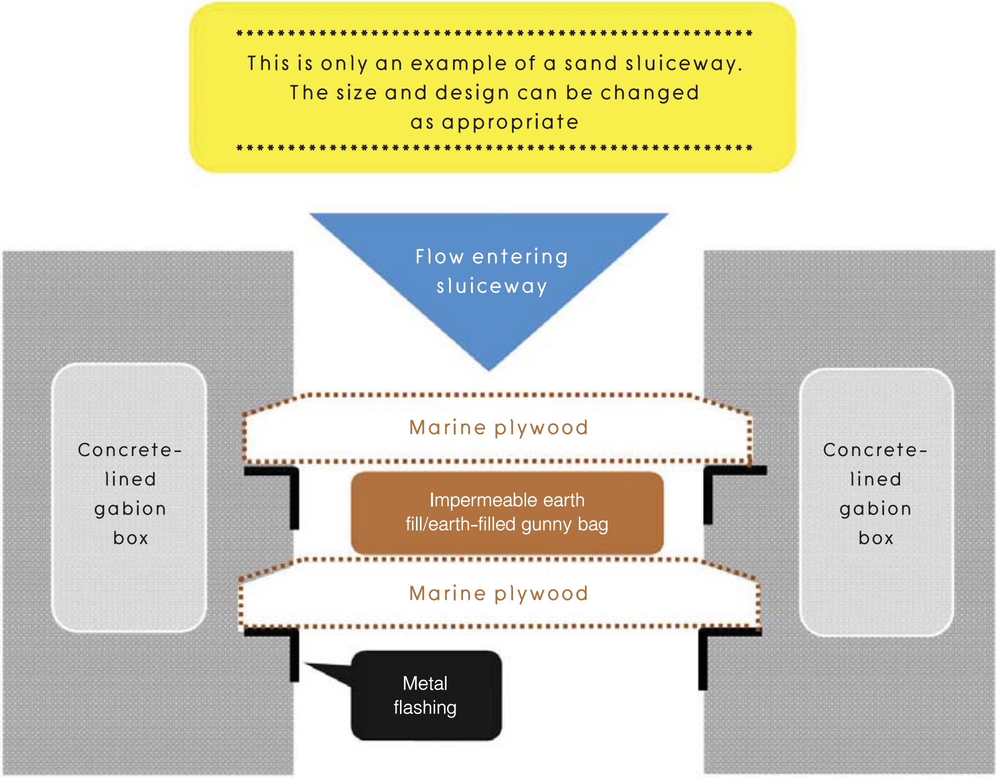
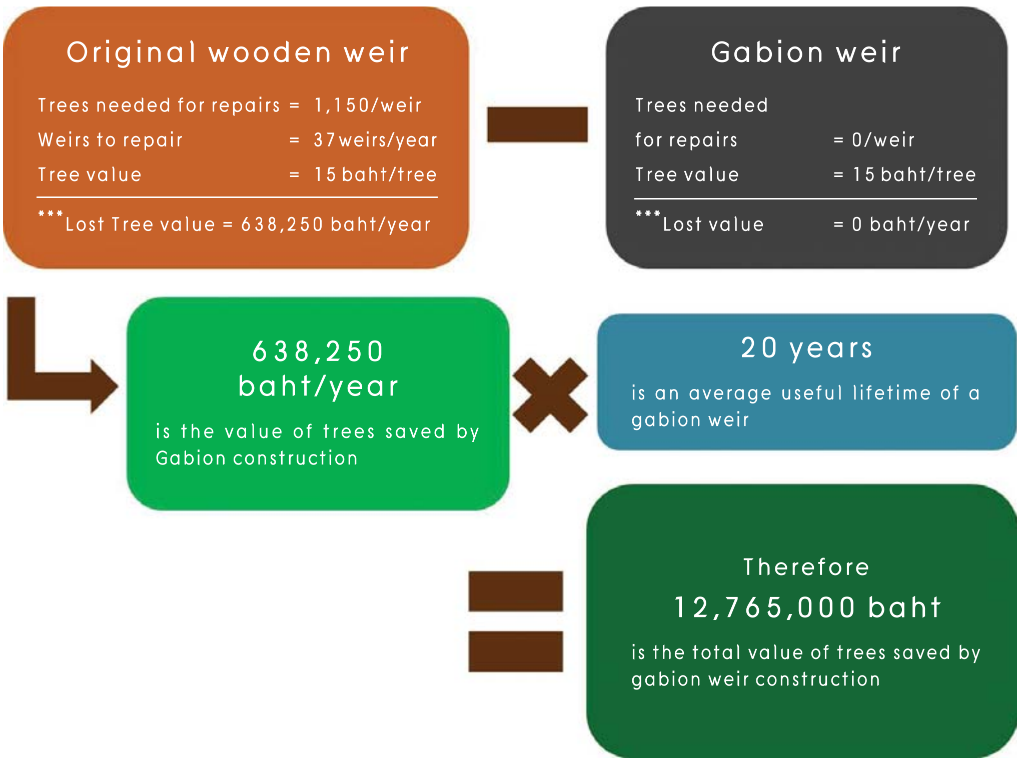


Figure 111:
The sluiceway of a gabion weir when the mould is removed

Figure 112:
A completed gabion weir

4.3 Value of Gabion weir

Prior to the irrigation program by the Royal Initiative Discovery Foundation at Nam Chang, Nan Province, the local people were forced to cut down approximately 1,150 trees with the diameter about 3-4 inches for weir construction and repairs. After the construction of 37 new Gabion weirs, the community was able to save 42,550 trees per year. Following the construction guidelines in this handbook, one weir should last at least 20 years and save 851,000 trees which in turn gain in value over time.



5. Masonry weir

Masonry weir is a type of weir made of concrete and rocks. Usually resembling a trapeze shape, the base of a masonry weir is larger than the weir crest, making it robust and durable enough to withstand collisions from water motion.

Figure 113:
A masonry weir ready for use

5.1 Construction plan for masonry weir

After completing the preliminary site survey and weir design to ensure the dam suits the typographic conditions, a construction plan should be initiated by taking the following issues into account:

5.1.1 Team Composition

1) Site supervisor: this person is responsible for mentoring the team and giving advice according to his personal experiences. A supervisor can be recruited from local construction sites or hired from a private or public company with extensive experiences in irrigation construction or domestic construction. A site supervisor should have the following qualifications:

- Minimum three years of experience in construction supervision
- An ability to perform construction work and supervise the construction process
- Understand the structure and different types of weirs, and is able to read architectural drawings

- Possesses the know-how on how to lay a rock foundation and is able to transfer the knowledge to other workers

2) **General technician:** either one or two per project, depending on workload and urgency. This technician is responsible for performing tasks as instructed by the supervisor and delegating jobs to general labourers. A technician should have previous experience as a construction worker. This position can also be recruited from the villagers or people who are working as construction workers.

3) **General labourer:** While the number of general labourers is not limited, their scope of work is to perform a variety of construction tasks such as steel lacing, concrete mixing and pouring, and form construction. Local people can be recruited as general workers. Not only does this provide job opportunities to them but also indirectly teaches them skills needed in weir construction, maintenance and management in preparation for subsequent handover to the community.

5.1.2 Materials and equipment

1) Materials

- Cement
- Sand
- Rocks, diameter of 20-30 cm
- Crushed stones
- Plastic sheet-to waterproof the diversion dam
- Plywood board-to set up as concrete forms (1.20 m wide x 2.40 m long x 1 cm thick)
- Wood sticks-to brace forms
- Nails of different sizes
- Metal flashings

2) Equipment

- Steel measuring tape
- L-square metal ruler
- Hoe
- Spade
- Crowbar
- Pickaxe
- Nail hammer
- Sledge hammer
- Pincers
- Typical saw
- Hack saw
- Concrete trowel
- Concrete bucket
- Water level
- Plumb bob
- Clamshell baskets

5.1.3. Site preparation or foundation preparation[9]

5.2. Constructing a masonry weir

5.2.1 Site a core trench[10]

5.2.2 Concrete-fill the keys[11]: Once dredging is completed, pour concrete mix using a dewatering technique into the keys. Evenly flatten the concrete to produce a smooth surface.

[9] See details on site preparation on page 66

[10] See details on siting core trench on page 71

[11] A key is a trench excavated at the front, rear or side of weir to protect the weir from seepage underneath the structure. A key has a similar appearance to a cut-off trench

Figure 114:
Filling concrete mix into a core trench and flattening the surface

5.2.3 **Set up concrete forms:** Set up 2 plywood boards, tilting each board inward with slope ratio between the vertical and horizontal line of 5:3. In other words, the forms should resemble a shape of a trapezoid which makes the weir sturdy enough to withstand impact from water pressure. Place metal flashings at the base of the form boards to protect the concrete from damage.

Figure 115:
Concrete forms set up for masonry weir construction

5.2.4 **Insert a pipe:** The pipe should be inserted into the concrete layer, and secured with wire.

5.2.5 **Pour concrete:** For one cubic metre of concrete slab, mix together 5 bags of cement, 3.5 m^3 of sand, 0.4 m^3 of crushed rocks, and 1.15 m^3 of large rocks. Pour the mix over the steel pipe and metal flashings until it reaches the weir crest. Make sure the small rocks do not touch the frame and large rocks are apart so that the concrete has space to cement each rock and making the construction stronger. If it is necessary to pause the pouring process, it is advised to put the rocks on the surface of the concrete which will allow the new layer of concrete to fuse with the previous layer.

Figure 116–117:
Leave rocks on the surface of the concrete
if a pause is needed

Make sure the concrete does not slope when poured in because it will flow to the lower area. It is suggested to pour the mix evenly until it reaches the weir crest position. Strike the concrete off even with the top of the forms. Leave until dry for 24 hours and remove the forms.

5.2.6 **Remove the wooden frames:** Remove the wooden frames and finish the surface. When the forms are removed, it is important to cure the concrete or spray it with water to prevent drying shrinkage resulting in cracking of cement.

5.2.7 **Final Finish:** To prevent seepage or scour caused by the stream, it is a good idea to pour the rock and concrete mixture at the front and rear toes, as well as on both sides of the weir. The sides of the weir should be about 1 metre higher than the crest.

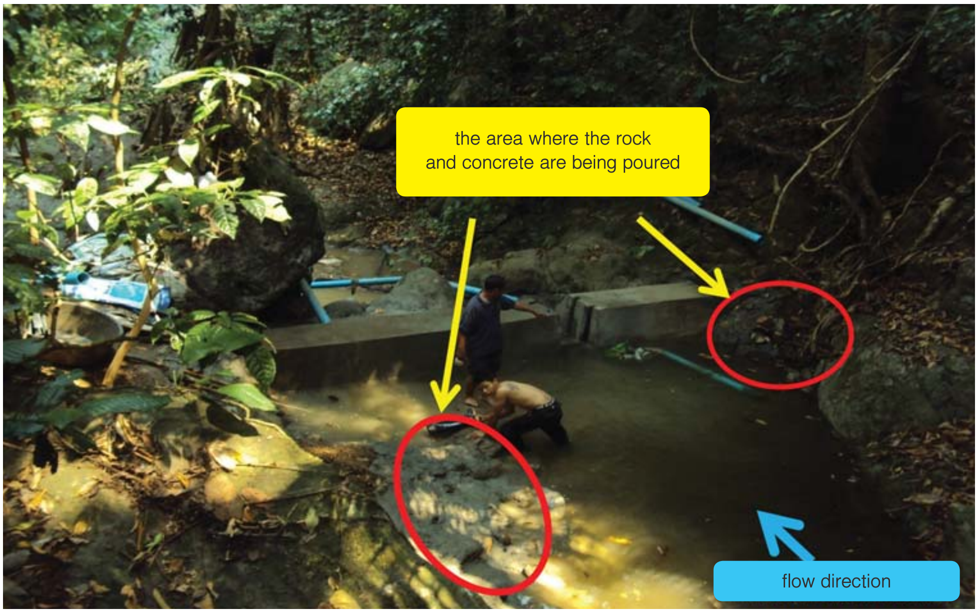


Figure 118:
Final finishing of a masonry weir

Figure 119:
Final finishing of a masonry weir

Upon completion, test the function of the weir by releasing the natural inflow. If the water overflows the crest and continues downstream, it means that weir is in a good condition with sufficient impermeability and zero seepage.

6. Reinforced concrete weir

Reinforced concrete weir is a type of weir made of steel topped with concrete. Reinforced concrete weirs are usually in a rectangular shape.

Figure 120:
A reinforced concrete weir

Figure 121:
A reinforced concrete weir

6.1 Construction plan for reinforced concrete weir

After completing the preliminary site survey and weir design to ensure the dam suits the typographic conditions, a construction plan should be initiated by taking the following issues into account:

6.1.1 Team Composition

1) **Site supervisor:** this person is responsible for mentoring the team and giving advice based on personal experience. A supervisor can be recruited from local construction sites or hired from a private or public company with extensive experiences in irrigation construction or domestic construction. A site supervisor should have the following qualifications:

- Minimum three years of experience in construction supervision
- An ability to perform construction work and supervise the construction process
- Understand the structure and different types of weirs, and is able to read architectural drawings
- Possesses the know-how on laying a rock foundation and is able to transfer the knowledge to other workers

2) **General technician:** either one or two per project, depending on workload and urgency. This technician is responsible for performing tasks as instructed by the supervisor and delegate jobs to general labourers. A technician should have previous experience as a construction worker. This position can also be recruited from the villagers or people who are working as construction workers.

3) **General labourer:** While the number of general labourers is not limited, their scope of work is to perform a variety of construction tasks such as steel lacing, concrete mixing and pouring, and form construction. Local people can be recruited as general workers. Not only does this provide job opportunities to them but also teaches them skills needed in weir construction, maintenance and management in preparation for subsequent handover to the community.

6.1.2 Materials and equipment

1) Materials

- Portland cement
- Crushed rocks
- Sand
- Metal flashings
- Black steel wire
- Nails (1-4")
- Plywood board-to make concrete frame (1.20 m wide x 2.40 m. long x 1 cm thick)
- Soft wood
- Steel bars with the diameter of 9 - 12 mm

2) Equipment

- Pincers
- Steel wire cutter
- Steel measuring tape (30 m)
- Regular saw

- Crowbar
- Pickaxe
- Nail Hammer
- Wrench (9 and 12 mm) for bending steel
- Hoe
- Spade
- Shovel
- Clamshell baskets
- Water level
- Plumb bob
- Concrete bucket

Remark: For 1 cubic metre of concrete, mix 7 bags of cement, 0.28 m^3 of sand, and 0.78 m^3 of crushed rocks together. This ratio provides an estimate of the materials needed.

6.1.3 Site preparation or foundation preparation[12]

6.2. Reinforced concrete weir construction process

6.2.1 Siting cut-off trench

1) Determine footprints of the dam. Mark the four corners of the construction with pegs and rope according to the design. Make sure that all pegs are levelled using a water level. The weir should make a right angle to the flow of water.
2) Excavate the site down to rock layer to site the core trench and keys but the depth should not be more than 1 metre.
3) Place reinforcement steel bar forms into the core trench. If the site has a muddy foundation, fill the trench base with concrete before bar placement. This is to ensure that the foundation is stable with no seepage underneath the structure.

[12] see more details on measuring total water withdrawal on Pages 66

4) Lace the reinforcement steel bars to the weir mattress according to the design.

Since this type of weir has a short downstream slope, the headwater moves downward in a rather sharp drop. This may cause severe impact and erosion on the downstream side of the weir. As a consequence, this type of weir has a short useful lifetime and is easily damaged. To protect from such erosion, additional keyed gabions[13] or masonry rock bed[14] can be added at the end to lengthen its useful lifetime.

6.2.2 Setting up concrete forms

1) Cut steel bars and lace them to form the weir structure.
2) Build concrete frames according the weir design, utilising plywood or softwood.
3) Put the wooden frames in place. Drill a hole for the water pipe according to the design.
4) Place the metal flashings at the channel for the stop lock.
5) Brace the concrete frame.

6.2.3 **Pour concrete into the frame until the space is filled up.** Leave it to dry overnight and remove the frame. Regularly cure the concrete or spray it with water to prevent drying shrinkage which may crack the concrete.

6.2.4 **Final finishing:** Finish the edged of the concrete around the weir.

6.2.5 **Reinforcing the banks upstream and downstream.** Place a steel mesh mattress and reinforce bars before applying a concrete casting. At this stage, it is possible to utilise local resources such as rocks to save materials and transportation cost. There are three methods of rockfilling, depending on the size of rocks available in the area.

1) If the area is covered with both small and large rocks, it is advised to use a free laying method; keep the surface even, and tighten the gaps between large rocks with small rocks.

[13] see more details on gabions on Pages 63

[14] see more details on mansory on Pages 93

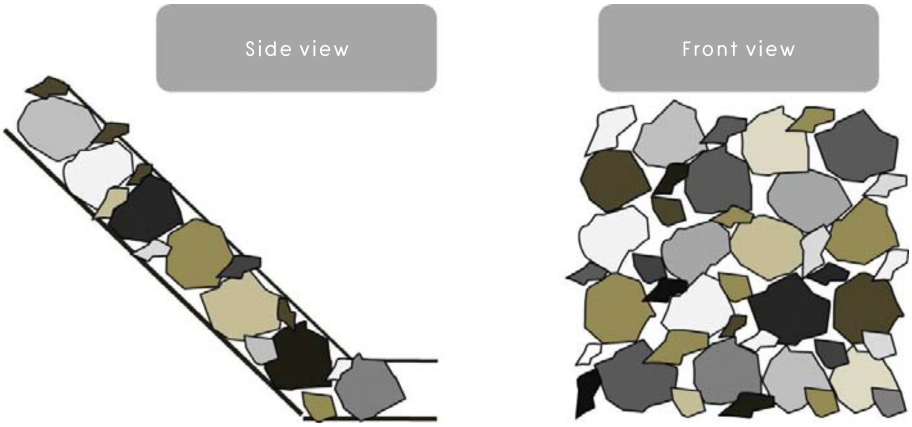


Figure 122:
Free laying method

2) If the site is covered by many different sizes of rocks, it is advised to use a pitching method. To do so, the width side of the rocks is stacked up to make the even surface. This method results in a lot of gaps between the rocks. Therefore, it is necessary to fill the available spaces with concrete. The concrete will also strengthen and protect the bank of a stream.

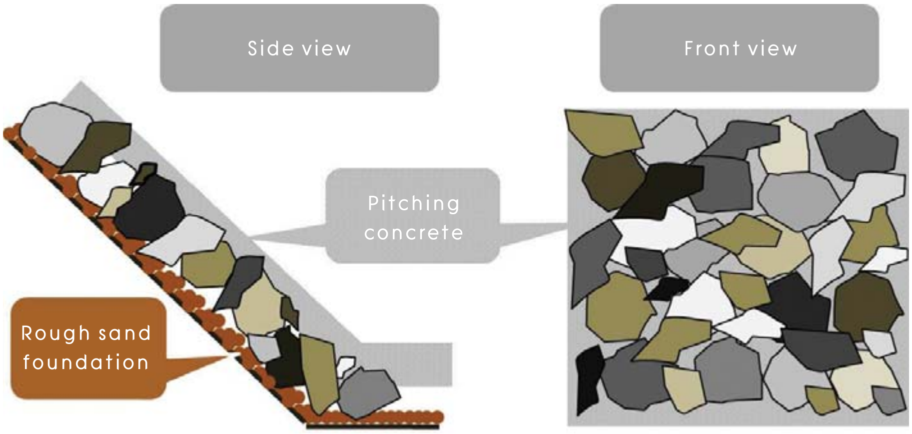


Figure 123:
Pitching method

3) If the site is dominated by long and flat rocks, it is advised to use the even laying method. With this method, the rocks are aligned vertically with the sharp edge in the same direction. It will require a large number of rocks and leave only small gaps. This type of rockfill will yield a tight and durable weir without actually requiring concrete.

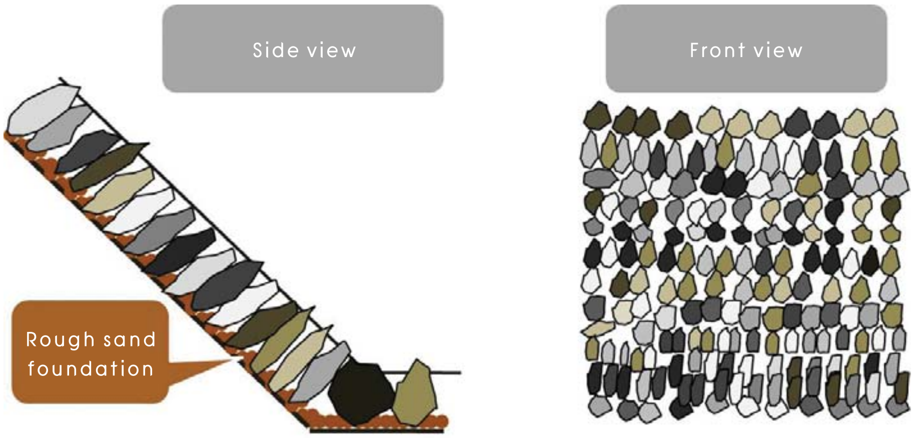


Figure 124:
Even laying method

(04)
WATER SUPPLY CONSTRUCTION

1. Definition of water supply system

Water supply system is a network of conveyances which transfer water from the main reserve such as reservoir, pond, or clarifier tank to other destinations such as households and communities for householdconsumption or agriculture purposes (e.g. orchards, farms, or aquaculture ponds).

2. Types of water supply system

There are three types of water supply systems utilised by the Mae Fah Luang Foundation; 1) piping system, 2) earth canal, and 3) concrete canal. Each of them offers different advantages and disadvantages. Before initiating a program, the Mae Fah Luang Foundation takes into account the topographic constraints and the output efficiency to the local communities. The advantages and disadvantages of the three types of water supply systems are summarized in the following table.

Table 6:
Advantages and disadvantages of each type of water supply system

	Piping system	Earth canal	Concrete canal
Suitable topography	Hilly area with steep slopes. This system requires a high gravitational pressure from the original water resources to convey water into the pipe	1. Relatively flat terrain. 2. Contains a large basin area because the earth canal will be constructed along a contour level.	1. Relatively flat terrain. 2. Contains a large basin area because the earth canal will be constructed along a contour level.

	Piping system	Earth canal	Concrete canal
Space required for construction	Underground. No loss of farmland.	Ground surface, resulting in a loss of arable farmland.	Ground surface, resulting in a loss of arable farmland.
Cost	Pipe lines are expensive, but the construction cost is relatively low.	Relatively low construction cost	High construction cost for canals and water control station.
Water conveyance	The capacity of conveyance depends on the size of the pipe. There is no water loss caused by evaporation during the conveyance.	The capacity of conveyance is high (depends on the total water withdrawal). A certain volume of water is lost by evaporation and leakage during conveyance.	1. The capacity of conveyance is huge (depends on the total water withdrawal). 2. High distribution speed and less leakage than earth canal due to concrete material.
Maintenance	Little maintenance is required.	1. Leaks might be caused at the streambank by wild animals. 2. Susceptible to stream bank erosion. 3. Requires high maintenance labour	1. Not susceptible to stream bank erosion, compared to earth canal 2. Requires less maintenance labour than earth canals

Once the topographic data are considered, determine the height level of the area to design an appropriate water supply system.

3. Preliminary site survey for water supply construction

3.1. Prerequisite preparation

3.1.1 Equipment required

1) Dumpy level
2) Auto level
3) Tripod
4) Target object
5) Levelling rod
6) Measuring tape with the minimum length of 30 m
7) Oil paint - to mark survey area. Pick a clearly visible colour such as red
8) Notebook and pen
9) Machete
10) Nail hammer
11) Nails (1")
12) Wood sticks - to use as survey pegs. The wood could be of any kind found in the area. Split the wood into pegs 1 cm in diameter and 50 cm high. Sharpen one end for ground anchoring. Carve a 3-inch-deep straight line on the other end to create a paper holder slot which marks the distance. The number of pegs required depends on the survey distance. In average, one kilometre requires about 50-100 wooden pegs.
13) Paper (3x3") - to mark distance. Quantity required depends on the numbers of pegs.
14) Camera
15) Vehicle suitable for the area
16) Global positioning system device (GPS)
17) Portable laptop (if available)
18) GPS data processing software (if available)

3.1.2 Team Composition

1) **Survey engineer:** this person is responsible for mentoring the team and giving advice based on his personal experiences. A survey engineer can be recruited from private or public agencies which have extensive experiences in irrigation construction such as Irrigation agencies or Department of Lands. A survey engineer should have 3-5 years of experience in engineering survey.

2) **Three survey engineer assistants:** One is responsible for carrying the survey camera and recording the data, while the other two are responsible for measuring the level of the ground, utilising a levelling rod.

3) **Six general labourers:** While the numbers of general labourers is not limited, their scope of work is to perform a variety of tasks such as grass mowing, distance measuring, and food supplying. Local people can be recruited as general workers. Not only does this provides job opportunities to them but also teaches them skills needed in water supply construction, maintenance and management in preparation for subsequent handover to the community.

3.2 Clear the weeds out of the optical line. Leave a clear space of 1-2 m wide to ensure that nothing blocks the camera. With clear path, the team can also perform the survey more effectively.

3.3 Measure the distance, utilising a measuring tape and anchor a peg every 10-20 metres. Paint the top of the peg. Put a piece of paper which identifies the distance between the peg and the beginning point into the slot on top of each peg. To identify an effective footprint, follow these steps:

Figure 125:
Measuring distance

Figure 126:
Anchoring pegs, painting them and identifying the distance with a piece of paper

3.3.1 For an area with steep slopes where you can visually estimate a height difference of over 3 metres over a distance of 10 metres, anchor a peg every 10 metres.

3.3.2 For an area with relatively flat terrain where you can visually estimate a height difference of less than 3 metres over a distance of 20 metres, anchor a peg every 20 metres.

3.3.3 Mark a peg every 10 or 20 metres respectively, taking the height difference into consideration. If there is a height difference within the 10 and 20 metres mark, it is important to mark that difference. For example, after the 90 metres mark, a team might find a canal blocking the survey line at 94 metres. It is necessary to mark the 94 metres position as well since it reflects a height difference. This can be marked by anchoring a peg at the beginning of the downslope, mid-canal, and the slope-up position where the ground returns to its normal level. At these canal-like positions, it is advised to put at least 5 marks to record topographic changes as well as obstacles such as road or levee that blocks the survey line. The next distance to survey is 100 metres distance where it requires marking every 10 metres onwards as shown in the example below.

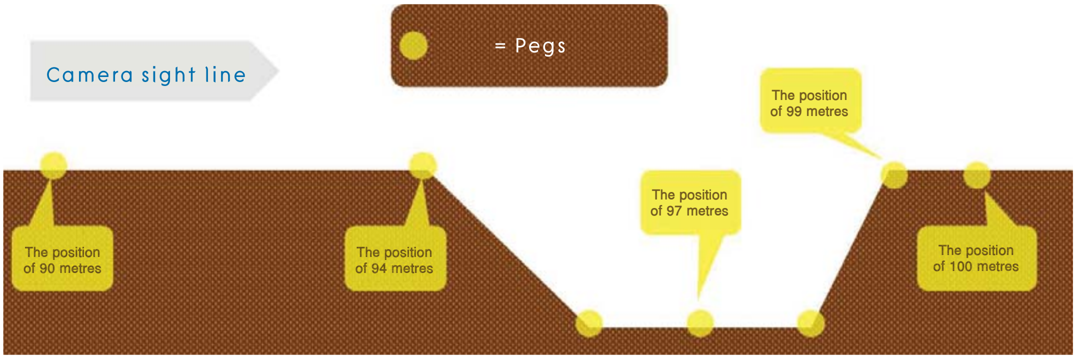


Figure 127:
A sample footprint demonstrating height differences

3.4 Set up a dumpy level and line up with the marked pegs. Record the data and photograph the following:

3.4.1 Topographic details

3.4.2 Characteristics of foundation soil type where the canal cuts through (e.g. clay, granular soil, or rock outcrops)

3.4.3 Channel profile. This refers to stream, canal, levee, or any construction that is caught within sightline.

3.4.4 Soil sample. It is also possible to collect soil and rock samples for further examination which would be useful to the engineering design.

3.5. Plot the data into a cross-section site plan of the irrigation canal. Include other details within the canal area such as streams, roads, andterrain. The designers assess these data and determine the size of the canal, canal type, distribution control station, division box, as well as turnouts.

3.6. Calculate reference points and plot down data on the architectural drawing and basin map.

3.7. Submit the map with coordinate details to the designers of water supply system.

4. Water supply piping system

If it is decided that the topography of the target area is suitable for piping system, a key factor that should be considered is pipe size selection that matches the pressure of the water withdrawal in the local area.

4.1 Calculating pipe size by using the following formula:

$$\frac{x}{100} = \frac{H}{L}$$

Where X = Pressure loss in 100 metre distance

H = Vertical distance between water head and the release opening

L = Total pipe length

Example:

If the water withdrawal in the target area is 666,850 litres per day, the total length of the surveyed and designed pipeline is 1,267 metres, the water head is at 827 metres altitude and the release opening is at 792 metres,

Therefore H = 827 - 792 = 35 metres

L = 1,267 metres

Insert the value into the above equation to calculate the pressure loss:

$$\frac{x}{100} = \frac{35}{1267} \rightarrow x = \frac{35 \times 100}{1267} = 2.76$$

If the value X has two decimal points, disregard the second decimal point. Though the result is less than the actual value, the remaining water is always returned to nature. Compare value X (2.76 in this case) with equivalent pressure loss value in the table below.

Table 7: Pipe sizing chart compared to pressure Loss

Pipe size (inches)	1/2"		3/4"		1”		1 1/2”		2”		2 1/2”		3”		4”		6”		8”	
Value X	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V
1.9	0.1	0.5	0.2	0.5	0.5	0.6	1.2	0.8	2.2	0.9	4.1	1.1	6.1	1.2	11.8	1.4	31.2	1.8	66.2	2.1
2	0.1	0.5	0.2	0.5	0.5	0.7	1.2	0.8	2.2	1	4.2	1.1	6.3	1.3	12.1	1.4	32.2	1.8	67.1	2.2
2.1	0.1	0.5	0.2	0.5	0.5	0.7	1.3	85	2.3	1	4.3	1.1	6.5	1.3	12.3	1.5	32.8	1.9	68.8	2.2
2.2	0.1	0.5	0.2	0.5	0.5	0.7	1.3	0.9	2.3	1	4.3	1.2	6.6	1.3	12.3	1.5	33.4	1.9	69.5	2.3
2.3	0.1	0.5	0.2	0.5	0.5	0.7	1.3	0.9	2.4	1	4.4	1.2	6.8	1.3	12.6	1.6	34.4	1.9	71.7	2.3
2.4	0.1	0.5	0.2	0.6	0.5	0.7	1.4	91	2.4	1	4.6	1.2	6.8	1.3	12.9	1.6	36.2	2.1	73.2	2.4
2.5	0.1	0.5	0.2	0.6	0.5	0.7	1.4	0.9	2.5	1.1	4.7	1.3	7.1	1.4	13.9	1.6	36.2	2.1	75.7	2.4
2.6	0.1	0.6	0.2	0.6	0.6	0.8	1.4	0.9	2.5	1.1	4.9	1.3	7.3	1.4	14	1.7	37	2.2	77.2	2.5
2.7	0.1	0.6	0.2	0.6	0.6	0.8	1.5	1	2.6	1.1	4.9	1.3	7.4	1.5	14.3	1.7	37.7	2.2	79.7	2.6
2.8	0.2	0.6	0.3	0.7	0.6	0.8	1.5	1	2.7	1.2	5	1.3	7.6	1.5	14.6	1.7	39.5	2.2	80.3	2.6
2.9	0.2	0.6	0.3	0.7	0.6	0.8	1.5	1	2.8	1.2	5.1	1.3	7.7	1.5	14.8	1.8	39.3	2.2	81.5	2.7

Compare X with other values in Table 7. The followings are the findings:

1) If a 2'' pipe is used, the velocity in the pipe is 2.6 litres/second, or 60 x 60 x 24 x 2.6 = 224,640 litres/day.

2) If a 3" pipe is used, the velocity in the pipe is 7.24 litres/second, or 60 x 60 x 24 x 7.42 = 641,008 litres/day.

3) If a 4" pipe is used, the velocity in the pipe is 14.25 litres/second, or 60 x 60 x 24 x 14.25 = 1,231,200 litres/day.

With water withdrawal in the target area at 666,850 litres/day, a 3" pipe should be used. This is because the conveyance capacity does not exceed the total water withdrawal, allowing the remaining water of 25,762 to be return to nature or be utilised by downstream users.

If a 4" pipe is used, it could also convey water but at a much higher cost and unnecessarily wasteful.

4.2 Choosing the materials and thickness of the pipe

The selection of pipe material and size depends on the height difference between the water head or distribution tank and the release opening. The higher the difference, the higher the pressure that the pipe system needs to withstand. Inappropriate pipe size selection may eventually lead to rupture.

There are three types of pipe utilised by the Mae Fah Luang Foundation:

4.2.1 PVC pipe is the main pipe type used by the Mae Fah Luang Foundation. This is because the materials can be bought easily and are not expensive. When damaged, the community can always find materials to repair.

Figure 128:
PVC pipes

To find a suitable pipe size at a specific height, multiply the pressure bar of the pipe by 10. The result is the height equivalent to the maximum pressure a pipe can withstand; for instance, a PVC pipe with 8.5 bars is able to withst and pressure from heights up to 85 metres.

4.2.2 Polyethylene or HDPE pipes are more durable and more expensive than PVC pipes. This type of pipe is usually used in a piping system with a network of more than 5 km or that has to withstand pressure that is too high for PVC pipes. However, it is not advised to use this type of pipe in a community area since it is difficult to find the supplies in local markets when repair work is needed. If it is unavoidable, however, the contractorshould order spare pipes and fittings in advance.

Figure 129:
Polyethylene or HDPE pipe

To find a suitable pipe size at a specific height, multiply the pressure bar of the pipe by 10. The result is the height equivalent to the maximum pressure a pipe can withstand; for instance, a PE pipe with 6.3 bars is able to withstand pressure from heights of up to 63 metres.

4.2.3 **Steel pipes** are highly durable but very expensive. This type of pipe is usually used in constructing the intake structure and the weir itself since it can be completely connected to concrete upon construction.

Figure 130:
Steel pipe

However, it is not advised to select the pipes with pressure bar equivalent to the maximum permitted pressure head. For example, if the elevation difference is 80 metres, it is not advisable to select PVC pipe 8.5 because the system might wear off very quickly. A PVC 13.5 is preferable. The criteria for pipe size selection can be referred to in the following diagram.

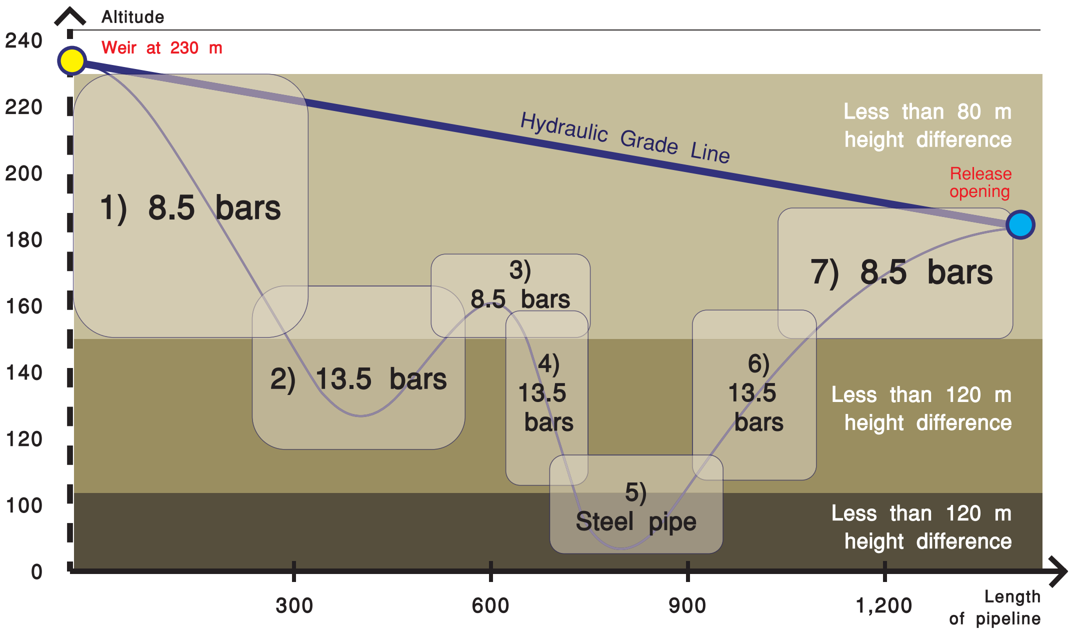


Figure 131:
Correspondence of pipe sizing
and materials at different altitudes

In the above diagram, the weir structure is located at an altitude of 230 m. Seven different pipes are used in the system.

1) At 300 m from the weir structure, the height difference is less than 80 m. Therefore, the most suitable size pipe is NP 8.5.

2) At 300-500 m, the height difference is more than 80m but less than 120 m.

Therefore, the most suitable size pipe is NP 13.5.

3) At 500-700 m, there is a small slope and the height difference is less than 80 m. Therefore, NP 8.5 can still withstand the pressure.

4) At 700-780 m, there is a sharp drop and the height difference is more than 80 m but less than 120 m. Therefore, the most suitable size pipe is NP 13.5.

5) At 780-900 m, the section is at the lowest altitude compared to other sections. The height difference is over 120 m which means it bears the maximum pressure load from the head. Thus, a steel pipe is required.

6) At 900-1,000 m, the height difference is more than 80 m. but less than 120 m. Therefore, the most suitable size pipe is NP 13.5.

7) At the end of the pipe line, the terrain turns uphill and the height difference is less than 80 m. Therefore, the most suitable size pipe is NP 8.5.

Caution about piping installation: the length of each type of pipe is predetermined by the manufacturer. For example, a PVC pipe with diameter less than 8 inches is only 4 m long. One common issue found during installation is that the junction point does not correspond to the designed pipe requirements of the network. For example, if a system requires 119 m of NP 8.5 followed by a section of NP 13.5, 30 pieces of NP8.5 (4 m each) are required to complete the first section with 1m overtop to the NP 13.5 section. In such a case, it is necessary to install the NP13.5 pipe 3-5 metres before it reaches the junction point. Alternatively, when new sizing is required, extend the higher NP into the lower NP pipe section by 3-5 metres. See in the following diagram for illustration.

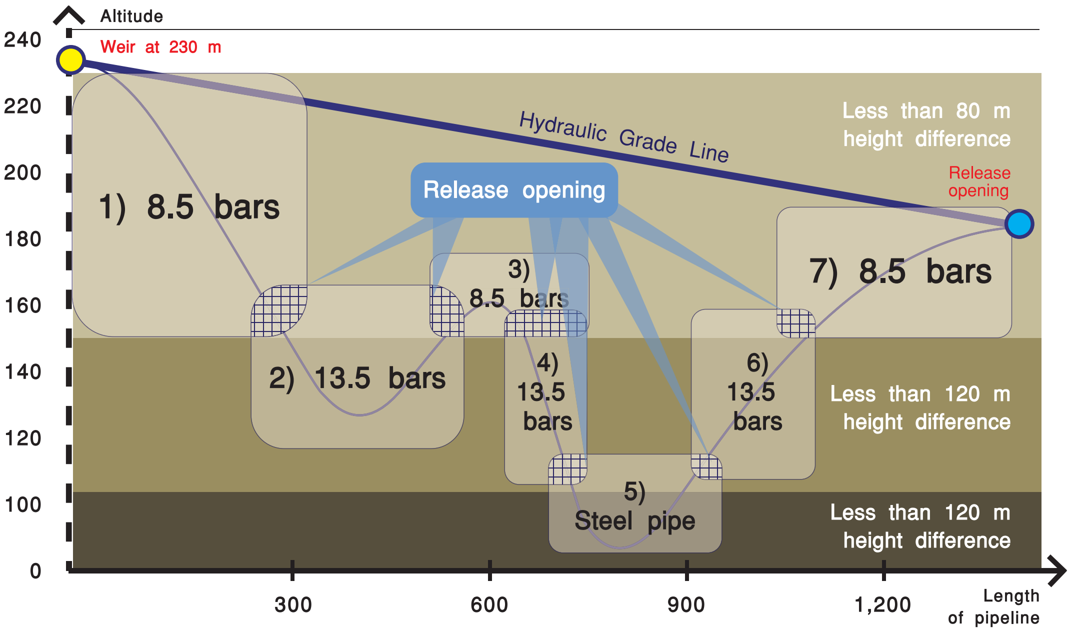


Figure 132:
Changing points in a piping network

According to the example above, it is clear that water supply installation requires a complicated engineering design that involves multiple pipe materials and sizing. Actually, we could build the whole system with steel pipes all the way. However, it is not recommended because it is not easily available in the market. If the system needs repairs, the local community is responsible for sourcing the pipes and paying a high price for them. As a result, the Mae Fah Luang Foundation decided to use PVC pipes which are easy to find and cheap. Although the system requires different pipe sizes, the community can still benefit from it compared to the steel pipe system. More importantly, the community can also find PVC pipes in local shops if repair work is required. The main consideration for Mae Fah Luang is to ask how the villagers can benefit from the development program.

4.3. Designing wash-out valves and air-bleeding valves

The basic principle for designing wash-out valves and air-bleeding valves is to locate the highest and lowest points of the network. Sediments are often found in the lowest points of the pipeline while air bubbles are usually formed in the highest points because they are lighter than water and always go upward. Without air-bleeding devices, the air creates an air plug, a barrier to the water flow, resulting in air lock phenomenon.

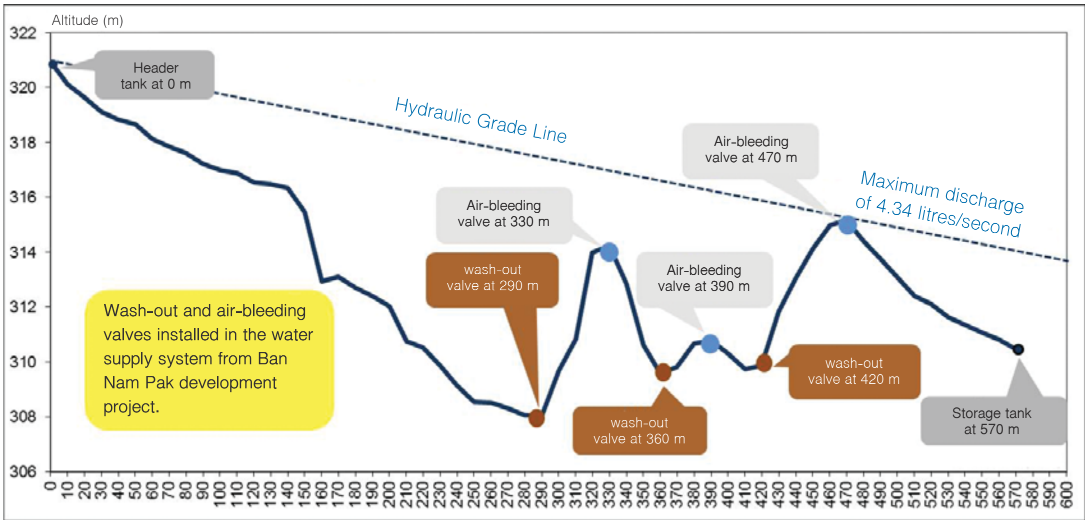


Figure 133:
Profile with wash-out
and air-bleeding valves

When designing wash-out and air-bleeding valves, there is one thing to keep in mind. If a pipeline contains series of small downslopes towards the lowest point of a network, or a series of small upslopes toward the highest point of the network, it is not necessary to install the valves at all highest and lowest points. This is because eventually, sediment falls down to the lowest part of that section and air always goes upward to the highest point of that section as well.

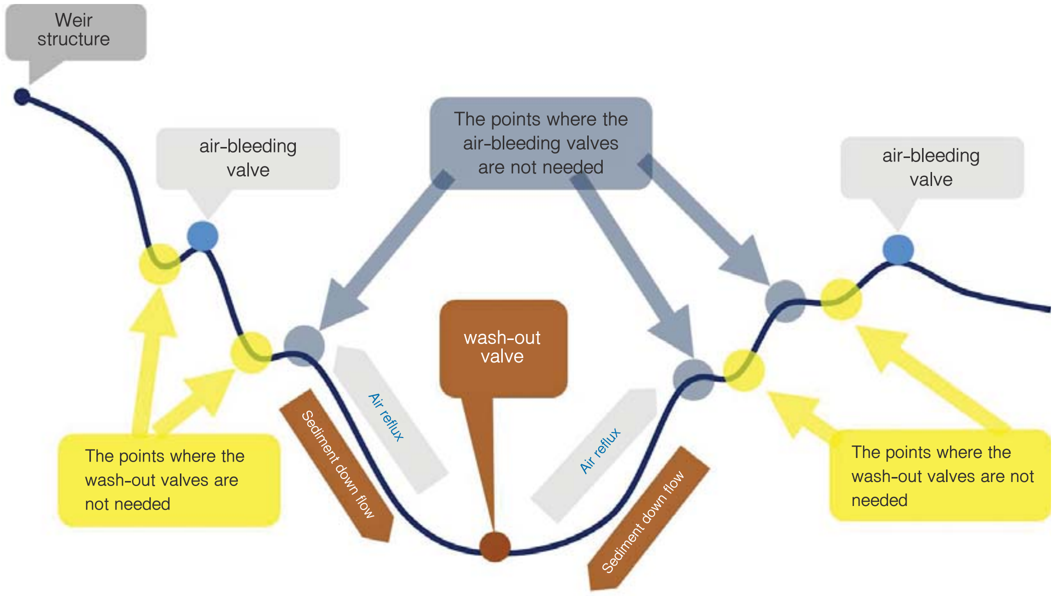


Figure 134:
The points where wash-out and air-bleeding valves are not necessary.

4.4 Construction planning

4.4.1 **Set up a material inventory:** After designing the water supply piping system, estimate the construction materials required and keep track of the inventory as a written record. The data in the inventory should include the following:

1) Size of pipe
2) Type of pipe
3) Length of pipeline. Add 5-10% to the required length estimated by site surveying. The figure of increment depends on the slope of the pipeline network. Sharper slope requires higher increment.
4) Pipe fittings such as valves, elbows, joints, T-joints, and others as specified in the design.

4.4.2 Equipment required

1) Hoe
2) Knife
3) Pickaxe
4) Crowbar
5) Saw
6) A set of wrenches for screwing and unscrewing
7) Monkey wrench for tightening pipes larger than 3”

4.4.3 **Team Composition:** The team members should consist of the following:

1) Engineer: The engineer should have at least three years of experience in piping system and piping construction.
2) Two engineer assistants: The assistants should have at least one year of experience in construction work
3) General labourers: While the numbers of this position is limited to the size of the project, the team should recruit local people as general labourers. Not only does this provide job opportunities to them but also teach them skills needed in water supply construction, maintenance and management in preparation for subsequent handover to the community.

4.5 Pipe installation

4.5.1 Place each type of pipe as close to the designated pipeline as possible. The accessibility to the site should be divided into sections according to the design.

Figure 135:
Placing pipes near the designated pipeline.

4.5.2. Trench construction along the surveyed line. If the construction is executed shortly after the survey, use survey line as a guideline.

Figure 136:
Trench construction

4.5.3 The trench should be at least 50 cm deep with and wide enough to fit each size of the pipes.

Figure 137:
The trench should be at least
50 cm deep.

4.5.4 Install all components of the pipes as specified in the design. Should the survey team fail to detect underground obstacles such as rocks or tree roots, or the foundation of another building, which makes it unable to follow the design, it is possible to change the position of the washout valve or air-bleeding valve to fit the actual topography of the area. The decision shall be made by the engineer. The change shall also be reported to the designer for adjustments.

4.5.5. Examine the construction, fill the pipe with water and test for worthiness. Should any leaks be found, repair immediately and backfill tightly.

5. Water supply canal system

The water supply canals initiated by the Mae Fah Luang Foundation are generally constructed with a top width of less than 2 metres, a bottom width of 1 metre, and depth of 1metre. This is because the the Mae Fah Luang Foundation focuses on the development of small basins which yield results within a short time.

5.1 Designing a water supply canal

To design a water supply canal, the following factors should be considered.

5.1.1 Side slope should be of 1:1.5 ratio. If the site has a limited construction space, it is possible to use the ratio of 1:1 instead. The latter, however, is susceptible to bank erosion.

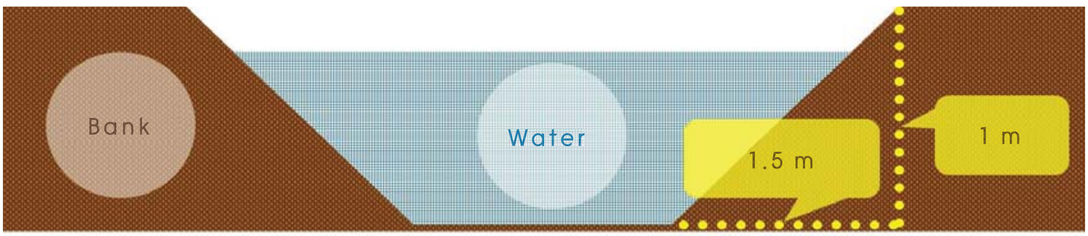


Figure 138:
Cross-section view showing the ratio of side slope

5.1.2 Bottom slope should be designed by taking the local topography into account. For example, if the area under the project has an average slope ratio of 1:1,000 (a rise of 1 metre for every 1,000m), the bottom slope of the canal should be 1:1,000 accordingly.

5.2 Construction planning

5.2.1 **Set up a material inventory:** After designing the water supply piping system, estimate the construction materials required and keep track of the inventory as a written record.

5.2.2 Equipment required

1) Saw
2) Nail hammer
3) Sledge hammer
4) Pincers
5) lineman pliers
6) Crowbar
7) Pickaxe
8) Clamshell baskets
9) Concrete bucket
10) Hoe
11) Shovel
12) Steel measuring tape
13) Concrete mixing tub
14) Concrete mixing machine
15) Plastic trowel
16) Leaf trowel
17) Triangular protractor

5.2.3 Team Composition: The team members should consist of the following:

1) Engineer: The engineer should have at least three years of experience in piping system and piping construction.
2) Two engineer assistants: The assistants should have at least one year of experience in construction works
3) General labourers: While the numbers of this position depends on the size of the project, the team should recruit local people as general labourers. Not only does this provides job opportunities to them but also teaches them skills needed in water supply construction,

maintenance and management in preparation for subsequent handover to the community.

5.3 Construction process

5.3.1 For earth canals

1) Determine the size and line of the canal using a dumpy level. Set up level and mark the distance, section by section.
2) Clear the weeds along the optical line. If heavy machinery is used, it is possible to clear the weeds and adjust the surface level to the specification at the same time. If human labour is used, surface scraping can be done simultaneously with trench construction.
3) Determine the width of the canal according to the design.
4) Excavate canal channel as specified in the design. If heavy machinery is used, it is advised to excavate backward to prevent the excavated soil from falling into the channel. If human labour is used, a supervisor is needed to make sure that the channel reflects the size as specified in the design.
5) During the excavation, the dug soil is to be spread out, trimmed and compacted as a canal bank. Supervisor and workers can walk on this pathway to check the construction work progress. This earth structure also allows accessibility to the canal for maintenance and provides a service road to the local people who might need to transport their agricultural produce to the market.

Figure 139:
Canal bank construction and channel excavation simultaneously

6) Finish the construction details as specified in the design. Human labour is preferable at this because they are more precise and detailed than machines.

5.3.2. For concrete canals, follow the same steps as that of the earth canal. Upon completion, pour concrete into the channel by taking the following steps:

1) Firmly compact the canal bed and slope as specified in the canal design.

Figure 140:
Canal bed compaction

2) Place concrete forms on the canal bed every 2-3 metres to allow the worker to finish the finer details of concrete work.

Figure 141:
Concrete forms placement

3) Pour two-inch slabs of concrete into the forms along the canal line. If the slab is thinner, the canal might become fragile and susceptibleto cracks. If it is thicker, it is an unnecessary waste of concrete. It is advised to pour alternate sections of concrete so it's easier to whitewash, and saves time setting up the forms

4) Remove the forms from the concreted sections. Place a polystyrene slabs (1 cm thick x 2" wide) along the sides of the poured concrete . Make sure the polystyrene slabs reach the top level of the concrete surface in each section. This is to prevent the freshly-poured concrete being attached to the dry section.

5) Fill the concrete in the remaining sections to complete the canal. Leave at least 24 hours until dry.

Figure 142:
Pouring concrete into the canal

6) Remove all polystyrene slabs. Mix asphalt with sand at the ratio of 1:1. Pour the mixture into the gaps between each concrete section.

(05)
Water Storage Construction

1. Definition of water storage

Water storage is the key element in a water supply piping system. This is because the pipes only convey water from the catchment and is limited by the network capacity. Water storage, on the other hand, completes the whole supply network by collecting the water conveyed from the natural source, and distributing it to other end users in the community.

Water storage is not necessary for irrigation canal systems because canals are directly connected to the intake structure upstream and therefore function as water storage themselves.

2. Types of water storage

There are two types of water storage utilised by the Mae Fah Luang Foundation: 1) concrete tank and 2) small reservoir. Each of them offers different positive and negative effects. Before initiating a program, the Mae Fah Luang Foundation takes into account the topographic constraints and the output efficiency to the local communities. The details on advantages and disadvantages of the three types of water supply systems are summarized in the following table.

	Concrete tank	Small reservoir
Function	Suitable for consumption purpose due to its closed structure.	Suitable for agricultural purpose due to open structure that allows dust and particles to fall down
Construction	If the construction site is not easily accessible, there might be some difficulties in transporting the construction material into the area	Has potential for any rural area
Size	Due to its weight, the maximum capacity is usually below 1,000 m^3	If the area is suitable, the maximum capacity might be more than 1,000 m^3
Cost	Approximate construction cost at 3,000 baht/1 m^3	Approximate construction cost at 150 baht/1 m^3

Once the topographic data are considered, determine the height level of the area to design an appropriate water supply system.

3. Storage tank

A storage tank is a reinforced concrete water tank used for storing water for consumption. The shapes may vary, depending on the usage within the community and topographic constraints. It could be in the shape of a sphere, cuboid, or multi-angular. The size and capacity depend on the total storage requirement. The minimum capacity is 100 m^3 or 6 m. wide x 2.15 m. high — a standard size for easy maintenance.

Figure 143:
A concrete tank ready for use

Apart from the tank itself, a storage tank consists of other five key components:

1) Inlet pipe: usually made of PE or PVC pipe installed at the brim of a tank

Figure 144:
An inlet pipe at the brim of the tank

2) Outlet pipe: usually made of steel and installed at the lower part of a tank
3) Spillway: usually made of PE or PVC pipe installed at the brim of a tank
4) Wash-out pipe: usually made of steel and installed at the terminal point of the pipeline to drain out all the water from the pipe.
5) Open-close valve installed at the inlet and outlet pipes.

Figure 145:
An outlet, spillway, wash-out, and open-close valve.

3.1 Determine the location of water storage

In principle, water storage should be located at a lower altitude than the water source (generally the water source refers to a weir structure from which the water flows throughout the year). However, it must be placed higher than the distribution network. The construction site must not be a landfill because the foundation may collapse and the tank will be damaged.

3.2 Construction plan for a storage tank

3.2.1 Team Composition

1) Site supervisor: this person is responsible for mentoring the team and giving advice according to his personal experiences. A supervisor can be recruited from local construction sites or hired from a private or public company with extensive experiences in irrigation construction or domestic construction.

2) General technician: either one or two per project, depending on workload and urgency. The technician is responsible for performing tasks instructed by the supervisor and delegating jobs to general labourers. A technician should have prior experience as a construction worker. This position can also be recruited from the villagers or people who are working as construction workers.

3) General labourer: While the number of general labourers is not limited, their scope of work is to perform a variety of construction tasks such as steel lacing, concrete mixing and pouring, and form construction. Local people can be recruited as general workers. Not only does this provide job opportunities to them but also teaches them skills needed in weir construction, maintenance and management in preparation for subsequent handover to the community.

3.2.2 Material and Equipment

- Portland cement
- Concrete spacer (5 cm)
- Crushed rocks
- Sand
- Metal flashing
- Black steel wire
- Nails (1-4")
- Plywood board - to create forms (1.20 m x 2.40 m x 1 cm)
- Softwood
- Rebars (diameter 9-12 mm)
- Pincers
- Steel wire cutter
- Steel measuring tape (30 m)
- Saw
- Crowbar
- Pickaxe
- Nail hammer
- Wrench (9 and 12 mm) for bending steel
- Hoe
- Spade
- Shovel
- Clamshell baskets
- Water level
- Plumb bob
- Concrete buckets
- Concrete mixing machine

Remark: For 1 cubic metre of concrete, mix 7 bags of cement, 0.28 m^3 of sand, and 0.78 m^3 of crushed rocks. This ratio gives an estimate of the materials needed.

3.3 Levelling the surface of the construction site

Figure 146:
Levelling the surface of the construction site

3.4 Construct the base of the tank structure: Pour Portland cement at the foundation of the structure. The cement base should be approximately 3 cm high.

3.5 Lay the concrete spacers (5 cm) on the foundation. Place the 12 mm rebar formworks on the spacers, followed by washout valve installation.

Figure 147:
Concrete spacers, rebar formworks,
and washout valve placement

3.6 Mix concrete, using the ratio between cement, sand and crushed rock of 1:2:3. Add waterproofing solution into the mixture.

Figure 148:
Concrete mixing ratio

3.7 Pour the mix on the ground to create a 30 cm high floor slab.

3.8 Weave and lace the 12 mm rebar to the 9 mm rebar according to the design.

3.9 Place interior wooden forms inside the structure. Spare a space of 5 cm between the form and the rebar.

Figure 149:
Placement of an interior wooden form

3.10 Place exterior wooden forms outside the structure. Spare a space of 20 cm between the exterior forms and the interior forms. Firmly brace the forms from the outside and inside to prevent deformation during casting.

Figure 150:
Exterior concrete form bracing

Figure 151:
interior concrete form bracing

3.11 Install the inlet pipe and spillway according to the design.

3.12 Install mason's lines at the top of the interior and external forms to de-angle the cast.

3.13 Pour concentrated Portland cement to the thickness of 3 cm. Let the freshly-poured concrete blend with the concrete foundation.

3.14 Cast four walls with the prepared concrete mixed with the waterproofing solution. Try pouring the mixture in a circular manner to evenly level the cast. During casting, compact the concrete very well for an even density.

3.15 Level the storage tank according to the cornice formwork.

3.16 Leave concrete to dry for about 48 hours. Remove then forms; finish the surface until smooth and even.

3.17 Cure the concrete by spraying all sides of the wall with water. Cover the tank with a plastic film or gunny bags to prevent the concrete from drying shrinkage. Cure the concrete for another three days and remove the forms.

3.18 Fill in the tank with water. Gradually increase the water level. It is not recommended to fill the tank to the maximum capacity of the tank at once.

4. Small reservoir

A small reservoir is a type of water storage situated on a hill slope or a long mountain ridge. Functioning as a reservoir to support agricultural and livestock activities during dry season, it can also be a home to aquaculture which in turn provides additional income to the local people. Small reservoir can distribute water with the piping system connected between at least two storage units.

4.1 Construction plan for small reservoir

The construction of a small reservoir should be performed during the dry season. This is because a compacted and stabilized foundation is required to construct an efficient reservoir. If the construction takes place in rainy season, the foundation might become unstable and muddy. Before starting the construction, the following should be considered.

4.1.1 Team composition

1) Engineer: this person is responsible for mentoring the team and giving advice according to personal experiences. A supervisor should have extensive experiences in reservoir construction.

2) Two engineer assistants: These assistants are responsible for performing the tasks assigned by the engineer as well as distributing them to general labourers. Engineer assistants should have at least one year of experience in construction works

3) General labourers: While the number for this position is not limited, the team should recruit local people as general labourers. Not only does this provide job opportunities for them but also teaches them skills needed in water supply construction, maintenance and management in preparation for subsequent handover to the community.

4.1.2 Materials and equipment

- Hoe
- clamshell basket
- Hose
- Manual wooden compactor - to compact the soil
- Wood plank - to compact the soil
- Plastic film
- Pipe (diameter 2-3”)
- Bamboo stakes (diameter 3-4”)
- Nylon rope

4.2 Prepare the surface of the site. Make sure that the foundation spans 2 metres beyond the designated size at all sides. The reservoir must be on a prepared foundation only. No part of the reservoir should be built on newly deposited soil.

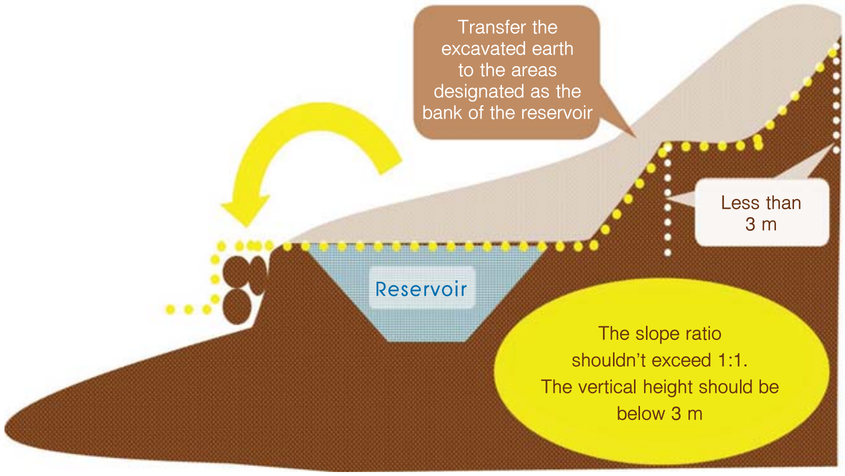


Figure 152:
The cross-section view showing the site preparation for small reservoir construction

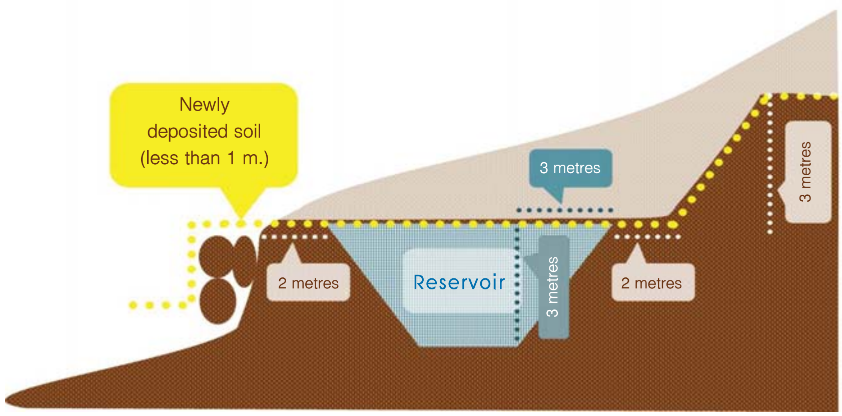


Figure 153:
The cross-section view showing small reservoir excavation

4.3 Perform land excavation according to the design. There are two excavation methods.

4.3.1 Hand excavation: human labour is preferable if it is impossible to utilise heavy machinery on the site or if the employment needs in the local area are high. With hand excavation, one worker can perform the job at an average of 1 m^3 per day. The total excavation time depends on soil volume and the number of workers per day. In general, one worker needs a work space of 2 m^2. Smaller area will reduce the workability.

4.3.2 Machine excavation: This method is considerably more time-saving but also costly. Besides, it does not generate income for local people and does not create a sense of ownership among the villagers.

Figure 154:
Machine excavation

4.4 Remove rocks, sticks and sharp objects from the site to prevent rupture during plastic sheet placement.

Figure 155:
Clearing away unwanted rocks and debris from the site

4.5 Streamline the surface of the side slope, utilising heavy wood plank, rocks or manual wooden compactor. Make sure there are no rocks or wood sticks in the site. If the site is in proximity to a natural water source, sprinkle the soil with water to soften the earth and facilitate the compaction.

Figure 156:
Compacting the side slope of the reservoir

4.6. Establish a bank of 1.5 metres wide and level the foundation. Make sure the inner edge and the outer edge are parallel.

Figure 157:
Preparing a bank

4.7 Excavate a trench 50 cm from the reservoir's inner edge. The trench should be 30 cm deep and 50 cm wide to bury to edge of the plastic sheet.

Figure 158:
Excavate a trench for the edge
of plastic sheet can be buried

4.8 Open the plastic sheet at the bed and spread it over the whole structure. Handle with care and make sure the plastic is not ripped. If a rip or cut is found, repair it immediately. For plastic sheets with 0.5 mm thickness, blow over a puncture with hot air which gradually softens the plastic and welds it together. For plastic with 0.15 mm thickness, apply rubber adhesive on a patch of the same plastic material. Attach to glued patch on the ripped section.

Figure 159:
Opening the plastic sheet at the bed of a reservoir

Figure 160:
Spreading the plastic sheet over the reservoir structure

4.9 Stretch the lining toward the excavated trench. Put the line of the sheet into the trench one side at a time to prevent it from loosening and falling into the reservoir. Backfill the trench and firmly compact the ground to prevent it from loosening.

Figure 161:
Film placement into the excavated trench

Figure 162:
Backfilling the trench

Figure 163:
Soil compaction is important to prevent to film from loosening

4.10 If the plastic sheet is not long enough, extend it with another sheet. To extend the length, mark an overlap area of 50 cm from the edge of the plastic sheet. Dig a trench 50 cm wide and 30 cm deep across the bed. When excavation is completed, place a new plastic sheet over the first, with the edges parallel. Fold in the edges of both sheets three times, making each fold 15 cm. wide and tuck the fold into the trench. Backfill and compact the ground.

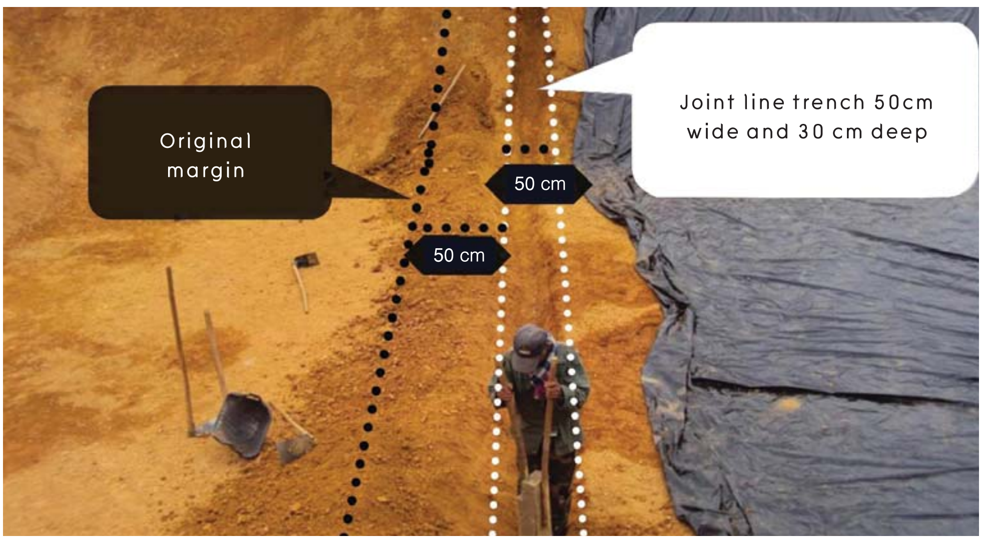


Figure 164:
Excavate a trench to hold a joint line

Figure 165:
Folding the margin of the plastic films to connect them together

Figure 166:
Securing the plastic sheet in the trench

4.11 After a firm compaction, flip the upper plastic sheet and spread it towards the other side to continue the work. Follow the lining instructions in 4.7-4.9.

Figure 167:
Sheet extension

4.12 Install the piping system. Three piping systems can be installed in a small reservoir; 1) the water inlet system, 2) the water outlet system, and 3) the drainage system.

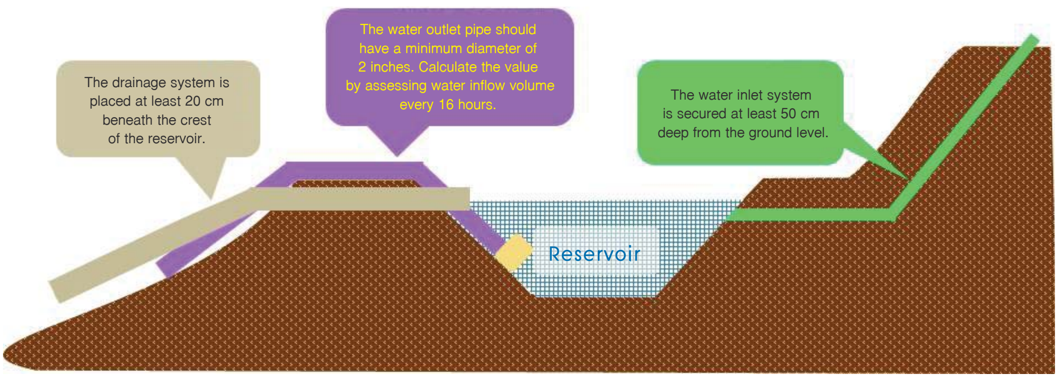


Figure 168:
The piping system for Small reservoir

4.12.1 The water inlet system for a small reservoir can be installed according to the following instructions.

1) Excavate a pipe trench

2) Connect the water inlet pipe to nearby water sources such as check dam, agriculture weir, or water pools on the mountains.

3) Install the pipe in the trench at least 50 cm deep from the ground surface to prevent any damage from wildfire, falling rocks or tree branches.

4) Pipe size depends on the total water withdrawal and the distance between the water source and the small reservoir[15]

4.12.2 The water outlet system which connects the small reservoir to the receiving areas can be installed. The pipe is activated by the siphon principle, the same principle as filling a car petrol tank at a station.

1) Siphon system for reservoirs with aquaculture

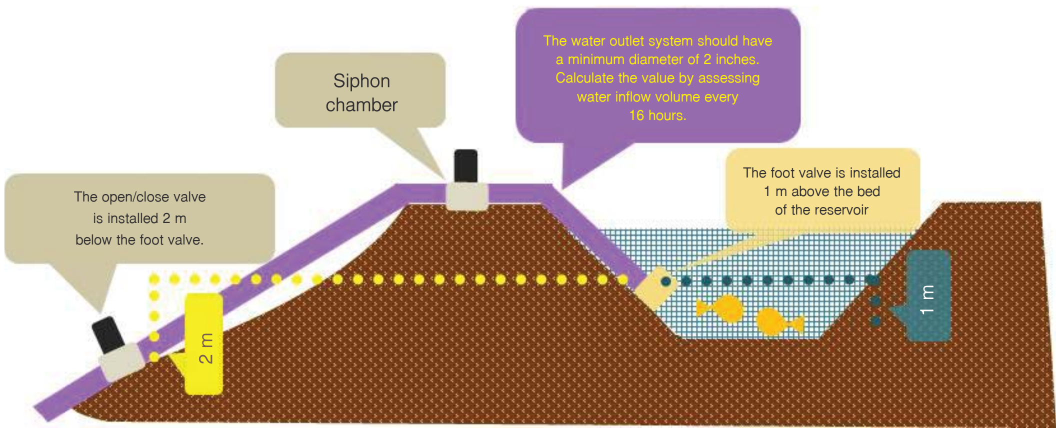


Figure 169:
Distribution system utilising siphon principle
for small reservoirs with aquaculture

[15] See details on pipe sizing and selection on page 112-124

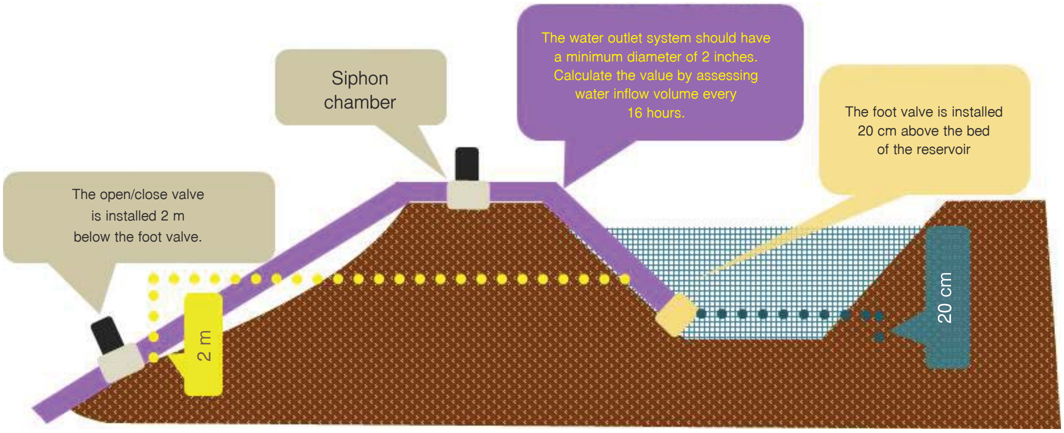


Figure 170:
Distribution system utilising siphon principle
for small reservoirs without aquaculture

4.12.3 Drainage system: The drainage system is installed to prevent the water from overflowing the edge of the pool, destroying the edge or even the whole structure. The size of the drainage pipe should be twice the size of the inlet pipe. The drainage pipe should be installed 20 cm from the edge of the reservoir to avoid conveyance delay when there is a high inflow and heavy rainfall. To properly install the drainage pipe, it is important to assess the width and length of the reservoir as well as the total water withdrawal. The release opening of the drainage pipe should be linked to nearby streams or canals.

4.13 Build a fence and line floating aid ropes. The plastic sheet lining the small reservoir is very slippery. If a child or pet falls in, there could be fatal consequences. Therefore, after once a pipes are installed, surround the reservoir with a bamboo fence immediately.

Figure 171:
Before fencing

Figure 172:
After fencing

After constructing the fence, line a couple of floating aid ropes tied with buoys across the reservoir. If someone falls in, he/she still has something to hang on to.

Figure 173:
A floating aid rope. If someone falls in, he/she will have something to hang on to.

4.14 Plant vetiver grass on the slope around the reservoir to prevent soil erosion. Place 20 plants every 1 m and spare 5 cm between each plant to allow it to grow and become a natural vegetative barrier. Vetiver grass takes 2 months to fully grow.

Figure 174:
Planting vetiver grass to prevent soil erosion

Procedures	Cost	Remark
1. Trench excavation 1) Backhoe is required if human labour is not available or speed is required. 2) Human excavation: daily capacity is 1 m^3/worker/day.	1) 28 baht/m^3 2) 150 baht/worker/day	Cost as in 2011
2. Plastic sheet lining 1) Plastic sheet 0.15mm thick 2) 8-10 workers, wage 150 baht/head. Process takes 1 day.	1) 20 baht/m^2 2) 10 workers x 150 = 1,500 baht	Transportation cost not included
3. Piping system installation 1) Pipes 2) 3 workers, wage 150 baht/head. Process takes 1 day.	1) Depending on pipe size. 2" 4m is 270 baht. 2) 3 workers x 150 = 450 baht	If the area is suitable, the maximum capacity might be more than 1,000 m^3
4. Fences and floating aid ropes 1) Bamboo stakes diameter 3-4 inches, 4 m long, 25 baht/piece. 40 stakes required 2) Nylon rope 9 mm, 15 m long, 4 pieces required 3) 2 workers, wage 150 baht per head. Process takes 1 day.	1) 40 stakes x 25 = 10,000 baht 2) 200 baht 3) 2 workers x 150 = 300 baht	
5. Planting vetiver grass 1) Vetiver grass 2) 5 workers, process takes 1 day.	1) Available Financial support from Department of Land Development, Ministry of Agriculture and Cooperatives 2) 5 workers x 150 = 750 baht	

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for use as a guide in the future.
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King Bhumbol Adulyadej

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