CHAPTER

7

HOW SHOULD OPERATION AND MAINTENANCE OF PMS METHOD IRRIGATION FACILITIES BE IMPLEMENTED?

How are Proper Operation and Maintenance of PMS Irrigation Facilities achieved?

The existing PMS irrigation facilities constructed under the leadership of Dr. Tetsu Nakamura materialized through trial and error, based on 20 years of experience in irrigation projects, and they demonstrated to be suitable for Afghanistan as completed irrigation facilities.

However, in situations where information and data related to river floods and droughts are limited and where projects are carried out based on short-term on-site observations and measurements, continuous inspection after construction is extremely important. For example, after floods, irrigation facilities should be carefully inspected and all possible damages repaired. Water distribution should be reviewed in the event of unexpected drought, and distribution facilities should be restored accordingly. In other words, after the construction of irrigation facilities, the residents themselves must operate and maintain the irrigation facilities. It is important to maintain and improve irrigation facilities by the local community. It is important to contribute and cooperate to improve and continue sustainable and beneficial irrigated agriculture according to the local situation, after the PMS irrigation facilities are constructed. By maintaining fair and proper water distribution and through continuous inspection and improving of the irrigation facilities, if any damage or malfunction is detected, the systems can fully and sustainably perform their designed functions.

This chapter describes the operation and maintenance of the PMS irrigation facilities, organization and institutions for operation and maintenance, operation of irrigation facilities (intake gate operation, water distribution) and maintenance of irrigation facilities.

In the organization and institutions, firstly the current situation of water management in the area is comprehended. The types of operation and maintenance works for irrigation facilities are sorted out, and the roles of beneficiary farmers and project implementation entities/persons (related government agencies) are clarified, all aiming to reach an agreement. The Chapter also describes ensuring availability of funds for operation and maintenance. A clear allocation of roles is set. In particular, the residents (beneficiaries) play an active role in the daily operation and maintenance of irrigation facilities. Maintenance and management also require large amounts of funds for situations such as large-scale disaster recovery. In such a case, project implementation entities/persons are responsible for its implementation.

Regarding the operation of irrigation water distribution facilities, the response to normal requirements and extreme situations, such as floods and droughts, are considered separately, and a fair and proper method of water distribution is formulated. Water distribution and disaster response are considered in advance, implemented when the situation requires and continuously improved. It is necessary for the beneficiary farmers to take the initiative, and for the project implementation entities/persons to respect the elected consensus building by the beneficiary farmers, and to support their activities for three years after construction.

Regarding maintenance of irrigation facilities, it is necessary to understand that the existing PMS irrigation facilities experienced improvements made through repeated trial and error experiments. The kinds of irrigation facility demolition, changes in river channels, repair/restoration details, etc., are recorded for future maintenance activities with an aim of improved reconstruction (build back better). In addition to displaying contents of daily maintenance of irrigation facilities and regular simple repairs, this Chapter also shows the main types of damages of PMS irrigation facilities experienced so far, and how to deal with them for large-scale disaster recovery.

The activities are explained further in the following sections.

7.1 Establishment of Organizations and Institutions Related to Operation and Maintenance of Irrigation Facilities

7.1.1 | Basic Concept of Operation and Maintenance of PMS Irrigation Facilities

Irrigation facilities are to be maintained and improved by the local community. The operation and maintenance of irrigation facilities done by the PMS method irrigation project is basically carried out and sustained by the beneficiary farmers proactively and in a sustainable manner. This is a very important principle and one of the keys to the success of the PMS method irrigation project. To this end, the local communities and beneficiary farmers should be willing to operate and maintain the facilities independently and sustainably, through awareness that the irrigation facilities are their properties (ownership), and by setting the rules for gate operation and water distribution by themselves. On the other hand, project implementation entities/persons are required to respect the will of local communities and the beneficiary farmers. This model is called Participatory Irrigation Management (PIM), which is a concept which reflects the opinion of farmers - who are water users - in all aspects of irrigation management, and that the farmers themselves participate in its implementation. Many countries are implementing this practice. It is highly pliable water management method for Afghan communities, which have a high awareness of independence.

The PMS method irrigation project is not just the construction of irrigation facilities, but also the establishment of facility for operation and maintenance and as such, constitutes a regional restoration project. Therefore, as the complete project period, a minimum of three years of support should be ensured, to build and strengthen structures which carry out operation and maintenance (such as water users' associations and irrigation associations), to develop the institutions, and to actually operate and maintain the irrigation facilities. During that time, the project implementation entities/persons should establish an operation and maintenance organization (such as a water users' association and an irrigation association) to develop their capacity while jointly (with farmers) operating and maintaining them. This means that three years of On the Job Training should be ensured. After the system is fully operational and maintainable, the irrigation facilities are handed over to the organization, completing the PMS method irrigation project.

However, it should be noted that not all operation and maintenance can be done by beneficiary farmers and local communities alone. In a case of a flood, landslide, or drought, resulting damages require large-scale repair or restoration which cannot be done by the operation/maintenance organization or the local communities. In this situation, it is essential for the project implementation entities/persons or the Afghan government to support the local communities, from the perspective of sustainability of the irrigation project. Appropriate measures such as preparation of contingency budgets need to be taken, in preparation for emergencies like that.

7.1.2 | Understanding of the Current Situation of Organizations that Carry Out Operation and Maintenance (Community Water Governance)

The organization which will operate and maintain the irrigation facilities is generally the water users' association (WUA) or the irrigation association (IA). If these have not been established, the traditional organization *Shura* of villages and districts, or the community development council (CDC) established under the National Solidarity Program (NSP), should operate and maintain the irrigation facilities together with the *Mirabs* (water manager) in some cases. The roles of these organizations and *Mirabs* are summarized in Table 7.1.

Table 7.1 Community Organizations and Roles to Operate and Maintain PMS Irrigation Facilities [2)]

Organizations	Classifications	Roles
Water Users' Association (WUA)	Legal	• Consists of various water users who manage water use based on water rights. • Operates and maintains the irrigation canal. • Monitors water distribution based on water rights to prevent water conflicts.
Irrigation Association (IA)	Legal	• Consists of persons responsible for managing irrigation water in specific areas. Its members are landowners (farmers) and manage irrigation water based on the water rights granted. • Inspects the irrigation canals and performs maintenance. • Shares information on the use of irrigation canals, and suggests and encourages farmers on better ways to use irrigation canals.
Village *Shura*	Traditional	• Is a village-level council consisting of villagers trusted by the village head (Marek). • Resolves internal village issues such as land conflicts and other conflicts.
District *Shura*	Traditional	• Is a district-level council consisting of village heads representing the district. • There is no fixed process for solving the problem, and *Shura* consults, identifies the problem and finds a solution.
Community Development Council (CDC)	Legal	• Established under the National Solidarity Program (NSP) to support rural development projects. It implements civil charter projects funded by Ministry of Rural Reconstruction and Development (MRRD) and the World Bank. • Members of the council are elected by community voting. • In order to implement projects related to community development, it consults with governments such as MRRD and obtains funds to implement priority projects.
Mirab (water manager)	Traditional	• *Mirab* is an individual in charge of operating the gates and responsible for distributing water. It is an indispensable and venerable profession in traditional Afghan rural areas. In the eastern part of Afghanistan, it is usually inherited within families. In the north, it is freely elected among the farmers. The situation differs depending on the area. There ar the following three. - *Mirabbashi* (or Senior *Mirab*) is responsible for managing the main gates and managing the distribution of irrigation water based on water rights. He overseas maintenance of major irrigation canals with the help of farmers and settles disputes resulting from illegal water intakes. - *Mirab* operate gates which divert water from major canals to irrigation beneficiary areas, to control irrigation and settles disputes resulted from illegal water use. *Mirab* is an experienced water manager who has often been promoted from *Chakbashi* to *Mirab*. - *Chakbashi* is the assistant of *Mirab* in managing water. Usually, *Mirab*'s sons and relatives serve in this capacity.

In the target area of the PMS method irrigation project, it is necessary to investigate the kinds of organization shown in Table 7.1, which is responsible for operation and maintenance of the existing irrigation facilities. Following that, the current situation of operation and maintenance done by the organizations is comprehended. For example, it should be confirmed whether the organizations responsible for operation and maintenance of the facilities are based on tradition and customs (such as Shura), whether Hashars (voluntarily cooperation in agriculture and social services) is carried out in the community, and whether the farmers work together in harvesting and canal cleaning work. In addition, there may be a possibility that a legal organization (WUA or IA) is introduced based on the Water Law4) enacted in February 2009 for operation and maintenance, or a new organization has been formed based on the Water Law revised in Early 2020. Furthermore, it should be investigated whether both of these organizations exist. Therefore, the first step in forming a sustainable organization is to investigate and clarify the form of organization already in place, responsible for the operation and maintenance of the irrigation facilities and the actual situation in the project area.

7.1.3 | Understanding of Current Situations of Water Governance in Basins or Regions

In Subsection 7.1.2, the water governance of communities related to the operation and maintenance of irrigation facilities has been explained. In this Subsection 7.1.3, the water governance of the basins or regions is explained. The public institutions involved in water governance in Afghanistan are shown in Table 7.2. Those are NWARA, MAIL and MRRD in central and regional offices and the River Basin authorities. They together with the PMS method irrigation project must be closely associated and in cooperation for the organization of the irrigation facility operation and maintenance.

Relationship between various organizations involved in the operation and maintenance of irrigation facilities and organizations related to water governance in basins or regions is shown in Figure 7.1. In the PMS method irrigation project, the involvement of such water governance in the irrigation beneficiary area is first clarified, and the water governance mechanism shown in Figure 7.1 is established. In Afghanistan today, official organizations by the government and customary organizations of the local communities are often intricately related, and other stakeholders are often not negligible. Careful understanding of the situation is essential.

Table 7.2 Official Agencies Involved in Watershed or Local Water Governance [2)]

Organizations	Roles
National Water Affairs Regulation Authority (NWARA)	NWARA plays a leading role in water resources management. Water resources facilities such as dams, intake facilities, weirs and large irrigation canals have been developed by NWARA in the past. Based on the new water law, in addition to the management of water resources facilities developed by NWARA, the management of facilities developed by other agencies such as small waterways and riverbank protection works will be gradually taken over by NWARA. At the basin level, the River Basin Agency (RBA) and at the sub basin level (corresponding to the provincial level), the sub-river basin agency (Sub-RBA) play the role of a subordinate organization of NWARA.
	• Estimates the availability of water resources. • Allocates water to various sectors. • Plans, designs, constructs and maintains water resources development facilities, including irrigation and other water uses.
Ministry of Agriculture, Irrigation and Livestock (MAIL)	MAIL is responsible for crops and irrigation water. Irrigation water management is essential for selecting optimu crops and reducing the impact of droughts and floods on farmers' livelihoods. Therefore, MAIL was involved in irrigation projects that included the design, operation and maintenance of a number of irrigation canals. At the provincial level, the District Agriculture, Irrigation and Livestock office (DAIL) plays the role of a subordinate organization of MAIL.
	• Calculates crop water requirement and advises farmers, based on the availability of water resources. • Improves farmers' capacities from the perspective of efficient water use. • Cooperates with NWARA on the distribution of irrigation water in each river basin.
Ministry of Rural Rehabilitation and Development (MRRD)	MRRD was in charge of designing and implementing of development projects such as irrigation facilities in rural areas based on NSP. However, the new water law requires all ministries to hand over water resource development projects to NWARA. The Provincial Regional Rehabilitation and Development (PRRDD) at the provincial level, the District Development Council (DDA) at the district level, and the Community Development Council (CDC) at the village level are subordinate organizations of the MRRD.
	• Monitors the project through the CDC. • Ensures funds and budgets for rural development and coordinates with NWARA on irrigation development and riverbank protection for small projects.
River Basin Council (RBC)	Composed of various water users, including government and non-governmental stakeholders, and advises on water allocation implementation, national water strategy, and conflict resolution.
Sub River Basin Council (SRBC)	Established under the RBC to advise on water allocation, national water strategy and conflict resolution. Its responsibilities are similar to RBC, but limited to matters related to each sub-basin.

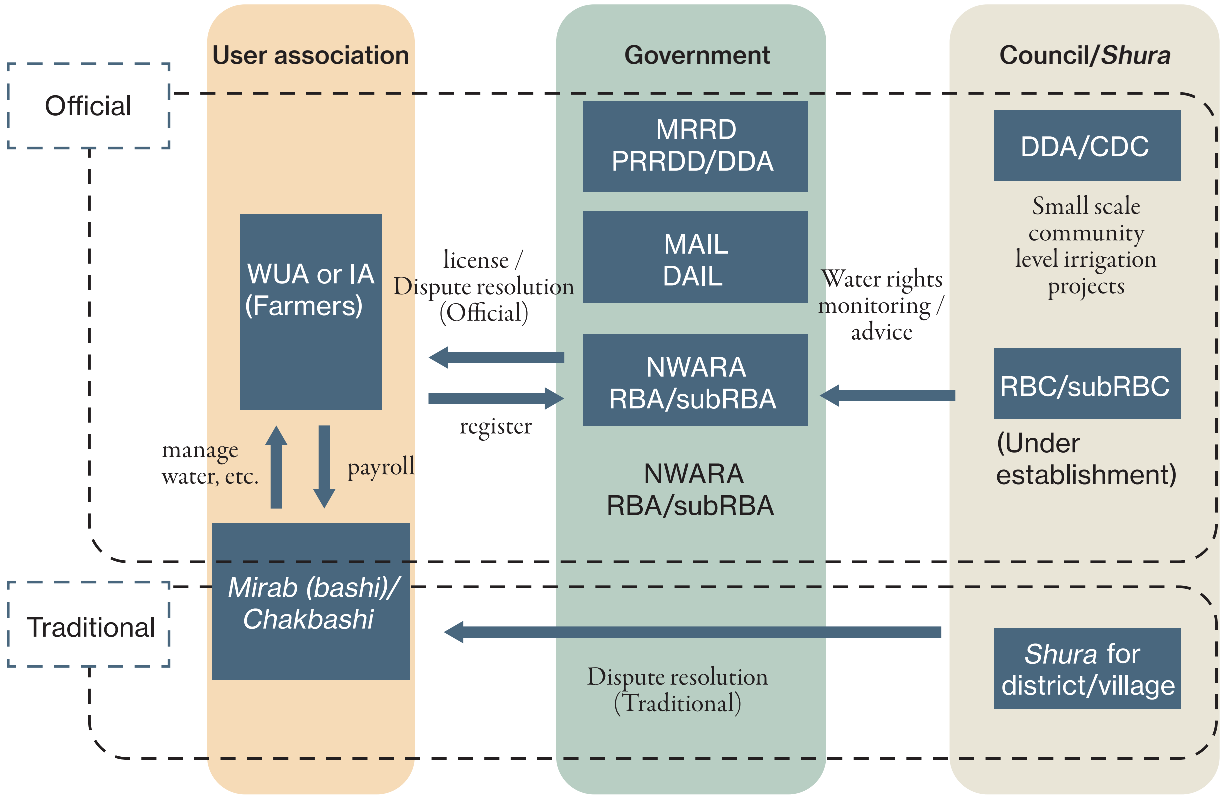


Figure 7.1 Water Governance in Basin or Region [2)]

7.1.4 | Formation and Strengthening of Organizations that Implement Operation and Maintenance

The organization responsible for the operation and maintenance of PMS irrigation facilities is formed, by taking into account the current situation of the communities, the basin and the regional water governance. In principle, the responsible organization is the water users' association (WUA) or the irrigation association (IA). Depending on the situation of water governance in the community, *Shura* and CDC may be responsible for operation and maintenance in consultation with the local communities. In practice, they will refer to WUA or IA for convenience.

The general organizational structure of a WUA or IA is shown in Figure 7.2. In principle, the WUA or IA is established on an irrigation canal basis, not on a village basis. In the case of irrigation canals which pass through multiple villages, it is anticipated that it is difficult to form a union of villages, so strong leadership of the local communities and persistent discussions are required. In the discussions, the project implementation entities/ persons must respect the independence and project ownership by the communities. In small scale irrigation projects, one WUA or IA is formed, but in large-scale irrigation projects, one IA is formed for each branch irrigation canal, and a WUA for the main irrigation canal which integrates these associations are formed. WUA or IA is, in principle, composed of leaders, sub-leaders, accounting and members. In areas where there is a *Mirab* system, *Mirabs* operate the gates and manage water on a daily basis, but in areas where there is no *Mirab* system, it is necessary to hire a water manager and to implement capacity development.

In establishing the organization, legal procedures are carried out, such as setting of water rights for irrigation water and registering to WUA or IA in NWARA. The policy on the WUA or IA is discussed, and the responsibility and role of the organization, dispute resolution, consensus building, etc., need to be codified.

In addition, in order to strengthen the organization which implements operation and maintenance, it is an effective approach to utilize local festivals such as harvest festivals, to strengthen unity and encourage active participation in operation and maintenance activities by incorporating regular dredging as an event.

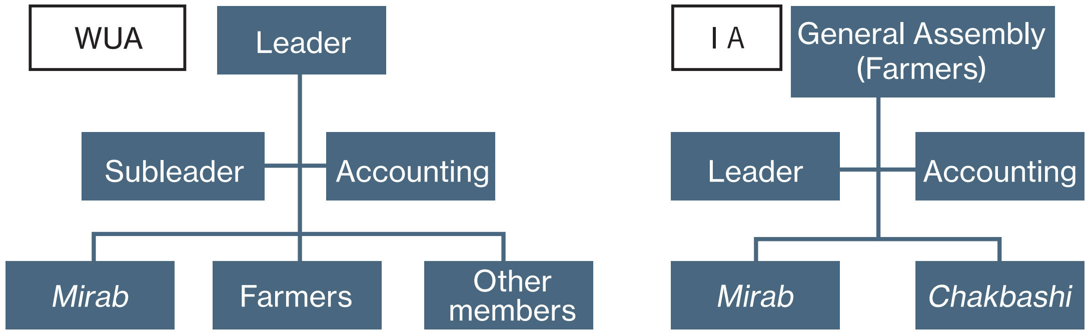


Figure 7.2 Formation of WUA or IA [2)]

Text Block 7-1: What to Do When There Is No *Mirab* System or WUA or IA

If there is no *mirab* or if a vulnerable *mirab* system exists, PMS operates the gate using PMS funds for five years after the completion of the project, and conducts training on gate operation to the "gatekeeper" who continues to operate the gates.
In the case of the Marwarid II irrigation canal constructed under the existing PMS irrigation project, a WUA or IA did not exist, a new WUA has be being established. In terms of the Marwarid I irrigation canal, although WUA has established, it is not fully functional yet in 2021 because the irrigation canal passes through multiple villages and the situation is complicated.

Photo: Meeting of Local Residents for Regular Dredging (Marwarid Ⅰ Irrigation Canal) [1)]

7.1.5 | Establishment of Institutions, Roles and Responsibilities of Organizations that Carry Out Operation and Maintenance

The roles and responsibilities of each organization involved in operation and maintenance are shown in Table 7.3. As shown, the allocation of roles and responsibilities of each of the organizations is clearly defined by documents, and discussions are held among the parties concerned to reach a consensus. The operation and maintenance of irrigation facilities are roughly categorized into the following three types:

- Operation of irrigation facilities- intake gate operation and water distribution (water users' expense): A fair and appropriate distribution of irrigation water is performed in the operation of intake gates and in adjusting the water volume of the main irrigation canals with measuring intake water level and intake water volume. The daily operations are carried out by the *Mirab* or the water manager, and compensation is paid by the association. The dues are collected by the WUA or IA from the beneficiary farmers.
- Maintenance of irrigation facilities (water users' expense): Simple maintenance which can be handled by beneficiary farmers, using basic civil engineering techniques is performed daily, such as inspection of irrigation facilities, and cleaning/dredging / repair of canals. These tasks are carried out by the WUA or IA and its member beneficiary farmers. The materials and equipment required for inspection, cleaning, and repair are covered by the WUA or IA dues collected from the beneficiary farmers, and on site unpaid work is done by the beneficiary farmers, in principle.

- Large-scale repair/restoration of irrigation facilities (project implementation entities/persons' or government's expense): Large-scale repair and restoration of irrigation facilities damaged by floods are performed. This corresponds to dealing with partial damage of an oblique weir and change in sandbars, caused by floods, with boulders. Large-scale repairs and restoration usually require a large amount of money, and it is difficult for water users to cover the full cost. Therefore, in principle, this cost is borne by the project implementation entities/persons or the government. The WUA or IA and the beneficiary farmers participate with labor input in large-scale repair and restoration work, using basic civil engineering techniques.

Table 7.3 Roles and Responsibilities of Organizations in the Operation and Maintenance of Irrigation Facilities [2)]

Operation and Maintenance Work	WUA or IA by Beneficiary Farmers	*Mirab* (water manager)	Project implementation entities/persons or Government
Operation of Irrigation Facilities - Intake Gate Operation and Water Distribution (Water Users' Expense)			
Water Allocation Plan	• Formulation	-	• Support
Intake gate operation and equitable water distribution	• Pay *mirabs* • Proper on-farm water management (Chapter 8)	• Intake gate operation and proper water distribution	• Uunderstanding the operational situation
Measuring and monitoring water level and intake amount		• Measuring the water level and intake amount • Monitoring proper water distribution	
Response to extreme situations	• Consensus building on water distribution rules during drought • Proper on-farm water management (Chapter 8)	• Implementing water distribution rules during drought • Response to floods	• Joint discussion on water distribution rules during drought • Response to floods
Maintenance of Irrigation Facilities (Water Users' Expense)			
Maintenance Plan	• Formulation	-	• Support
(Irrigation facilities) • Daily maintenance and regular simple repairs	• Implementation of repair work • Regular cleaning (participation in *Hashar*)	• Inspection/ Observation • Daily cleaning • Regular cleaning (participation in *Hashar*)	• Understanding the situation of maintenance activities • Observation • Regular survey
(River channels) • Understanding rivers and sandbars situation			
Large-Scale Repair of Irrigation Facilities (Project implementation entities/persons' or Government's Expense)			
(Irrigation facilities) • Repair of gabion at joint of the weir • Repair of the weir and downstream erosion • Repair of dike and revetment works	• Labor Participation in repair work		• Ensuring of budget • Inspection/ Observation • Understanding of field situation • Implementing large-scale repairs, restorations, and river construction • Implementing as a new PMS method irrigation project if restoration is required
(River channels) • Sandbar protection • River bank protection • Excavation and dredging for ensuring division of river channel			

Note: *Shura* and RBC arbitrate mainly to resolve water disputes. *Shura* is customary arbitration, while RBC is arbitration based on the water law. *Shura* convenes *Hashar*.

7.1.6 | Ensuring Funds for Operation and Maintenance

(1) Ensuring Funds for Operation and Maintenance by Water Users

Funds are required to establish the WUA or IA and to carry out operation and maintenance as shown in Table 7.3. In principle, water users bear such operation and maintenance expenses. In other words, the WUA or IA collects and stores association dues from beneficiary farmers, uses them to purchase materials and equipment, and pays the compensation to *Mirabs*.

The cost burden related to operation and maintenance to beneficiary farmers are discussed. The decision making process is clear and transparent, and the cost collection is fair and appropriate. If there are farmers who are dissatisfied with the water distribution, it is possible that they will refuse to bear the costs or will not get involved in operation and maintenance activities. Therefore, it is important to manage water distribution fairly and appropriately.

Text Block 7-2: Example of Cost Burden of Farmers in the Operation and Maintenance of Irrigation Facilities of the Existing PMS Irrigation Project

In accordance with the irrigated area, the farmers themselves can pay the cost in cash or in kind directly to the *Mirab* as compensation. In the case of the existing PMS irrigated areas at the Kunar River Basin, farmers give 35 kg/ha of wheat and 17.5 kg/ha of rice, or 35 kg/ha of wheat and 17.5 kg/ha of maize (corn) to the *Mirab* per year. According to a survey carried out by JICA in the northern and north-eastern regions5), the compensation to *Mirab* is about 1/80 of the beneficiary farmer's harvest, and the compensation to the *Chakbashi*, which is responsible for water distribution in a village, is from 3,000 to 4,000 Afg per month or 400 kg of wheat per year, depending on the region.

(2) Ensuring Funds for Large-Scale Repairs, Restorations and River Construction Work by Project implementation entities/persons or the Government

The cost for large-scale repair/renovation work on irrigation facilities and the necessary river works are extremely difficult for beneficiary farmers to bear, so that the project implementation entities/persons or the government take the responsibility from the viewpoint of enabling sustainability of the irrigation project. For example, restoration work for large-scale damage to weirs and dikes caused by floods, etc., has to be dealt with, promptly and necessary to complete the work before next planting season. Therefore, the project implementation entities/persons or the government must prepare a mechanism to ensure a budget, such as a contingency budget, that can handle emergency restoration works.

7.2 Operation of Irrigation/Water Distribution Facilities (Intake Gates, Sand Flushing Ditches, Drainage Gates, Transmission Gates and Distribution Gates)

7.2.1 | Formulation of Water Allocation Plan for Irrigation Beneficiary Areas

The water allocation plan for main irrigation canals is formulated based on the cropping pattern, examined in Chapter 2, in order to soundly distribute the amount of irrigation water required for each irrigation block and field in the target irrigation area, with the maximum irrigation water amount as the upper limit. In principle, the water allocation plan is formulated by the WUA or IA, which is responsible for the operation, maintenance and consensus building, in consultation with the beneficiary farmers. In addition, the project implementation entities/persons give suggestions and advice to the WUA or IA, taking into consideration gender issues and fair water distribution while respecting the customs of the local communities and the intentions of the WUA or IA and the beneficiary farmers.

7.2.2 | Formulation of Operating Rules of Intake Gates

The amount of water taken from intake gates is estimated by the river water level which overflows the intake weir and the flush boards. The intake gate may be a double flush board type with two rows of flush boards installed. The principle of flush board operation in the first row is for the river water to completely overflow the first row of flush boards, while the flush boards in the second row have the effect of reducing the water pressure applied to the first row.

Therefore, it is necessary to have the flush boards in the second row at a high position but not too high to avoid submersion of the first row. There is, however, a risk that the amount of water intake is reduced by hindering the complete overflow of water. It is necessary to pay attention to this occurrence when operating the flush boards of the double flush board type intake gate. (See Figure 7.5.)

(1) Relationship between Operation of the First Row Flush Boards and Water Intake Amount

The amount of intake water which will completely overflow the first row flush boards can be calculated by the following overflow formula:

$$Q = CBH\sqrt{2gH_1} \quad \cdots\cdots \quad (7.1)$$ [2), see 6)]

Here; Q: overflow (water intake amount); C: overflow coefficient (= 0.35 in case of complete overflow); B: overflow width; H_1 : overflow depth; g: gravitational acceleration (= 9.81m/s^2)

By using this overflow formula, the amount of water intake at various overflow depths can be calculated, and the relationship between the overflow depth and the amount of water intake is as illustrated in Figure 7.4. From this figure, the overflow depth of the first row of weir plates required to obtain a certain amount of water intake can be obtained. On the other hand, the height of the first row of flush boards can be determined by subtracting this overflow water depth of the first row of weir plates from the river water level that overflows the intake weir when the flush boards is operated.

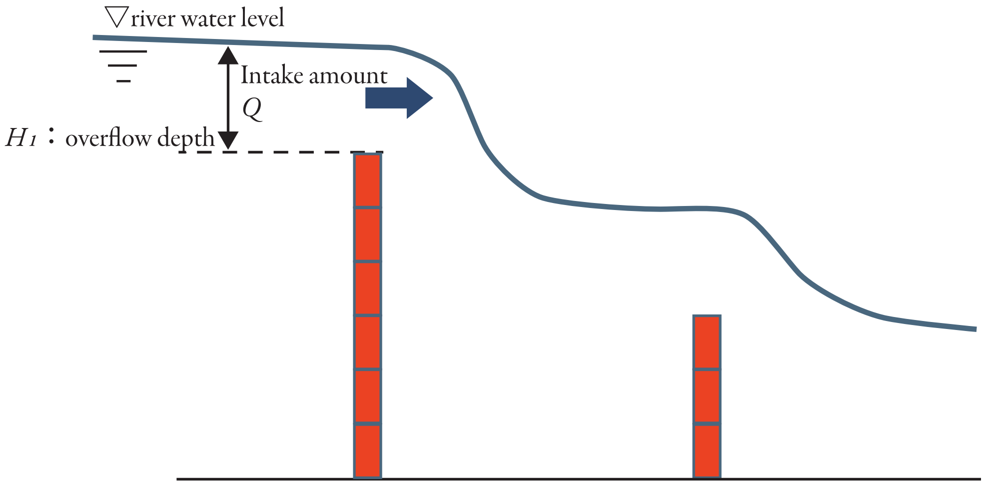


Figure 7.3 Image of Water Surface during Water Intake at the Double Flush Board Type of Intake Gate (Complete Overflow) [2)]

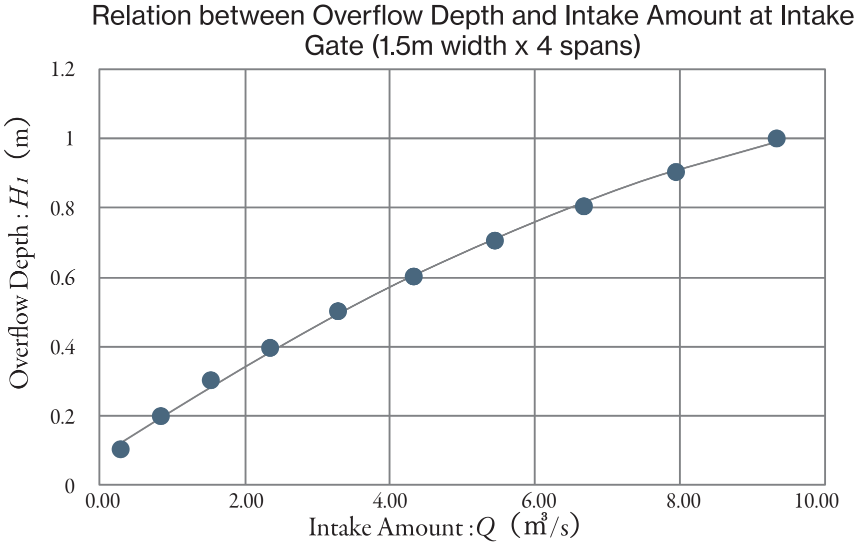


Figure 7.4 Relationship between Overflow Depth at the First Row of Flush Board and the Water Intake Amount in the Double Flush Board Type of Intake Gate [2)]

Photo 7.1 Double Flush Board Type of Intake Gate. Overflow Water Falls Stepwise. [1)]

(2) Operation of Second Row Flush Boards

The second row of flush boards is operated to reduce the water pressure applied to the first row and to avoid submergence, but not to impair the complete overflow at the first row. To determine whether submerged overflow occurs, the following equation, based on the height of the first row and the height of the second row is applied. If the water depth from the height of the flush board in the first row at the main irrigation canal side, H2, is greater than 2/3 of the river side overflow depth, H1, it is judged to be a submerged overflow.

$$Q = CBH_2\sqrt{2g(H_1 - H_2)} \qquad (H_2 / H_1 > 2/3) \quad \cdots\cdots \quad (7.2)^{6)}$$

Here, Q: overflow (water intake amount); C: overflow coefficient (= 0.91in case of submerged overflow); B: overflow width; H_1: overflow depth at river side; H_2: overflow depth from the height of the flush board in the first row at main irrigation canal side; g: gravitational acceleration (= 9.81m/s^2)

With the above equation, the height of the second row of flush boards is determined so that the overflow in the first row does not become a submerged overflow.

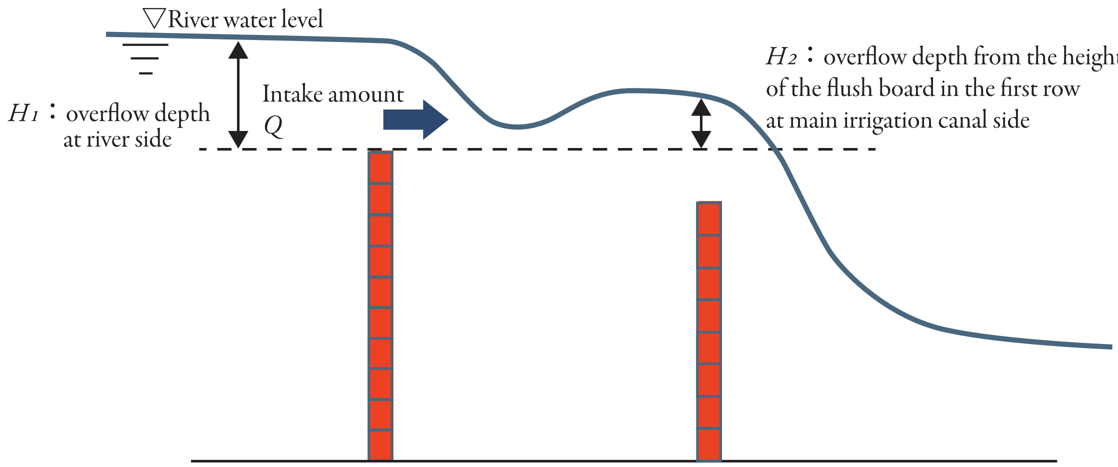


Figure 7.5 Image of Water Surface Shape at the Time of Water Intake at Double Flush Board Type of Intake Gate (Submerged Overflow) [2)]

(3) Understanding the Relationship between Overflow Depth and Water Intake Amount by Water Supply Test

After the construction of irrigation facilities, a water supply test is conducted to test for possible defects in the facilities. At that time, the relationship between the overflow depth and the amount of water intake is measured, and the amount of water intake at various overflow depths throughout the year is also measured. An example of a water supply test at the Marwarid II Intake Gate (width 1.5m x 4 gates) is shown below (See page 116 of the Afghan Green Ground Project in detail). The water depth from the base elevation of the intake gate, D, is measured at a certain river water level. Then, the number of flush boards of the intake gate is changed one by one, and the changes in the overflow depth and the amount of water intake is measured. The overflow depth at the top of the flush board decreases by 20 cm each time the flush board is increased one by one.

In the downstream main irrigation canal, the water depth (irrigation canal cross-sectional area), dn, and the flow velocity, v, is measured to calculate the water intake amount (dn × w × vn), and the relationship between the overflow depth and the water intake amount obtained is organized as shown in the following table. This results in a graph as in Figure 7.4.

Table 7.4 Organizing the Results of Overflow Depth and Water Intake Amount [2)]

Surveying Point	Flush Board	Water Depth (m)	Overflow Depth (m)	Surveying Point	Water Depth (m)	Canal Width (m)	Velocity (m/s)	Flow Area (m²)	Intake Amount (m³/s)
Intake Gate	3 boards (60cm)	D	D -0.6	Main Irrigation Canal 20～40m point	d_1	w	v_1	$d_1 \times w$	$d_1 \times w \times v_1$
	2 boards (40cm)	D	D -0.4		d_2	w	v_2	$d_2 \times w$	$d_2 \times w \times v_2$
	1 board (20cm)	D	D -0.2		d_3	w	v_3	$d_3 \times w$	$d_3 \times w \times v_3$
	No board	D	D		d_4	w	v_4	$d_4 \times w$	$d_4 \times w \times v_4$

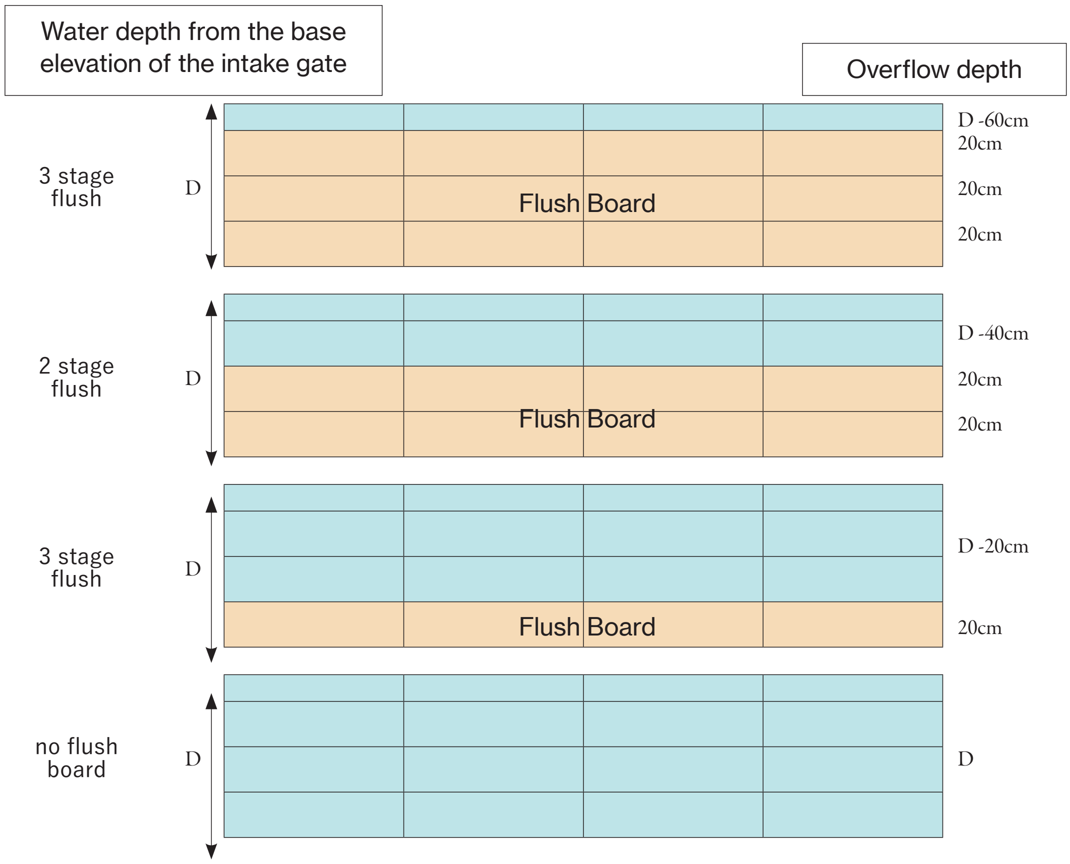


Figure 7.6 Example of Water Supply Test in MarwaridⅡ [2), 3)]

In principle, the operation of the double flush board type of intake gate is performed using the relationship between the overflow depth and the measured value of the intake amount. From the graph of overflow depth and intake amount, the amount of overflow depth that is required for the amount of water to be taken is confirmed, and the top height of the flush board is determined from the river water level. Then, the required number of flush boards are installed, so as to have the required top height of the flush board. The height of the second row of flush board should be carefully checked, so that submerged overflow at the first row does not occur.

7.2.3 | Operation Method of Sand Flushing Ditches, Drainage Gates, Transmission Gates and Distribution Gates

(1) Operation Method of Sand Flushing Ditches

The flush board of sand flushing ditches is basically always fully open and closed only in the event of extreme drought.

(2) Operation Method of Drainage Gates

In principle, the gate operation of the drainage gate at the sand basin is as follows:

- The drainage gate is fully closed from December to March (in winter) when the amount of water intake is low, and is open at all other times. Therefore, the drainage gate is opened and closed twice a year, opened at the end of the dry season and closed at the end of the flood season. During flood season, when the sediment concentration in the river water is high, a large amount of sediment is expected to accumulate in the sand basin, compared to the drought season. Therefore, the drainage gate is always open. The water in the sand basin is discharged from the bottom of the basin to ensure the flow velocity in the basin of about 2 to 7 cm / s, so that the sediment is evenly deposited in the sand basin.
- The height of the gate opening of the drainage gate is about 30 cm, and drainage is performed from the bottom of the drainage.
- The water depth in the sand basin is always kept at about 2 m during operation for drainage and sediment removal.

(3) Operation Method of Transmission Gates and Distribution Gates

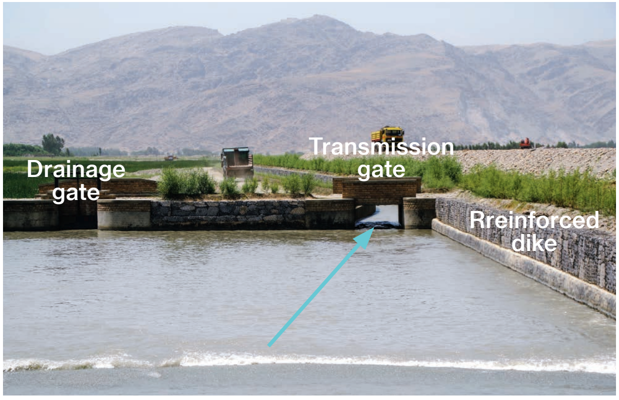
The transmission gates and distribution gates are installed in the sand basin. Since there is almost no change in the water level of the sand basin, in principle the gate flush board is operated about once every few months according to the amount of irrigation water required for each season. The operation method of this flush board is the same as that of the intake gate. The relationship between the overflow depth and the water supply amount is graphed, the overflow depth is determined from the required water supply amount, and the number of flush boards is determined based on the relationship with the sand basin water level.

7.2.4 | Operation of Intake Gates, Sand Flushing Ditches, Drainage Gates, Transmission Gates and Distribution Gates

Intake gates, sand flushing ditches, drainage gates, transmission gates and distribution gates are operated in accordance with the established operating rules and operating method principles. When in operation, the operational situation such as the number of flush boards installed at each gate, the gate opening, the water level on the upstream and the downstream sides, and the overflow depth are recorded together with the date and time. Furthermore, for the intake gate, the river water level (intake level) and the water level in the main irrigation canal are measured and recorded daily, and the amount of water intake is calculated, in order to check whether the appropriate amount of water is taken. Changes in the river water level are summarized and compared to the same period in the past, and used as basic information for proper water intake gate operation in the future.
In addition, by monitoring results obtained from daily operations, the validity of the operation rules of the intake gates and the operation principles of the sand flushing ditches, drainage gates, transmission gates and distribution gates is verified, and the operation rules and operation principles are continuously improved.

Intake Gate

Sand Flushing Ditch



Transmission Gate/Drainage Gate

Drainage Gate (outflow)

Photo 7.2 Operation of Intake Gate, Sand Flushing Ditch, Drainage Gate, Transmission Gate and Distribution Gate [1)]

7.2.5 | Patrols Related to Water Use

Irrigation facilities are operated to ensure that beneficiary farmers receive the benefits of irrigation water fairly, but some unruly irrigation and illegal water intake may adversely affect the entire irrigation area. Therefore, the WUA or IA needs to patrol the irrigation facilities and suppress such inappropriate or illegal activities.

For example, in the existing PMS irrigation project, there are cases where many water wheels are built in the main irrigation canal without permission, or houses are built protruding into the main irrigation canal. Regular patrols are necessary to prevent such instances. The frequency of patrols is determined by the scale of the irrigation facilities, the size of the beneficiary area, and the access to the main irrigation canal. Sometimes patrols are done every day, and sometimes once every two weeks. In addition, in order to prevent such inappropriate or illegal activities and achieve proper and fair water distribution and use, the cooperation of community leaders and organizations in charge of watershed/community water governance is essential.

7.2.6 | Response to Extreme Situations such as Droughts and Floods

In order to reduce damage as much as possible in extreme situations such as droughts and floods, it is important to make preparations in advance, and decide on how to deal with such extreme situations when they occur.
In other words, with the aim of preventing the spread of damage to irrigation facilities and irrigated areas in extreme situations and recovering quickly, a drought response manual and a flood response manual are both prepared in advance, and consensus among the parties concerned is built in a participatory manner.
If a drought or flood is expected or occurs, the parties concerned discuss with each other in accordance with relevant manual and take proactive and post-action measures. In particular, by preparing a drought response manual in advance, prompt response in the event of drought, and fair and appropriate water distribution can be performed even under drought conditions.
It is expected that droughts and floods occur frequently in the future as the effects of climate change become significant. Damage can be significantly reduced by forecasting droughts and floods and taking countermeasures in advance, by referring to Chapter 3.

(1) Response During Drought

In the event of drought, it is important to distribute the limited available irrigation water fairly to the beneficiary farmers. The WUA or IA discusses, obtains the consent of members, and prepares a drought response manual in advance. In addition, it is essential to raise awareness of the necessity of consultations between stakeholders rather than taking water selfishly, all required to maintain order in the community during droughts.
In accordance with the drought response manual, the parties concerned work together to ensure fair water use in all irrigated areas from upstream to downstream. The manual encourages farmers to save water and strengthens patrols to prevent unauthorized water intake. During droughts, other irrigated farmlands and water supply facilities that use the same river as the water source are also affected by the drought, so that it is necessary for the WUA or IA and the water supply companies upstream and downstream of these rivers to discuss and coordinate matters related to all water intakes.
In the PMS, orderly water supply to villages is made during drought to make sure that water distribution is fair and to avoid missing planting opportunities while the users are waiting for their turn. In addition, water saving measures are taken by incorporating irrigation on ridges method.
Since a large amount of water is required for paddy fields, it is also important to distribute water fairly between the upstream and downstream users of the irrigation canal by rotation, so that abandonment of paddy fields does not occur during droughts and conflicts do not take place.

(2) Response in the Event of Floods

In Afghanistan, it is necessary to pay attention to heavy floods caused by heavy rains during the snowmelt flood season/monsoon season when the river flow is high. For example, the Kunar River experienced heavy floods in 2010 and 2013 due to heavy rainfall around July, which is the peak of snowmelt season/monsoon season. Response to floods at irrigation facilities and irrigation beneficiary areas include proactive measures to reduce the risk of flood damage, measures during floods, and measures after floods. The WUA or IA should prepare a flood response manual, which would include the following contents:

- ***Preparation measures to reduce the risk of flood damage:*** Since flooding is likely to occur in locations where floods have occurred in the past (in low-lying areas) land use in those areas is restricted by using those lands only as cultivated land while strictly prohibiting its residential use. In addition, boulders, cobblestones, gabions, etc., are stocked up. Measures such as emergency reinforcement and restoration of irrigation facilities during and after floods are planned, and budget for the restoration of irrigation facilities damaged by floods is ensured. The condition of rivers, sandbars, and irrigation facilities is observed since they may show a sign of deterioration, such as the movement of sandbars after small and medium-sized floods. It is also a good idea to prepare in advance a contact route (telephone contact list) that promptly informs the local community, *Shura* and *Jirga*, and the government of what is happening locally from *Mirabs* and local farmers and reports of extreme situations. In addition, when the main irrigation canal passes through a small basin in a mountainous area, damage caused by flash floods (which is a sudden flood and debris flows) is also expected. In addition to grasping the risk areas based on damage records (by interviews to residents), measures against flash floods and debris flows are also taken, such as extension of the siphon or flood crossing bridge length. The PMS method irrigation facilities also serve as a disaster prevention measure against unexpected flash floods and debris flows.
- ***Flood Response***: In the event of a floods, *Mirab* closes the intake gates to prevent flood flow from entering the main irrigation canal, then, conducts patrols as much as possible paying attention to safety, and inspects and records the condition of irrigation facilities and rivers/sandbars (erosion status of facilities, flood levels, river flow conditions, movement of sandbars, etc.). If erosion has occurred, flood control activities are taken to reduce flood damage, such as placing of boulders and gabions of stored cobblestones to prevent erosion damage.
- ***Post-flood response***: After flood, the condition of flood damage to irrigation facilities and beneficiary areas and the situation of river channel changes are checked and recorded. In particular, in the case of a large flood, it should be ensured that a check of the flood marks and the range of erosion and sedimentation of river channels has been done. Information gathered is used for repairs and future design of intake weirs/intake gates and dikes/spur dikes. If large-scale flood damage occurs, the restoration work is carried out promptly by project implementation entities/persons /government. If the irrigation facilities are damaged, they should be urgently repaired. If the condition of the river channel or sandbar has changed, it is verified whether the functions of the irrigation facilities can be fully performed. If not, measures are taken such as excavating the river channel to restore the function of facilities. If damage occurs to irrigated farmlands, floodwaters are drained from the fields, and land preparation/restoration of the fields is carried out.

7.3 Maintenance of Irrigation Facilities

7.3.1 | Formulation of Maintenance Plan

In the PMS method irrigation project, concrete structures are avoided as much as possible and natural materials such as stones and vegetation are heavily used. Therefore, the maintenance of irrigation facilities by local residents is possible and sufficient. On the other hand, because the irrigation facilities consist of structures which make the best use of natural materials, it is expected that they will be slightly damaged, so that the PMS method irrigation project is very focused on maintenance activities. In other words, as with any irrigation facility, irrigation facilities in river channels and along rivers may be eroded by floods, etc., and the stones and gabions may move or be damaged; therefore, functional maintenance of irrigation facilities is essential through continuous maintenance work. In addition, it is necessary to regularly carry out the management of the removal of sediment inflow and undertake the dredging works on canals.

In the PMS method irrigation project, a maintenance plan for irrigation facilities is formulated at early stages of project conception. As described in Subsection 7.1.1, the PMS method irrigation project considers integration of the construction and maintenance of irrigation facilities. For at least three years after the completion of construction, operation and maintenance of irrigation facility projects are carried out by project implementation entities /persons or the goverment with the WUA or IA and the beneficiary farmers, and capacity development is organized to manage water distribution, sediment management and facility repairs by on-the-job training. In addition to implementing such activities, the WUA or IA and the beneficiary farmers are encouraged to formulate specific operation and maintenance plans, and the project implementation entities/persons support them.

The points to keep in mind when formulating a maintenance plan for irrigation facilities are as follows:

- Irrigation facilities are inspected as often as possible, for detecting defects and meteorological conditions such as temperature and rainfall, river water level and water intake are measured regularly, daily as possible. As a result, it is possible to take immediate action when a defect occurs.
- Regular cross-section river surveys and surveys after major flood damages to understand changes in the irrigation facilities and changes of the river channels are carried out. Notably, in the PMS method irrigation project, the stability of river channels and sandbars are very important, and changes in them need to be fully comprehended.
- Detection of defects in irrigation facilities at an early stage are followed through the above-described daily inspections and regular surveys, and small-scale repairs are repeated throughout lifespan of the irrigation facilities.
- The design drawings and as-built drawings of the irrigation facilities are kept by the project implementation entity and the WUA or IA. The changed situation of the structures are followed by comparing these drawings with the current situation.
- It is compulsory to record and store maintenance activities with photos which show the situation before and after repairs.
- Knowledge and experience gained through maintenance activities such as continuous inspections and facility repairs are stored, analyzed and evaluated to gather lessons learned. The maintenance plan and activities are continuously improved by running the PDCA cycle (Plan, Do, Check, Action).

7.3.2 | Examples of Daily Maintenance Activities and Regular Simple Repairs

Daily maintenance activities include the following activities:

- Routine inspection and cleaning of irrigation facilities such as intake gates and irrigation and drainage canals.
- Management of vegetation and vegetation works in and around irrigation and drainage canals.

Inspection of Intake Gate

Mowing of Grass on the Waterside

Photo 7.3 Examples of Daily Maintenance Activities [1)]

Simple repairs include the following works:

- Repair of gabion, vegetation, masonry and soil cement in irrigation and drainage canals.
- Repair and rust proofing of flush boards and *charha* (Afghan winder) at intake gates and transmission gates.
- Dredging and lining repairs for irrigation and drainage canals and sand basins. (See Chapter 4 for dredging frequency)

If failure or small-scale destruction, which requires urgent repair, is found in the irrigation facilities through daily inspections and regular surveys, immediate action is taken. If it does not require urgency, repair works are taken at the time of regular simple maintenance repairs. For repairs, the PMS basic civil engineering techniques learned by the WUA or IA and the beneficiary farmers are utilized.

It is also important to call *Hashar* (volunteer activities) to carry out daily maintenance activities and regular simple repairs involving local people and leaders. By doing so, it is expected that the local people understand that the PMS method irrigation facilities are important in their area and can be maintained soundly by implementing regular maintenance. It is, therefore, expected that the ownership of the project area is augmented.

Once the irrigation facility is constructed, that's not the end. Irrigation facilities are to be maintained and improved by the local community throughout their lifespan. Therefore, maintenance by the local people is required based on detailed observations when the water level rises, and when it rains heavily, as well as when there is a drought. It is important for people to have an awareness that "we are the ones who maintain and improve our irrigation facilities". To leave it to the government and project implementation entities/persons, should be avoided.

Lining Situation in an Irrigation Canal

Dredging Situation

Photo 7.4 Examples of Regular Simple Repair [1)]

7.4 Large-Scale Repair and Restoration of Irrigation Facilities - Typical Destruction Patterns and Countermeasures

Large-scale repairs and structures' restorations are technically and financially difficult for the WUA or IA. Examples of such works are repairs of scouring weir abutment, foot protection works of dikes, dike bodies and revetment works, as well as protecting and stabilizing sandbars and securing river channel streamway (See Table 7.3). In principle, large-scale repairs and restorations are carried out at the expense of the project implementation entities/persons or the government, and beneficiary farmers utilize their PMS basic civil engineering techniques to devote their labor to the repairs and restoration works.

Post-flood facility inspections are extremely important since damages to irrigation facilities that require large-scale repair and restoration are mainly caused by floods, larger than expected. By referring to the report of Dr. Tetsu Nakamura[1)], examples of typical destruction types which require large-scale repairs and restorations in PMS method irrigation facilities and countermeasures are as shown in the photos below.

The existing PMS irrigation facilities have been repeatedly damaged and improved, through trial and error. Finally, they have reached the present shape. While understanding these past experiences, the destruction form of irrigation facilities, the changed situations of river channels, and the contents of repairs and restorations have been organized and recorded. Based on the concept of better reconstruction (build back better), the records are utilized for maintenance activities. In addition, it has become standard practice to stockpile construction materials such as stones and gabions in the vicinity of the facilities for future emergency response.

Photo 7.5 Stockpile of Stone [1)]

(1) Washout of Sandbar at Intake Weir Abutment

When protection of the intake weir abutment was insufficient and the sandbar of abutment was washed out, the wing part was reinforced with boulders and cobblestones. The changes in the sandbar before and after the flood and the scouring destruction around the structure have been observed, and the scouring damage has been repaired.

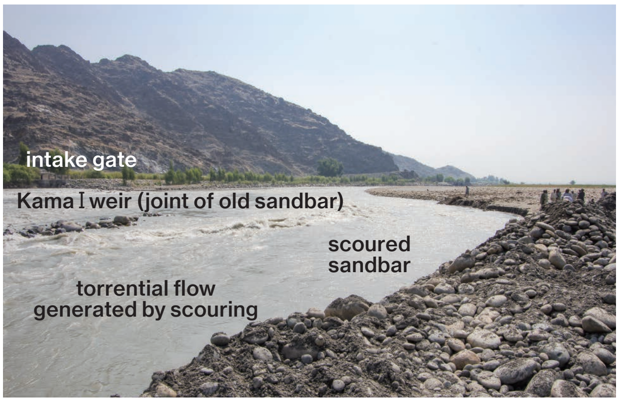


Photo 7.6 Scouring of Sandbar due to Floods[1)]

Photo 7.7 Restoration of Sandbar by Gabion Works[1)]

(2) Scouring at the Downstream Part of Intake Weir and at the End of Sand Flushing Ditch

Due to the movement and scouring of boulders by flood flow, additional boulders were put into the scouring section. In the boulders' /oblique weir, steps are made from the top of the weir to the apron where measures are taken to reduce the water force (raise the front edge of the weir). If the boulders are washed out due to occurrence of strong current and riverbed scour at the downstream part of the weir and the end of the sand flushing ditch, it is necessary to reinforce them by replenishing the boulders.

Photo 7.8 Ingenuity to Reduce the Warter Force from the Top of the Weir[1)]

Photo 7.9 Repair Work of Riverbed Scouring due to Torrents at the Ends of Apron and Sand Flushing Ditch [1)]

(3) Erosion of Riverbank around the Weir

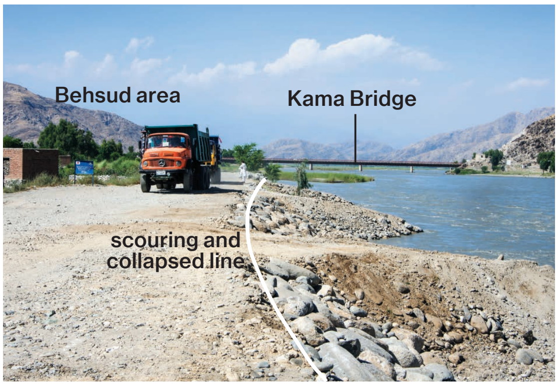
Insufficient foot protection works caused riverbank erosion due to flood flow. Therefore, spur dikes were installed to direct the flood flow toward the center of the river channel. The erosion of the riverbank due to flood flow is observed. If necessary, spur dikes are constructed or stones are added to the existing spur dikes to reinforce them.

Photo 7.10 Riverbank Erosion Due to Flood Flow [1)]

Photo 7.11 Reinforcement of Riverbanks and Correction of Streamway by Installing Spur Dikes [1)]

Text Block 7-3: Case of Emergency Response Actually Performed by PMS (From a Report of Dr. Nakamura) [1)]

Due to the flood in June 2013, the bank protection collapsed over 140m in the Behsud area on the opposite bank of the Kama I weir. Since the material of the lower part of the dike on the back of the root consolidation was weak, it collapsed due to the flow generated on the back side of the stone of the root consolidation. The depth of scouring was 3-5 m. For the repair, the amount of boulder was carried by 560 dump trucks.



In the floods of July 2015, in the Miran area, PMS worked all night to stop erosion and raise it. Where the "buried spur dikes" were effective, no erosion was observed. The residents were panicking due to anxiety of overflowing. The dike raising work of about 60 to 80 cm was carried out, and the atmosphere calmed down.

When responding to a disaster, it is highly appreciated that the situation where staffs take the initiative in patrols and ideas, and work despite holidays. With this, the technology will be obtained later, even if it is a little wrong.

Immediately before the emergency work, a part of the top of the dike was Flooded. The work was carried out desperately. July 17, 2015 7:30 pm

Prevention work of erosion by boulders was carried out throughout the night. Currently, the entire top of the dike is being raised. July 20, 2015

(4) Damages to Water Intake Due to Changes in Mainstream of Rivers and Changes in River Channels such as Sediment Deposition

The mainstream of the river and the sandbar have been observed, and excavation and dredging have been carried out to direct the mainstream of the river to the intake gate even during drought, for guiding the mainstream and for maintaining the sandbar. If it becomes impossible to convey water to the intake due to sediment deposition, the river flow should be guided to the intake by excavating or dredging the river channel or sandbar.

In the case of the existing PMS irrigation project, as shown in the figure below, the boulders' oblique weir is installed at the curved part of the river channel to reduce sediment deposition. By frequent floods due to torrential rains, sandbars or mainstreams changed and moved the sediment deposition in front of the Miran Weir Intake. Thereafter, river channel excavation and dredging were carried out to convey the river water to the intake.

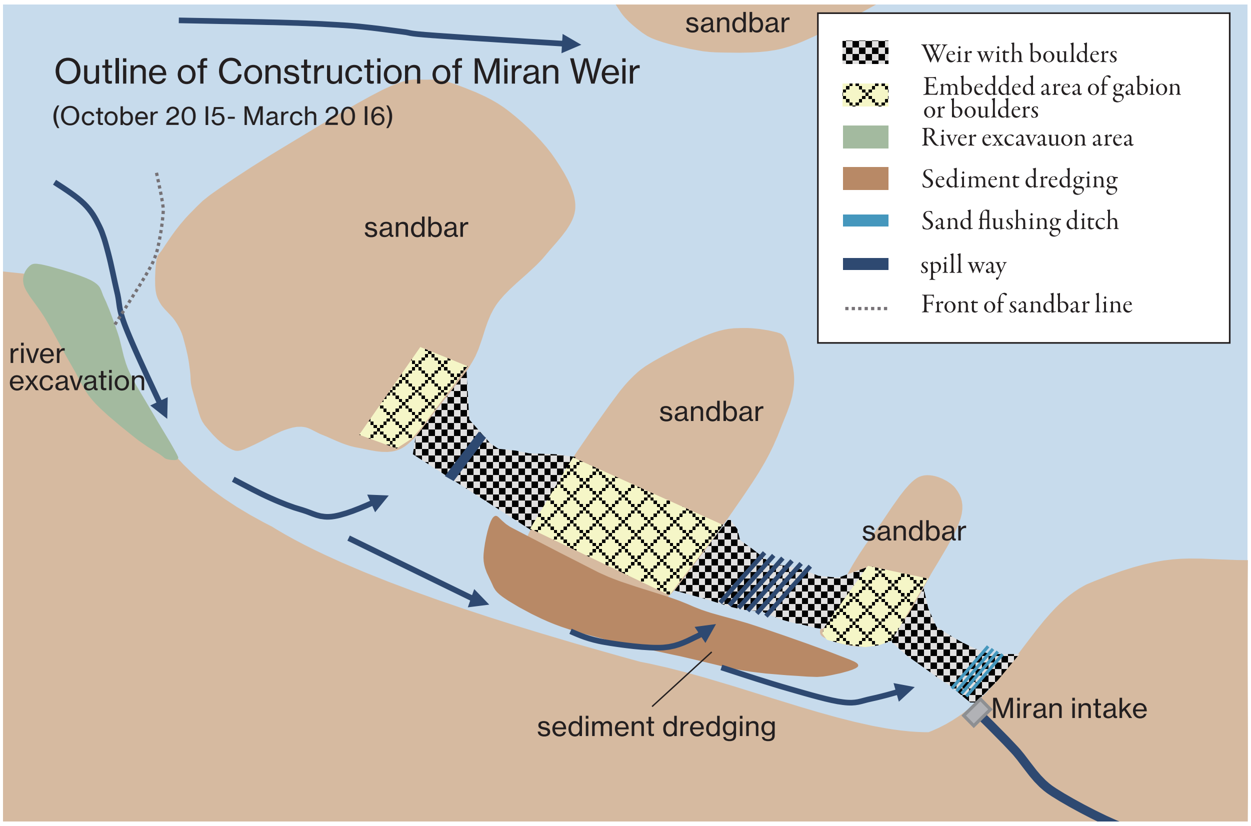


Figure 7.7 Sedimentation at Miran Weir [1)]

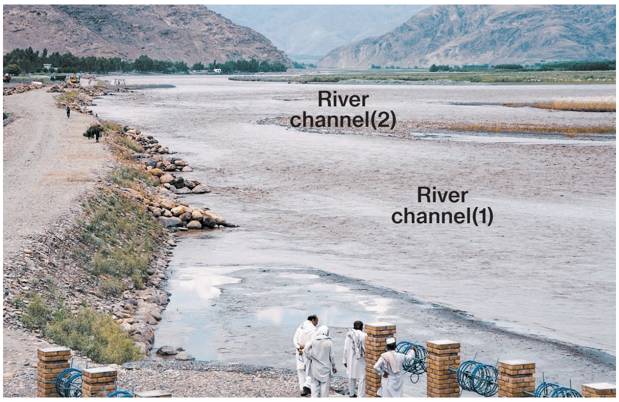


Photo 7.12 River Channel Excavation and Sediment Dredging at Miran Weir [1)]

(5) Destruction and Sediment Deposition at Main Irrigation Canal Due to Flash Floods and Debris Flows

Flash floods and debris flows in rivers and wadi (dried-up river) which cross the main irrigation canal cause destruction of the revetment and also cause excess inflow of sediment. Thereafter, emergency response, regular revetment repairs, and dredging of inflowing sediment are required. For sections where flash floods and debris flows frequently occur, measures such as siphoning a part of the main irrigation canal are taken. Depending on the widths of flash floods and debris flows, revisions of the width of the siphon section or the flood passage bridges are made. Revisions are implemented at the section where the training dikes are installed in order to prevent the inflow of sediment into the main irrigation canal. In the case of the existing PMS irrigation project, as shown in the figure below, a flash flood and a debris flow destroyed a part of the main irrigation canal, and sediment was deposited. Thereafter, the sediment was dredged, and the flood crossing bridge was extended.

Photo 7.13 Destruction of Main Irrigation Canal Due to a Flash Flood and a Debris Flow [1)]

Photo 7.14 Damage Caused by a Flash Flood and a Debris Flow [1)]

Photo 7.15 Extention Work of the Above Flood Passing Bridge (Left) and After Completion (Right) [1)]

Text Block 7-4: Damage Caused by Flash Floods and Debris Flows and Examples of Countermeasures [1)]

In the night from July 31st to August 1st, 2020, there was a local heavy rainfall in the mountainous area of the Laghman Province, which is adjacent to the Nangarhar Province, and flash floods and debris flows flowed into the valley of the Marwarid irrigation canal. Resident properties and fields in the valley were damaged. The irrigation canal with a total length of about 1.8 km and two siphons of 30 m and 40 m length were completely filled with boulders and debris. The PMS started the survey on August 2. Since it is the time when water is needed for rice and maize, restoration work was carried out immediately, with the aim of resuming water supply as soon as possible. Water supply was resumed on the 10th. The restoration work even during holidays encouraged the villagers who were disappointed by the loss of their houses and fields. One of the reasons why PMS was able to start water supply at an early stage is that the roles of gabion and willow branch on both walls of the irrigation canal were firm. When the sediment was scraped out from the buried irrigation canal, both walls of the irrigation canal were not damaged much and firmly formed the body of the irrigation canal. In addition, no one had lived at the time of construction in the area which became the flood way. However, as the fields had expanded, people gradually had begun to live. As a result, they were damaged during the flood. Therefore, it is necessary to promise with a region that they will not live on the flood way.

Photo Extended Flood Crossing Bridge [1)]

CHAPTER

8

HOW SHOULD AGRICULTURE AND IRRIGATION TECHNOLOGY BE IMPROVED?

To achieve more productive agriculture, how to improve irrigated agricultural technology?

PMS has faced many issues on crop cultivation since the project started. In this chapter, the main issues related to irrigated agriculture occurred in the PMS irrigation project area and useful technologies to improve them are summarized. Similar issues may occur in future projects. At that time, it is hoped that these technologies will be applied to achieve the target at an early stage.

In this Chapter, the establishment of demonstration farm for technical extension, water management technology, cultivation technology, and soil improvement technology are described.

A demonstration farm for technical extension is established for the purpose of efficient disseminating of cultivation technologies in irrigated agriculture, and the outputs of the PMS method irrigation project are ensured for agricultural workers who have little experience in crop cultivation.

In terms of the water management technology, proper water use in irrigated fields is an important issue to prevent waterlogged damages and improve crop productivity. If proper water use is known, fair water distribution based on it is possible, and it contributes to water saving. The useful technologies for that are explained for agricultural workers who have little experience in crop cultivation.

In terms of the cultivation technology, the effective technologies which solve the problems of cultivation and enable sustainable crop farming are compiled. In particular, crop rotation, shading culture, alley cropping, sowing technology, nursery production, etc. are effective cultivation technologies which have been demonstrated in the PMS demonstration farms and can be carried out using local materials.
In terms of the soil improvement technology, the countermeasures for maintaining crop productivity of farmland are soil improvement technology, soil analysis for appropriate soil management, and improving soil fertility with leguminous crops cultivation, etc.

The above is explained further in the following sections.

8.1 Establishment of Demonstration Farm for Technical Extension

The migrants and repatriated refugees in the existing PMS irrigation project areas are farmers with little cultivation experience, and their productivity is relatively low. To improve the existing situation, it is essential to extend cultivation techniques. Although there are currently agricultural extension workers, there is a lack of facilities that can effectively disseminate the technology. Therefore, the purpose is to establish a demonstration farm and efficiently extend cultivation technology.

(1) Issue

A rural social survey conducted in 2018 to evaluate PMS irrigation projects showed low crop productivity on irrigated farmland. The main cause is improper irrigation methods. MAIL has several extension workers in each county, but at present there is insufficient technical extension services to the villages, and farmers have very few opportunities to learn crop cultivation techniques. Therefore, a major problem to be solved in irrigation projects is low yield of crops due to lack of experience of farmers, and it is a problem to extend irrigation farming technology suitable for the area and extend it to farmers.

(2) Countermeasure

In order to improve the lack of experience of farmers, it is recommend to establish demonstration farm by irrigation project area for technical extension. The demonstration farm will be established mainly by the DAIL, WUA and IA during the project period and after the project period, WUA or IA will play a central role in operating the farm independently, and DAIL will play a main role in technical extension. Coordinate with related organizations to contribute to the agricultural research center for extension. It will be established in a place where the target farmers can easily visit and will be the center of technical extension. The main contents of the exhibition technology are as follows:

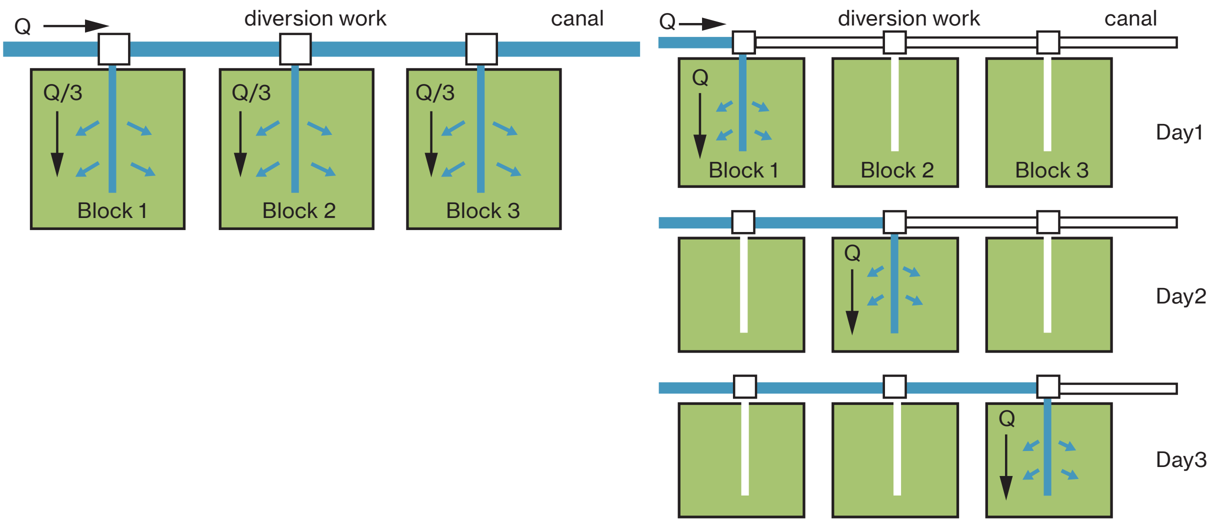
- Water-saving technology by appropriate irrigation methods.
- Prevention of soil degradation and pest control by crop rotation.
- Pest control by mixed cropping.
- Vegetable cultivation in summer by shading.
- Maintaining soil fertility by mixed cropping with legumes.

8.2 On-Farm Water Management

Proper water use in irrigated fields is an important issue to prevent waterlogged damage and improve crop productivity. In addition, if proper water use is clarified, fair water distribution based on it is possible. This section describes methods of water distribution based on the amount of water required for each crop and the appropriate water management of irrigated fields to ensure fair and proper water use.

8.2.1 | Irrigation Water Distribution Method

The allocation method of irrigation water is decided by the WUA or IA in consultation with the beneficiary farmers. As shown in Figure 8.1, there are basically two methods of irrigation water distribution in Afghanistan: (1) water distribution by flow rate, and (2) water distribution by time. In either method, it is ideal that the required amount of water is distributed monthly for each growth stage and the water is supplied within the irrigation interval of crops so that unfairness does not occur. Basically, water is distributed equally according to the irrigated area, but in villages and communities with common culture and social customs, water may be distributed to them together as one block.



Adjust the opening of the diversion work and distribute the required amount to each block in the field

1) Water distribution by flow rate

Fully open and close the diversion work, and allocate the required amount to each block in the field at a fixed time.

2) Water distribution by time

Figure 8.1 Irrigation Water Distribution Method [2)]

If a large amount of water is taken in the upstream block of the irrigation canal, water may become insufficient in the downstream block. This tendency becomes stronger especially during droughts. To prevent such unfair distribution of water, a fixed amount of water intake or water intake time is ensured with mutual the understanding and respect of farmers concerned. In addition, it is necessary to promote the effective use of water (reduction of invalid water intake, effective use of rainfall, etc.) and the rationalization of water distribution (appropriate response to fluctuations in water demand, stable water distribution throughout the irrigation period, etc.).

A major issue in the irrigation water distribution is the use of large amounts of water by paddy rice cultivation as explained in Subsection 8.3.5.

8.2.2 | Types of Irrigation Method in the Field

Irrigation methods are generally classified into three types: surface irrigation, sprinkler irrigation, and drip irrigation. Surface irrigation is further subdivided into four methods: flood irrigation, furrow irrigation, border irrigation, and basin irrigation. In Afghanistan, the three irrigation methods other than the basin irrigation are common. Since each irrigation method has advantages and disadvantages, the appropriate irrigation method is selected by referring to the cases in the target area. The characteristics of the irrigation method in the plot are as shown in Table 8.1.

Table 8.1 Characteristics of Irrigation Method in a Plot [2)]

	Irrigation Methods	Outline	Topographic Conditions
Surface Irrigation	Flood Irrigation (paddy rice)	A type of storage irrigation that creates ridges around the rice fields and floods them with water.	Flat farmland that enables even water distribution
	Furrow Irrigation (maize, onions, watermelons, tomatoes)	Surface irrigation method that replenishes crops by running water between ridges in the field	Farmland on gentle slopes
	Border Irrigation (wheat)	Surface irrigation method in which a laminar flow overflows the entire surface into a strip-shaped section separated by low ridges	Farmland on gentle slopes
	Basin Irrigation (paddy rice, wheat)	Small-scale flood irrigation in flat subdivisions surrounded by ridges	Relatively flat farmland
Spray Irrigation	Sprinkler Irrigation (onion, watermelon, maize)	An irrigation method in which high pressure is applied to water to make it into droplets and sprayed from a nozzle.	It is not easily affected by the topography of farmland.
Micro-Irrigation	Drip Irrigation (onion, maize, tomato)	An irrigation method that guides water to a perforated tube and supplies water directly to the soil surface and root zone.	It is not easily affected by the topography of farmland.

Advantages	Disadvantages	Photos
· Low installation and maintenance costs · Soil temperature control, pests, weeds, and lodging can be protected.	· Facilities that can supply sufficient water are indispensable · Salt accumulation is likely to occur near the soil surface · Large evaporation from the field surface · Percolation loss is likely to occur	
· Low installation and maintenance costs · A wide range of crop irrigation is possible	· Difficult to supply uniform water to the root zone · Large amount of loss since percolation water is likely to occur	
· High labor saving	· It is difficult to control percolation loss and runoff loss, so it is important to set the section length.	
· High irrigation efficiency when properly managed · Applicable to citrus fruits grown in parallel	· Large evaporation from the field surface · Percolation loss is likely to occur	
· High labor saving · Land preparation costs can be reduced	· Installation and maintenance costs are both expensive · Pumping is required	
· Minimize water and fertilizer consumption · It is also possible to mix liquid fertilizer to enhance the fertilizing effect.	· Installation and maintenance costs are both expensive · Clogs are likely to occur	

8.2.3 | Flood Irrigation, Furrow Irrigation and Border Irrigation Technology

(1) Flood Irrigation

The shape and area of the flood irrigated land is determined by the slope of the land, soil texture, amount of water conducted from the water source, irrigation depth and agricultural practices. The outline procedure for constructions in a flood irrigated land is as shown in Figure 8.2.

The most important thing in the maintenance of flood irrigation is to keep the soil surface horizontal. If the soil surface is not horizontal, there is insufficient flooding and weeds grow. If there are local depressions, the seedlings are submerged and die. Therefore, leveling is carried out during the off season. In addition, the ridge is gradually eroded by precipitation and the passage of people. Small animals such as mice may also dig holes on the ridge. Therefore, the condition of the ridge is checked regularly. If erosion is found, it is repaired promptly.

1) Irrigation Site Setting　　2）Formation of Ridges　　3）Leveling the Soil Surface of Each

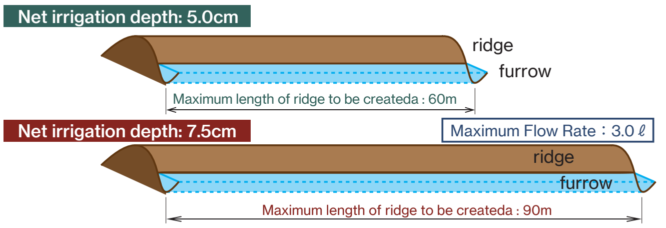
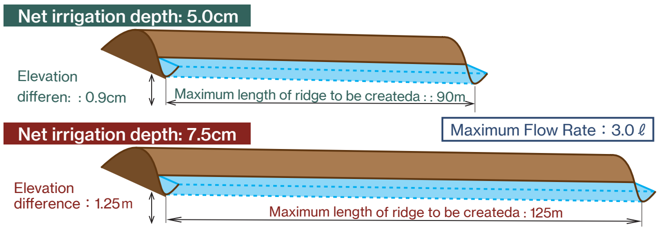
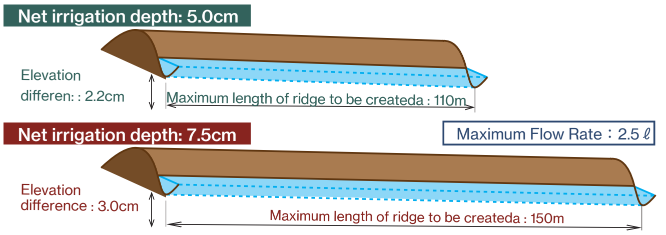
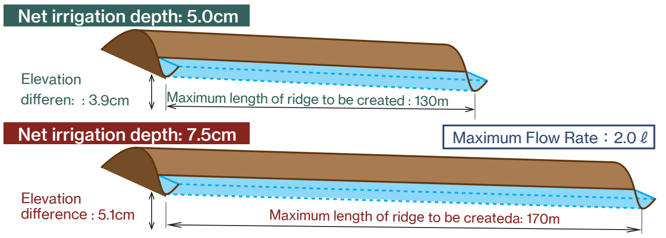
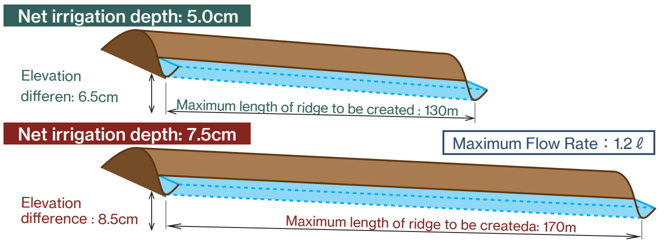
Figure 8.2 Flood Irrigation Construction Procedure (Outline) [2), see 3)]

(2) Furrow Irrigation

Field conditions of furrow irrigation are as shown in Figure 8.3. Furrows are small canals for watering crops and are constructed in parallel with each other. Crops are usually cultivated on ridges. Furrow irrigation is applied to fields on flat or gentle slopes. The slope of ridges is kept below 0.5% to prevent soil erosion due to running water. Also, taking into account the net irrigation depth (d net), the slope of ridges, the maximum flow rate between ridges, and the maximum length of ridges are determined with reference to Figure 8.3.

Here, the net irrigation depth is the irrigation depth determined by the growth pattern of crop roots and soil texture in order to supply irrigation water to the crops, and is outlined in Figure 8.4.

Regular maintenance is required to keep the ridges in proper condition to make sure that the irrigation water reaches the downstream ends of all ridges and that there are no dry or stagnant areas. In addition, it is important to remove weeds in the plot as much as possible so that they will not obstruct the running water or drainage.

<table>
<tr><td rowspan="2">slope</td><td>Maximum flow rate, maximum length of ridges and elevation difference corresponding to net irrigation depth</td><td colspan="2">Clay soil</td><td colspan="2">Loam soil</td><td colspan="2">Sand soil</td></tr>
<tr><td>Soil texture: Example of loam soil</td><td>(m)</td><td>(cm)</td><td>(m)</td><td>(cm)</td><td>(m)</td><td>(cm)</td></tr>
<tr><td rowspan="2">0.0%</td><td rowspan="2">
</td><td>a:100</td><td>b:-</td><td>a:60</td><td>b:-</td><td>a:30</td><td>b:-</td></tr>
<tr><td>a:150</td><td>b:-</td><td>a:90</td><td>b:-</td><td>a:60</td><td>b:-</td></tr>
<tr><td rowspan="2">0.1%</td><td rowspan="2">
</td><td>a:120</td><td>b:1.2</td><td>a:90</td><td>b:0.9</td><td>a:45</td><td>b:0.45</td></tr>
<tr><td>a:170</td><td>b:1.7</td><td>a:125</td><td>b:1.25</td><td>a:60</td><td>b:0.6</td></tr>
<tr><td rowspan="2">0.2%</td><td rowspan="2">
</td><td>a:130</td><td>b:2.6</td><td>a:110</td><td>b:2.2</td><td>a:60</td><td>b:1.2</td></tr>
<tr><td>a:180</td><td>b:3.6</td><td>a:150</td><td>b:3.0</td><td>a:95</td><td>b:1.9</td></tr>
<tr><td rowspan="2">0.3%</td><td rowspan="2">
</td><td>a:150</td><td>b:4.5</td><td>a:130</td><td>b:3.9</td><td>a:75</td><td>b:2.25</td></tr>
<tr><td>a:200</td><td>b:6.0</td><td>a:170</td><td>b:5.1</td><td>a:110</td><td>b:3.3</td></tr>
<tr><td rowspan="2">0.5%</td><td rowspan="2">
</td><td>a:150</td><td>b:7.5</td><td>a:130</td><td>b:6.5</td><td>a:75</td><td>b:3.75</td></tr>
<tr><td>a:200</td><td>b:10.0</td><td>a:170</td><td>b:8.5</td><td>a:110</td><td>b:5.5</td></tr>
</table>

Note: The soil texture of Afghanistan is generally loam or sandy loam.

Figure 8.3 Ridge Slope, Maximum Flow Rate and Maximum Length Corresponding to Field Texture and Net Irrigation Depth [2), see 3)]

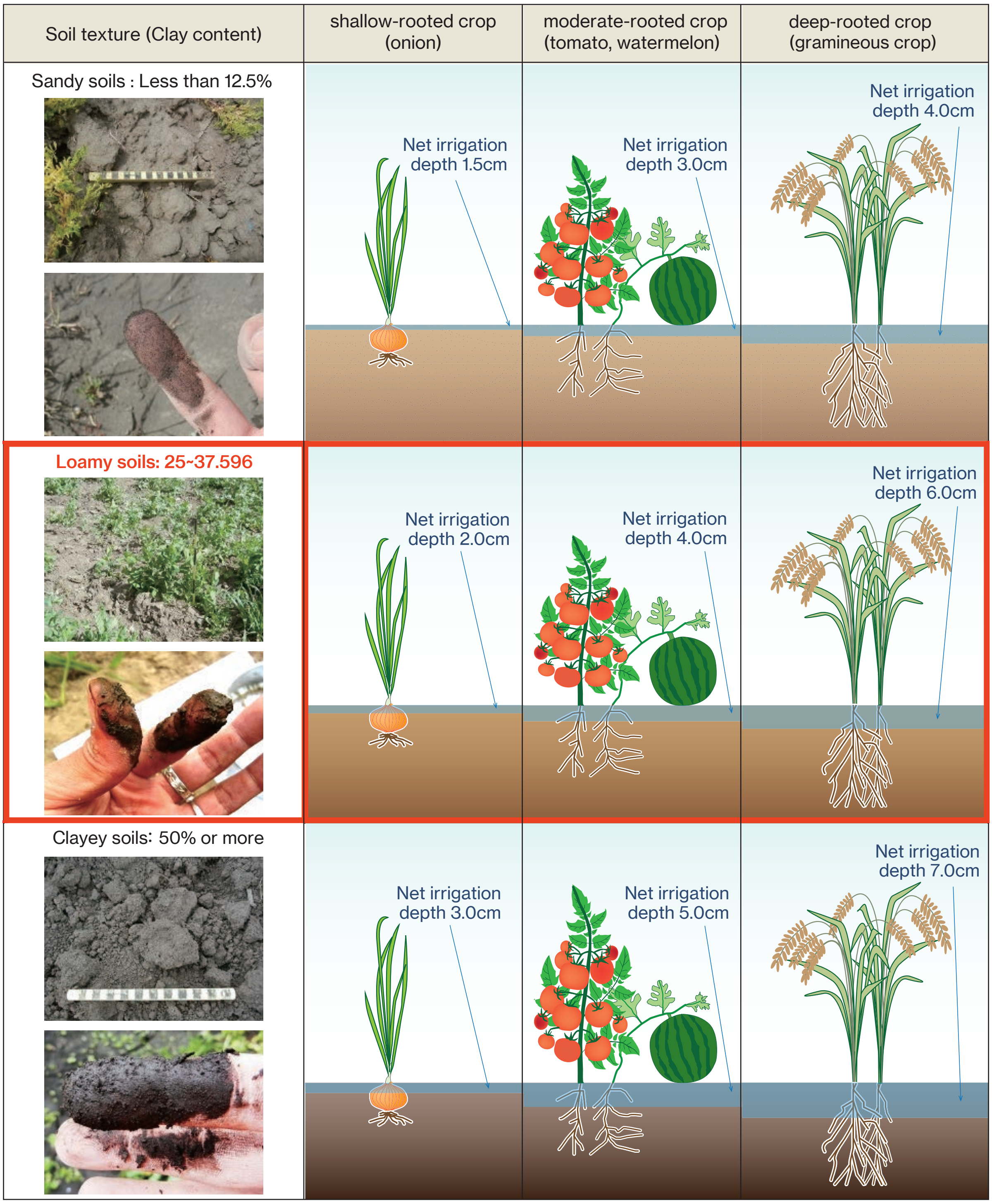


Figure 8.4 Net Irrigation Depth [2), see 3)]

(3) Border Irrigation

Border irrigation is generally designed as a long, continuous field for easy operation of agricultural machinery and is therefore unsuitable for small farms that are primarily manpowered or livestock cultivated. It is desirable that the slope of the border is uniform, the minimum slope for proper water distribution is 0.05%, and the maximum slope for controlling soil erosion is 2%[3)]. For border irrigation, homogeneous loam or clay with moderate percolation rate is suitable.

In the maintenance of border irrigation, it is essential to maintain a uniform slope, and not only weeding at the ridges and drains, but also physical damage on the ridges is repaired promptly.

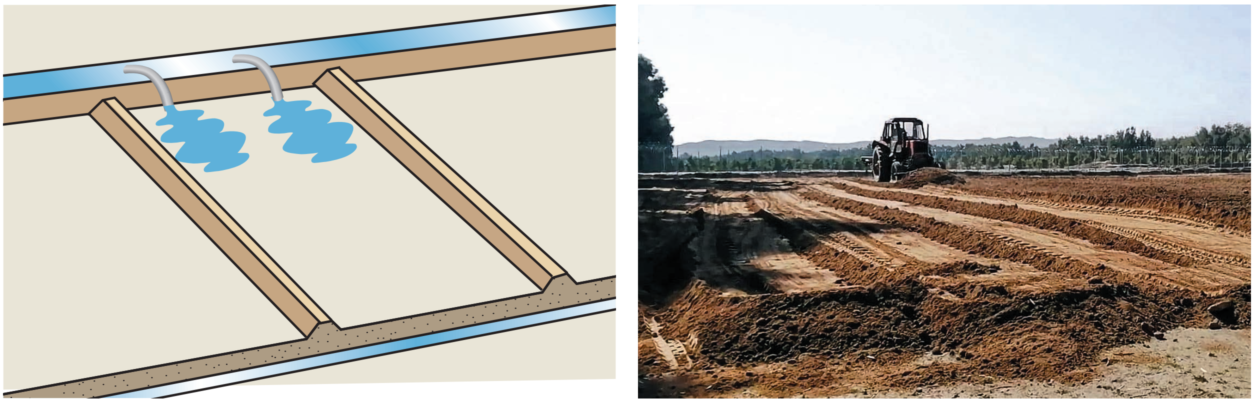
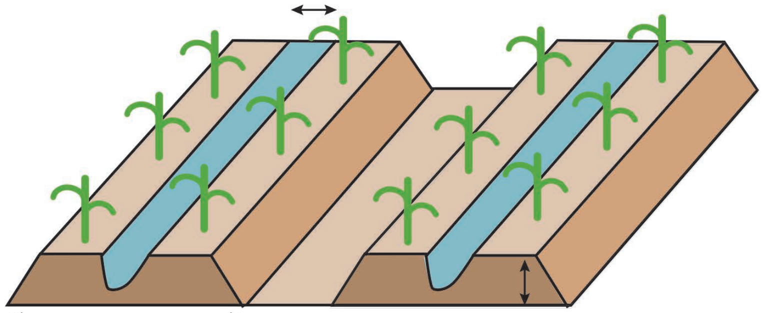


Figure 8.5 Border Irrigation [2), see 3)]

8.2.4 | New Irrigation Method Suitable for Afghanistan (Irrigation on Ridges)

In addition to the general irrigation methods shown in Subsections 8.2.2 and 8.2.3, irrigation methods that make wide ridges and supply water to the center of ridges have been successful in the existing PMS irrigation project areas recently. It is expected that the technology will be extended. This irrigation method has a high water saving effect because it irrigates only near the crop roots. In addition, since only the top of the ridge is irrigated, the roots can grow healthily due to the improved drainage conditions.



a) Schematic Figure

b) Situation of Ridge Cultivation

Figure 8.6 New Effective Irrigation on Ridges Method in the existing PMS Irrigation Project [2)]

8.2.5 | Points to Note in On-Farm Water Management

(1) How to Reduce the Damage Caused by Water Pressure at the Water Inlet

Poor water management may have a negative impact if the yields of paddy rice and vegetables are below average. In particular, when the water pressure at the water imlet is high, it has a great effect on the crop growth due to seed runoff, poor crop growth, and root rot, etc.around the water inlet. As a countermeasure, there is a method of placing stones/boulders at the water outlet to reduce the water pressure.

Photo 8.1 Damage Caused by Water Pressure at the Water Outlet [2)]

Before Dealing

After Dealing

Photo 8.2 Measures to Prevent Damage from Water Pressure at the Water Outlet (Placing of Stones or Bolder at Water Outlet) [2)]

(2) Field-Level Response to Droughts and Floods

Effective use of limited irrigation water and water conservation are important as a response to drought, such as controlling the amount of water used by performing detailed water management, saving water in the field, and rotational irrigation. In order to reduce the impact on crops, it is highly effective to save water by adjusting the planting season of rice and other crops that consume a lot of water. In addition, if the drought situation is severe, farmland that will not be planted is selected and agreed upon, and measures are taken such as taking water from the drainage channel and using the water repeatedly.

A response to flood inundation is to drain the inundation water at an early stage. In addition, remove the sediment deposited in the field, and the field is re-sown or replanted. If fertilizer is washed away, fertilizer is added to restore roots and foliage.

8.3 Cultivation Technology

At present, various problems regarding crop cultivation are occurring in the existing PMS project area. This section summarizes effective technologies for sustainable crop cultivation to solve these problems. In particular, techniques proven in PMS fields or techniques that are feasible and effective with local materials.

8.3.1 | Sustainable Production by Organic Farming

(1) Issue

If production can be increased by reducing the use of chemical fertilizers and pesticides, It will be possible for the rural Afghan villages to achieve food self-sufficiency. Increasing agricultural production by applying sustainable methods such as organic farming is a major goal for the future.

(2) Countermeasure

Crop rotation and companion crop are ways to stabilize crop production while reducing the amount of pesticides and fertilizers applied. Crop rotation is a method of growing different types of crops in a cycle, the purpose is to prevent diseases, insects control, nutritional balance and improve soil structure. Basic rotation is leaf vegetables, fruit vegetables, root vegetables and legumes as shown in following Table.

Companion crop is the planting of different vegetables in proximity for pest control, providing habitat for beneficial creatures and balancing nutrients in the soil.

Table 8.2 Crop rotation and Characteristics of Each Group [2)]

1st year	2nd year	3rd year	4th year
legumes	leaf vegetables	fruit vegetables	root vegetables
Green beans, Soybeans, Peanuts	Spinach, Cabbage, Onion, Napa cabbage	Tomato, Melon, Eggplant	Radish, Carrot, Turnip
Nitrogen fixing crop	Nitrogen hungry crop	Phosphorous hungry crop	Potassium hungry crop

Following table shows examples of companion crop.

Table 8.3 Example of companion crop [2)]

Good companion		Effect
Carrots	Onion	Onion repel carrot fly.
Maize	Beans	maize provides bean with a trellis for climbing and beans supply nitrogen to maize.
Tomatoes	Basil	Basil repels insects and disease, improves growth
Spinach	Peas, Beans	Peas and Beans provide natural shade and nitrogen to spinach.
Cabbage	Rosemary	Rosemary repels cabbage flies.
Eggplant	Marigolds	Marigolds deter insects

8.3.2 | How to Evenly Sow Seed in Small-Scale Farm

(1) Issue

Sowing density is a major management factor that affects growth and development of crops by modifying the light environment and interplant competition for water and nutrients. Therefore, planting density or sowing density play an important role to achieve higher productivity. In some fields, the seeds are sown unevenly or too much as shown in following photos in existing PMS field. Especially, tiny seeds are often difficult to handle.

Photo 8.3 Uneven Planting Density in PMS Project Area [2)]

(2) Countermeasure

It is effective to use a sowing machine or a sowing tool to uniformly spread small seeds. Photo 8.2 shows the sowing machine used to sow large seeds such as peanuts, corn and beans, and the hand seeder used to sow small seeds such as sesame seeds. As a simple method, there is also a method of using a PET bottle.


Seeder for bigger seed


Seeder for bigger size seed


Hand seeder using PET bottles (hole size is adjusted according to seed size)

Photo 8.4 Seeder and Hand Seeder [2)]

According to IRRI in Myanmar, rice yields are 25% higher in mechanical sowing than in manual sowing. Following photos show the field seeding by tools shown in Photo 8.4. Seed is evenly sown in the field.

Photo 8.5 Field Sown by Seeder [2)]

8.3.3 | Effect of Shade for Improving Productivity

(1) Issue

Crops such as rice and wheat tend to be stunted in strong sunlight. Summers in Afghanistan are very hot with very strong sunshine, and the excessive sunlight and heat cause physiological damage to crops. Therefore, it is necessary to soften the sunlight by creating shade by planting trees.

(2) Countermeasure

As a method of mitigating the influence of sunlight, there are shade culture such as alley cropping and use of shading net.

1) Alley Cropping

As shown in Photo 8.5, alley cropping is a method of planting perennial crops such as fruit trees in rows and cultivating the crops between them. The planted fruit trees create a shade to improve microclimate such as suppress evapotranspiration, maintain soil moisture for a long time, and create a suitable environment for crop growth. As a result, it is possible to minimize damage of crop growth due to high temperature and improve crop production especially in summer. It also has the effect of decreasing soil erosion.

By introducing alley cropping to irrigated farmland, it is possible to diversify the crops cultivated in the summer and stabilize the income of small-scale farmers (1 ha or less). The existing PMS irrigation project is currently planting wheat, vegetables and alfalfa between fruits trees.

Photo 8.6 Alley Cropping in PMS Field [1)]

Mango and beans   Pigeon pea and groundnuts

Photo 8.7 Case of Alley Cropping [2)]

2) Shading Net

Shading culture is a method of using shade nets to create shade and grow crops. Shading net is expected to reduce the light intensity and temperature as well as maintaining soil moisture, so with the shading net that can provide suitable conditions for crop growth. Accordingly, the use of shading net in high temperature area is expected to increase the yield.

Cultivation using a horticultural shading net (Case in Iran)   Cultivation using ordinary net (Case in Mauritania)

Photo 8.8 Case of Shading Culture [2)]

8.3.4 | Raised Bed Cultivation in Wetland to Prevent Waterlogged Damage

(1) Issue

In the irrigated farmland of the existing PMS project area, swamps have been scattered in the lowlands, and they tended to increase. When the higher-altitude farmland is irrigated, the water that has nowhere to go accumulates in the lower field, and the field become wetlands. Most crops in the lowland die from root rot. In these swamps, reed and pampas grass grow all over, and when viewed from a distance, they look like green spaces, and it is sometimes misunderstood that the results of irrigation have improved.

Waterlogged area along Shigi canal

Vast swamp

Photo 8.9 Case of Swamp [1)]

(2) Countermeasure

In the PMS method irrigation project, measures used to be taken to prevent becoming wetlands by improving drainage channels considering that the irrigation canal and the drainage canal were integrated. Here, measure by practical and economical methods such as raised bed cultivation is shown.

Raised beds allow excess water to drain out of the surface soil. In general, when growing upland crops in fields with poor drainage and high moisture, raised bed cultivation is effective to prevent waterlogging. For this reason, it has been widely applied to crop cultivation in wetlands around the world. It seems that raised bed cultivation is effective as one temporary solution even in wetland fields of PMS project area. (See photo 8.8).

Proper water use at the upstream is important to prevent moisture damage, and the method is shown in Section 8.2.

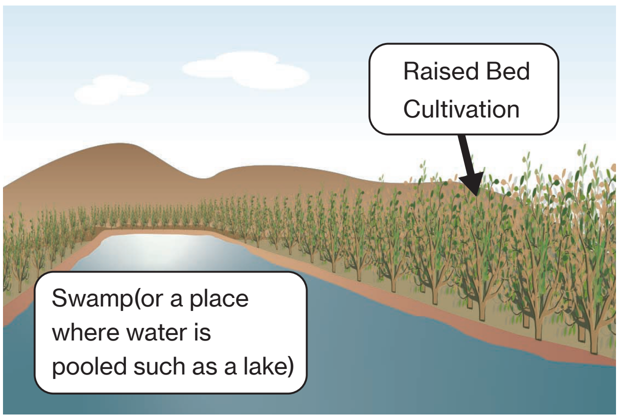


Figure 8.7 Raised Bed Cultivation [2)]

8.3.5 | Increase in Rice Cultivation and Countermeasures (Introduction of Appropriate Upland Rice Varieties)

(1) Issue

In the irrigated farmland of the existing PMS irrigation project, paddy rice is cultivated everywhere along the irrigation canal due to the technical cooperation of rice cultivation by JICA and the soaring price of imported rice. Paddy rice requires about five times as much water as wheat.

In Afghanistan, where water resource is not abundant, the large amount of water used for rice cultivation is not always optimal from the viewpoint of effective use of water. Although the farmers' intentions should be respected for crop selection, it is necessary to establish rules for paddy cultivation from the viewpoint of water efficiency in the future.

(2) Countermeasure

Rice cultivation in existing PMS project areas is said to be relatively profitable. In irrigated fields in arid areas, paddy rice is cultivated as part of the crop rotation system to avoid salt accumulation in soil. The rice cultivation has the advantage that accumulated salts can be leached out on a regular bases. On the other hand, rice cultivation in sandy soil also has disadvantages such as reducing soil fertility by leaching, and water logging and salt accumulation in the surrounding area.

As measures to mitigate this negative function, avoiding continuous cropping of paddy, cultivating leguminous crops after paddy cultivation to enrich nitrogen in soil and applying organic fertilizer, etc. can be considered.

The water amount obtained by the irrigation project is a limited and valuable resource. In order to distribute the irrigation water fairly in the beneficiary area, the rice cultivation area should set rule to manage paddy cultivated area etc. If farmers want to grow rice, it is necessary to consider the introduction of upland rice variety that require relatively little water.

For example, there is NERICA rice (abbreviation for New Rice for Africa), which JICA is promoting in Africa. NERICA rice is a upland rice variety developed in 1994 by crossing high-yielding Asian rice with African rice that is resistant to diseases and weeds.

8.3.6 | Improving Nursery Production (Kneaded Nursery Bed)

(1) Issue

The issue is how to grow vegetable seedlings that grow easily and uniformly in areas where there is no nursery pot.

(2) Countermeasure

Neri doko(Kneading bed) is the traditional method to prepare nursery in Japan. This technique is very effective in areas where plastic pots are difficult to obtain. Kneading bed is a technique that mixes soil and fertilizer well with water, removes excess water once, cuts it into block-shaped lumps (size varies depending on the crop), and puts seeds in it to make a nursery.

Figure 8.8 shows how to prepare the kneading bed. In Japan, plastic pots are currently used for nursery production, but in the days when there were no plastic pots, this technique called kneading bed was commonly used. Even in Afghanistan, if it is difficult to obtain the pots, it is possible to produce nursery by utilizing the technology shown in Figure 8.8.

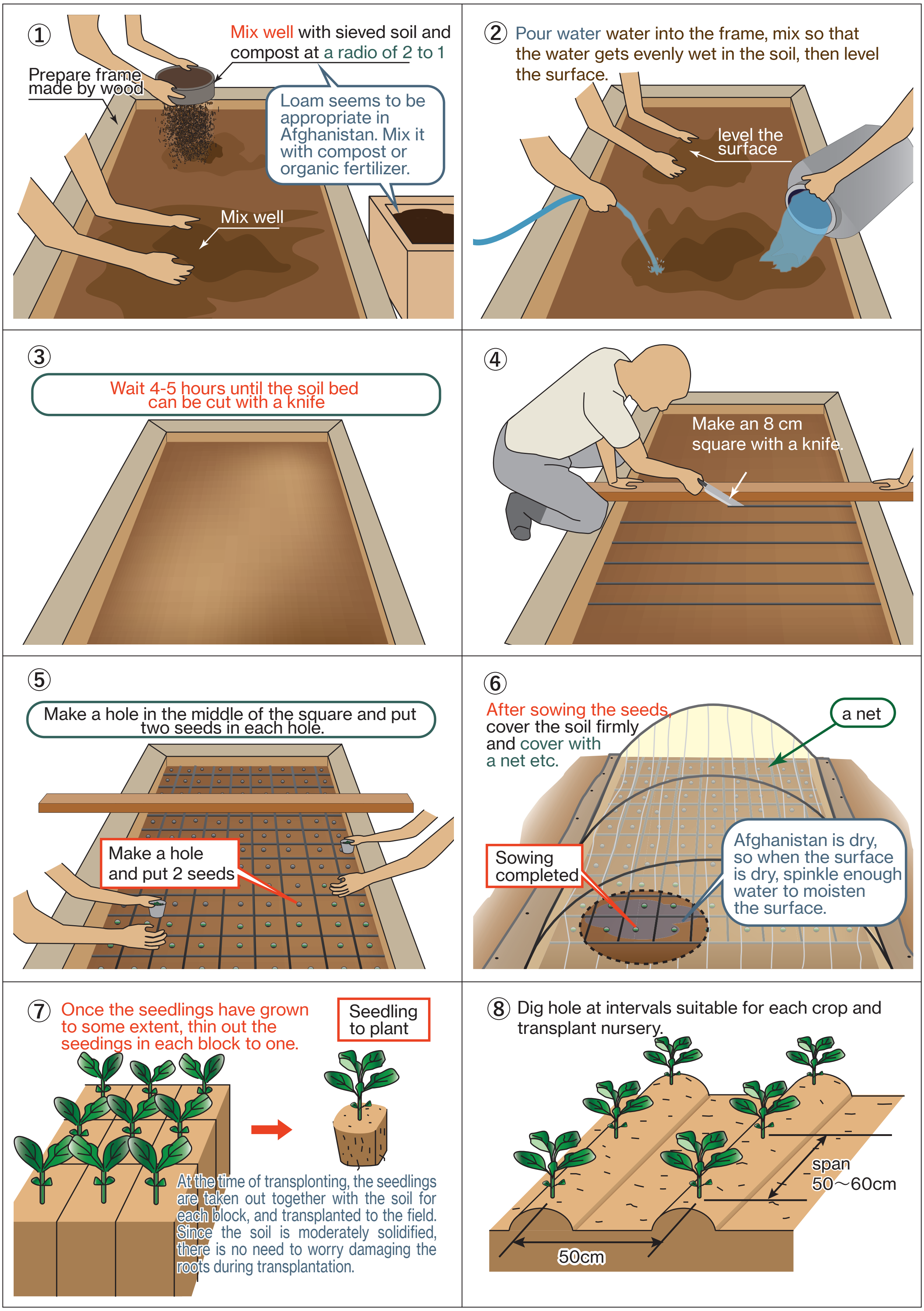


Figure 8.8 Preparation of Kneading Bed [2)]

8.4 Soil Improvement Technology

The soils in the study area are characterize by sandy and high pH. Such soils are fragile and very difficult to manage. In addition, there are few data on local soil. Soil analysis needs to be carried out in the future to improve the situation. This section presents techniques such as improving surface texture, the need for soil analysis for proper soil management, and improving fertility.

8.4.1 | Topsoil Improvement by Soil Profile Survey

(1) Issue

The issue is how to find the soil texture of irrigated farmland and how to improve the soil texture of topsoil. Soil texture, defined by the proportions of sand, silt and clay, affects the physical and chemical properties of the soil and is an important soil property for crop production and field management. The soil characteristics by texture are shown in Table 8.3. Since different soil textures have different nutrient and water holding capacities, soil management methods differ depending on the texture. For instance, finer soil textures, such as clay and silt, have a higher ability to hold nutrients and water in soils, and adding silt to the sandy topsoil makes them well-drained which is suited for upland crop.

If it is found that soil texture other than sand exists in a relatively shallow layer, the surface soil is improved by deep plowing. The deep plowing can improve the water and nutrient holding capacity of the surface layer by moving the lower silt and clay.

In irrigated farmland in existing PMS irrigation project area, there is a thick silty soil layer directly under the thin sandy layer (1 to 2 m). By transferring this silty and clayey soils to the surface, the surface soil is improved.

In addition, the silt soil is gradually transported by dump trucks, and soil dressing of silt clay is carried out to sandy farmlands which is not originally suitable for irrigation, to clear cultivated land, by mixing clay and sand. Soil suitable for irrigated crop cultivation is medium texture between sand and clay, and medium texture between loam " and "clay " is also suitable. Clayey soil is difficult to handle when dry, but it is always applicable in flood irrigation and basin irrigation. In addition, clayey soil moves to the upper layer by deep plowing and mixes with sandy topsoil to improve the water and nutrients holding capacity.

Table 8.4 Soil and Physical Property by Texture [2)]

Soil	Texture	Tillage	Air permeability	Drainage	Water holding capacity	Nutrient holding capacity
Sandy Soils	S,LS	Easy	Rapidly	Well	Low	Low
Loamy Soils	SL,L,SiL	Easy	Moderately	Medium	Medium	Medium
Clayey Soils	SCL,CL,SiCL	Slightly Difficult	Slow	Poor	High	Slightly High
Heavy Soils	SC,SiC,LiC,HC	Difficult	Very Slow	Very Poor	Low	High

(2) Countermeasure

In order to easily find texture of the lower soil layer in farmland, the soil is sampled using a soil auger and exam texture by layer. The method can easily estimate the presence of silty and clayey layers. Figure 8.9 shows a soil profile survey using a soil auger.

The soil texture of the collected soil samples can be estimated texture by feeling of fingers at the site. If done correctly, the soil texture can be estimate very accurately.

Soil texture can be estimated by how the soil feels when operated by, and is estimated by the shape of the soil when the soil is moistened and kneaded between the thumb and index finger, as shown in Table 8.4.

The sandy topsoil can be improved by checking the soil texture of the soil collected by the soil auger and, if silt or clay soil is confirmed in the lower layer, applying it to the sandy surface layer by top dressing.

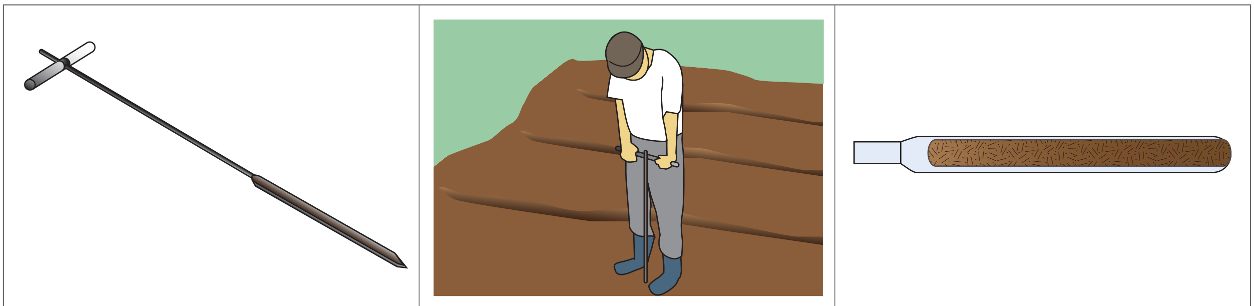
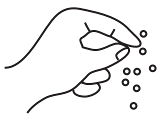
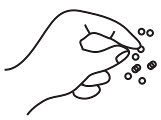
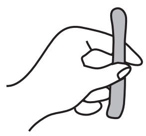
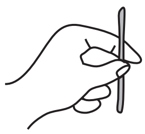
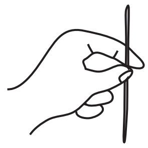


Figure 8.9 Soil Profile Survey by Soil Auger [2)]

Table 8.5 How to Estimate Texture by Feel [2)]

Texture grade	Sand	Sandy loam	Loam	Clay loam	Clay
Clay content(%)	＜12.5	12.5～25.0	25.0～37.5	37.5～50.0	50.0＜
Behavior	Coherence nil to very slight, cannot be molded	Bolus just coherent but very sandy to touch	Bolus coherent	Coherent plastic bolus, smooth to manipulate	Smooth plastic bolus, can be molded into rods without fracture
Measuring Method in Field					

8.4.2 | Soil Analysis for Appropriate Soil Management

(1) Issue

Calcareous soils relatively widespread in the dry areas such as Afghanistan. The soils are generally characterized by high pH and low EC.
The results of soil analysis of existing PMS project area were also pointed out that the soils are characterized by high pH and low EC. From these data, the institute reported that the land was a wasteland with poor productivity.
This soil contains large amounts of calcium salts, which can have a significant impact on crop productivity. There are some wetlands and swamps that are adversely affected by the calcium.
pH (index of acidity) and EC (electrical conductivity = index of salinity) are the most popular soil index to know soil characteristics and can be easily measured. The appropriate pH differs depending on the crop, and some crops are resistant to EC, but if both of them exceed the appropriate range, crop growth is inhibited. In calcareous soils, lowering pH or suppressing salt accumulation is a very important issue for maintaining and improving crop productivity. Therefore, it is necessary to measure pH and EC regularly to obtain reliable information, and take appropriate measures based on it.

(2) Countermeasure

Calcareous soils are widely distributed in Afghanistan. These two parameters are especially important factors for soil management. Table 8.5 shows cause and countermeasures for fluctuation in pH and EC values. It is very important for soil management to measure these indicators regularly and apply the results for soil management such as fertilizer application.
The measured pH and EC should record in a table such as Table 8.6. Base on the data, what kind of soil management is desirable for each farmland is examined. Regarding cultivation techniques that have been

practiced among local farmers, the pH and EC data of the soil in the fields to which the techniques are applied will be measured and the effects will be verified. Technologies that are effective will be actively extend.

The cause of high pH and low EC is that the soil contains a large amount of calcium carbonate. Measures to improve such soil is to apply acidic fertilizer containing sulfate sulfuric acid radicals (Do not use fertilizers containing sulfate radical in paddy fields). To adjust the pH of alkaline soil, planting alfalfa (forage crop) is said to effective. In fact, in the irrigated farmland of the existing PMS irrigation project, when alfalfa was planted between fruit trees, the soil pH decreased to 5 from 7 or higher. However, it is necessary to confirm the effect by measurement of pH.

Table 8.6 Primary Cause and Countermeasure of High and Low of pH and EC in Soil [2)]

pH / EC	Low EC	Optimum range	High EC
High pH	Cause: High calcium concentration Countermeasure: Appling potentially acidic fertilizer such as ammonium sulphate. (Avoid fertilizers containing sulfate in paddy field)	Cause: Large amount of ammonium nitrogen Countermeasure: Avoid fertilizer contain calcium, Applying physiologically acid fertilizer. (Avoid fertilizers containing sulfate in paddy field)	Cause: Excessive fertilizer, salt accumulation Countermeasure: Desalting (flooding, cleaning crops, etc.), deep plowing, fertilizer-free cultivation, fertilizer application of slow-release fertilizer, etc.
Optimum range	Cause: Lack of fertilizer Countermeasure: Proper fertilization	Optimum range pH: 5.5 – 7.0 EC: 0.4 – 1.0	Cause: Excessive nitrate nitrogen Countermeasure: Reduced fertilizer, deep plowing, desalting, organic fertilizer
Low pH	Cause: Lack of fertilizer Countermeasures: Application of liming material and organic fertilizer	Cause: High proportion of nitrate nitrogen Countermeasure: Application of liming material and proper fertilization	Cause: Excessive nitrogen Countermeasure: Nitrogen leaching, desalting

Table 8.7 Record Form of pH and EC [2)]

Year	Month	Date	Place	pH	EC	Records of fertilizer and crop etc.	Remarks

(3) Reference

In most Asian and Latin American countries, land capability classification map is prepared to select land for agriculture development. In order to select the target site for the irrigation project, it is desirable to create selection criteria that take into account the land conditions in Afghanistan. Here, the land classification system implemented in other countries is introduced as a reference for preparing Afghanistan's own selection criteria.

First, prepare a topographic map and soil map on an appropriate scale. At that time, the chemical and physical properties of each soil must be clarified. Based on this, evaluation criteria are prepared according to the conditions of each country. The evaluation items are topography (-), erosion (e), drainage (h), inundation (h), soil texture (s), effective soil layer (s), salt concentration (s), and fertility (s). I-VIII grade criteria are set and evaluated, and the evaluation of the lowest item is the grade of the land. The following shows criteria in El Salvador as an example of evaluation criteria. The land classification system classify land into eight classes based on broad interpretations of soil and topographic factors that affect agricultural yields and soil erosion.

Capability Class -I : Class 1 soils have few limitations that restrict their use.
Capability Class - II : Class 2 soils have moderate limitations that reduce the choice of plants or that require moderate conservation practices.
Capability Class - III : Class 3 soils have severe limitations that reduce the choice of plants or that require special conservation practices, or both.
Capability Class - IV : Class 4 soils have very severe limitations that reduce the choice of plants or that require very careful management, or both.
Capability Class - V : Class 5 soils are subject to little or no erosion but have other limitations, impractical to remove, that restrict their use mainly to pasture, rangeland, forestland, or wildlife habitat.
Capability Class -VI : Class 6 soils have severe limitations that make them generally unsuitable for cultivation and that restrict their use mainly to pasture, rangeland, forestland, or wildlife habitat.
Capability Class - VII : Class 7 soils have very severe limitations that make them unsuitable for cultivation and that restrict their use mainly to grazing, forestland, or wildlife habitat.
Capability Class - VIII : Class 8 soils and miscellaneous areas have limitations that preclude commercial plant production and that restrict their use to recreational purposes, wildlife habitat, watershed, or esthetic purposes.

In case of irrigation project, class I-III are selected as economically feasible areas because the project should select land where high profitability can be expected in order for the settlers to repay the construction costs.

8.4.3 | Maintaining Soil Fertility with Leguminous Crops Cultivation

(1) Issue

Among the leguminous crops such as alfalfa, haruhar, soybean and shakhtur, peanut was extremely effective to maintain soil fertility. After harvesting peanuts, watermelon and onion are grown very well.

It is a big issue in the future to continuously increase the crop production while maintaining the soil fertility by introducing organic cultivation methods such as crop rotation.

(2) Countermeasure

Legume is called a natural mini-nitrogen manufacturing factory and growing these crops play a vital role in increasing nitrogen in soil. The carryover of N derived from legume grown is also important. Therefore, introducing leguminous crops in crop rotation is essential for reducing the nitrogen (N) fertilizer requirement for crop production. Crop rotation including legumes fixes nitrogen, diversifies crop production systems and improves soil fertility. It is desirable to include legumes in planting systems such as

intercropping and mixed cropping.
Mixed cropping means that two or more types of crops are cultivated in the same field at the same time or for a certain period of time, and the crops have no distinction between main and sub crops. Intercropping is distinguished from main and sub crops. Therefore, sub crop is cultivated in the furrows and hill space within row of the main crop.
Legumes are cultivated with various crops in the cultivation system such as intercropping and mixed cropping. The typical one is mixed cropping of maize and beans. See photo 8.9. In addition, the following advantage is expected by mixing annual crops and perennial crops:
- Products and profits generate at different times,
- Land resources can be used more effectively by using three-dimensionally.


Maize and beans


Pigeon pea and sesame

Photo 8.10 Example of Intercropping and Mixed Cropping with Leguminous Crop [2)]

It has been recognized that nitrogen fixative amount by root nodule bacteria is significant amount, soybean is 57-94Kg / ha and clover is 104-220Kg / ha. However, there is a possibility that there are no effective root nodule bacteria depending on the land. Therefore, it is necessary to confirm the presence or absence of nodules on the roots of the legumes being grown. If the legumes have no root nodules, the root nodule bacteria must be inoculated into the field.

Appendix

(1) TECHNICAL TERMINOLOGY
(2) REFERENCES
(3) SPECIFICATION OF INTAKE FACILITIES
(4) CALCULATION SAMPLES

Appendix (1) TECHNICAL TERMINOLOGY

Terminology	Meaning
abutment	Connecting parts of a weir to both sides of the river.
allowable stress intensity	The limit point of resisting force exerted on a structure.
alluvial fan	The area where a river flows from the mountains to the plains.
apron	The floor made of boulders or concrete to protect it from scouring by a torrent.
apron works	A concrete or boulders floor installed on the downstream side of the structure.
area grid method	It is one of the riverbed material survey methods in which the thread is put in a grid at intervals of the maximum gravel diameter on the riverbed at the representative point, and the gravel below the intersection of the thread is sampled.
backhoe	A kind of construction machine suitable for excavation at a place lower than the ground surface.
bank	An embankment made from a small amount of soil. Dike.
base elevation	The height of the lowest surface that serves as a standard when setting the height of a structure.
basin irrigation	It is a type of irrigation system in which water slowly flows along the surface of cultivated land, wets the ground, and penetrates into the ground.
bearing capacity	The amount of force that the ground can support.
bed protection works	Groundsill. A method to protect the riverbed with boulders and/or concrete, reducing the gradient of the original riverbed and preventing from scouring.
bedload	Relatively heavy gravel that moves near the riverbed due to the running water of the river.
bending stress intensity	The stress that occurs in the cross section when a bending moment is applied.
beneficiary irrigation area	A farm land that benefits from the irrigation water.
berm	As the dike becomes taller, the length of the slope becomes longer. In order to maintain the stability of the slope, a horizontal small stage called "berm" is provided.
blanket works	A method using impermeable materials to coat the slope of the embankment on the reservoir side to reduce the seepage water to the inside of the embankment.
boiling	A phenomenon in which the bottom of the excavation trench is destroyed by water entrainment.
border irrigation	An irrigation method in which the field is divided into strips that allow water to flow in from the top of the section.
boulder	Gravel with the particle size of 300mm or more.
boulder oblique weir	A structure in which stones are piled up diagonally against the flow of water to guide the flow into the irrigation channel.
butyl rubber	A type of synthetic rubber.
cadastral map	A drawing that shows the rough position and shape of land.
cadastral survey map	An official drawing that describes the exact area, shape, positional relationship with the adjacent land, the position of the boundary and so on.
canal along foot of dike	A waterway constructed near the foot of an embankment to drain rainwater in a place where the ground is low.
charkha	A tool used traditionally in Afghanistan to wind and pull up and down ropes.
clayey soil	Soil with a clay content of 50% or more that is not suitable for cultivation.
clear water	Clear water that flows out from the ground and between rocks.
Coffer dike (Cutoff wall)	Temporary structure made for the purpose of temporarily blocking a part of the flow path to ensure protection of the foundation works of structures constructed in water.
compaction	The method of applying compressive force to soil to increase its density.
concrete pitching	The method of placing concrete with an average thickness of 5cm to 10cm for the purpose of preventing scouring, weed prevention, and fire prevention on slopes.
control unit	A type of electronic control unit.
critical flow	Flow velocity at the inflection point between the normal flow and the torrential flow.

critical particle diameter for sediment movement	The particle size calculated with the formula of the dimensionless critical tractive force.
critical water depth	Water depth at the inflection point between the normal flow and the torrential flow.
cross section	The shape that can be seen when the riverbed is cut from the left to the right side.
crown / crest	The highest part of a dike or weir.
current meter	A device that measures the flow velocity.
curved part	The meandering part of a river.
debris flow	A phenomenon in which stones and sand on the hillside are swept to the downstream at once due to heavy rainfall.
design draught water discharge	The lowest discharge amount at the river during the dry season (winter) in the year.
design draught water level	Water level when the design drought water discharge flows down.
design flood water discharge	The highest discharge amount at the river during the flood season in the year.
design flood water level	Water level when the design flood water discharge flows down.
dike	A structure that is built to stop water flooding onto a low area, such as farmland and residential area. In Afghanistan, the word "levee" is often applied instead of the word "dike". On the other hand, this guideline applies "dike" as the word to describe this structure.
dike revetment	A wall that protects the entire surface of the embankment from the streamway.
dike shoulder	The part above the intersection of the slope and the flat ground at the crown of a dike.
dike slope of land side	The slope on the landside of a dike.
dike width	The entire width of the embankment of a dike.
distributed load	Load per unit length.
double flush board method	A structure in which the floodgates are arranged in two rows and flush boards are used according to the water level of the river and the required discharge amount.
drain gate	A structure where sediment in the reservoir or sand basin is allowed to be discharged with the water, e.g., sand drain gate.
drain works	Ditches that collect water that have infiltrated the embankment to the foot of slope in land side, in order to allow the collected water drain out naturally from the embankment.
drainage canal	A waterway for returning excess irrigation water to the river.
drainage network	The network of all the streams and water bodies that are feeding water to the river.
dredging	A civil work in which sediment is removed from the bottom of a harbor, river or canal.
drip irrigation	An irrigation system that uses facilities such as distribution pipes and tubes to supply irrigation water to the soil surface and root area slowly and directly.
drop works	Bed sill with a drop or slump.
dry season	The period of the year when the river discharge amount is low.
earth pressure	The soil pressure applied to the structure.
earth works	Construction works such as digging, hauling, filling, and compacting soil.
effective rainfall	The amount of rainfall that directly flows out except the rainfall which penetrates into the ground.
equipment works	Construction related to the facilities in buildings, such as machinery, electricity, water supply and drainage, air conditioning, gas, communication and so on.
excavation	Digging the ground, sediment and rocks.
existing ground elevation	Elevation of existing ground.
existing riverbed elevation	Elevation of the existing riverbed.
exposed rock	Rock exposed from the surface of the earth.

farmland	A place to grow agricultural products. It is classified into rice fields, other crop fields, orchards, pastures, etc., depending on the agricultural product grown.
fascine revetment	A method for retaining soil to prevent the collapse of a slope by planting a wall of twigs. Used for the protection of sandbars in the PMS method.
fascine works	A kind of foot protection works using natural materials.
flash flood	A sudden flood of water caused by heavy rain or landslide.
flexibility	Bending so that it responds to stress.
float	Floating rod or device for measuring flow velocity.
flood control facilities	Facilities consisting mainly of dikes and spur dikes to protect irrigation beneficiary areas, irrigation facilities, residential houses, etc., from floods.
flood irrigation	A method of irrigation in which the entire cultivated land like a paddy field is flooded with irrigation water.
flood prone area	Area of land susceptible to flooding during floods.
flood season	The period of the year when the river discharge amount is high.
floor slab	A concrete floor that supports the weight of people and things.
flow regime	Flow regime is the flow condition in a river or the characteristics of river flow throughout the year, such as water level, flow velocity, etc.. The indicators are high water flow, average water flow, low waterflow and drought water flow.
flush board	A plate installed on a gate pillar to adjust the amount of water at an intake gate or sand flushing ditch.
focus irrigation	It is a system that supplies water at low pressure through a network of pipes which supply water to individual crops.
foot of slope in land side	The point where the slope of an embankment changes to the ground on the side of inland area.
foot protection works	A method that prevents scouring of riverbed in-front of revetment.
forced vortex	In fluid mechanics, this is a kind of vortex which receives external force in order to rotate.
foreman	The head of the workers or work force for each type of work.
foundation works	Structures that transfer and support the load acting from the superstructure to the ground.
free vortex	Defined in fluid mechanics as a kind of vortex which does not receive external force.
freeboard	The height that allows for a suitable margin above the highwater level by considering abnormal floods and waves for determining the height of the embankment.
friction velocity	The magnitude of friction that a flow receives from the surface of an object and expressed in terms of velocity.
Froude number	A dimensionless number that represents the ratio of fluid inertial force and gravity.
furrow irrigation	It is a type of irrigation system in which water flows in furrows provided or excavated in a field.
gabion mattress	One of the methods of gabion works.
gabion works	A type of works in which boulders are packed in a basket made of iron wire or bamboo. Mainly used for revetments of irrigation canals.
gate pier	Pier of the intake gate.
gentle slope river	A river that flows slowly.
groin	A dike built out into the river from the river bank.
guard of flood gate	The role of guarding the flood gates.
Hashar	A community collaboration project for cleaning and repairing roads and canals.
head	The mechanical energy per unit weight of water expressed as the height of the water column.
head loss	The water head lost due to frictional resistance and bending of the running water.
heading-up	A phenomenon in which water level is raised when a weir is installed in a river.
high embankment	An embankment with a height of 15m or more.
highest recorded flood level	The highest water level observed in the past.
hydraulic gradient	Head loss per unit length.
hydraulic jump effect	A phenomenon in which the running water is pushed to the center of the river flow to prevent bank erosion.

hydraulic radius	It is a numerical value of dividing the cross section area by weighted perimeter.
hydrology	The circulation of water on the earth.
inland area	The side of a river with houses and farmlands protected from floods by dikes.
intake gate	A gate for adjusting the water intake amount and the water level of the irrigation canal.
intake weir	A low wall or barrier built across a river to raise the river water.
internal friction angle in water	The angle that ensures water stability or the angle at which the ground begins to slide.
inverted siphon	A duct, as part of a canal, installed under the crossing point with a flood path or a drainage channel. Canal water can easly flow through it due to the water level difference between upstream and downstream.
irrigation	The method of watering or supplying irrigation water to crops and plants in an area of land through pipes or channels.
irrigation facilities	Facilities for supplying irrigation water to farmlands.
irrigation water	The sum of the net amount of water consumed in farmlands and the amount of loss in the irrigation canal.
Karez (Qanat)	Water-use facilities found in arid regions such as Western Asia and Northern Africa. An underground tunnel for irrigation used in dry zones.
land acquisition	Expropriation or use of land when needed for public utilization.
land classification map	A map or figure that grades the appropriateness of utilization of the land unit for various land uses.
land reclamation	Work to retrieve or recover submerged land and change its purpose.
levee	A structure that is built to stop water flooding onto a low area, such as farmland and residential area. The explanation in the word "dike" shall also be referred to.
line grid method	It is one of the riverbed material survey methods adopted when investigation by the area grid method is unsuitable, such as riverbed with a large rock which exceeds 1m. A straight line is marked with a tape measure on the riverbed at intervals of more than the maximum particle size, and gravel below the line is sampled.
lining works	A method covering the canal bed or corner by soil cement, etc.
loam	Kind of soil which contains suitable amounts of sand and clay, easy to cultivate and suitable for all crops.
main irrigation canal	A waterway that leads water to the farmland.
Manning equation	A formula for calculating the flow velocity and flow rate in a waterway.
manual sliding method	A structure of the manual sliding method is a kind of structure that is opened and closed by sliding it manually.
mason	A person who builds or works using stone.
masonry	One of the construction methods using stone to form a steep slope of less than 1: 0.1.
maximum scouring depth	The maximum depth that will be scoured by running water.
meandering	A river with bending curves rather than straight lines.
Mirab	Afghan traditional water caretaker.
moment	The force that rotates an object.
moment of inertia	Resistance to bending force.
narrow segment	The segment of river having s narrow width.
natural ground	The undisturbed ground without artificial filling.
non-overflow type	A kind of weir or stone spur dike structure where water does not overflow during floods.
nontransparent type of dam	A type of spur dike that does not allow water to flow through its body.
non-uniform flow calculation	A method of calculating water level and velocity in rivers where the shape of the channel changes.
oblique weir	A type of intake weir of which body is partly or entirely in a diagonal shape. Its intake mouth is located at the most downstream side.
open levee	A discontinuous embankment with an opening in a section of the embankment so that the upstream and downstream embankments are doubled. In case of flood, the levee has the effect of reducing the amount of discharge flowing to the downstream.

orifice	A small hole on the wall where fluids flow.
overflow	Flowing over of water that exceeds the flow capacity of a river or a water way.
overflow type	A kind of weir or spur dike that allows water to overflow during floods.
particle size	Size of grain of stone.
particle-diameter accumulation curve	A graph of the relationship between grain size and number percentage.
permanent works	The main structural works.
pile foundation	A foundation that supports a building by letting a cylindrical column reach the bearing earth stratum.
piping	A phenomenon in which fine particles in the soil are washed out by the seepage flow of groundwater, forming pipe-shaped water channels in the soil and discharging coarse particles.
plane alignment	Linear that represents a combination of flat lines and curves.
PMS Method irrigation facilities	Irrigation facilities planned and designed applying the PMS method.
precast concrete	A premolded construction part with concrete brought to the site where they are assembled and installed.
preparation works	As preparation before carrying out the main construction works, it refers to the construction, installation and processing of necessary equipment, and removal of obstacles.
profile	The shape which can be seen when the riverbed is cut vertically from downstream to upstream.
profile and cross section	Meaning "along" and "across" a river flow.
profile survey	A survey that measures the ground height along a river to create a vertical section.
radius of curvature	Radius of a circle in which the curve is approximated.
reference crop evaporation ratio	Evapotranspiration when sufficient water is supplied to the reference crop.
regulating pond	A pond having the role of temporarily storing and dividing the water in the main irrigation canal and then adjusting the flow discharge rate.
reinforcement works	Reinforcing bars arranged according to the blueprint in the reinforced concrete construction work.
representative particle diameter	Average particle size that represents the particle group, i.e., 60% value of particle size distribution curve.
required irrigation water	Water requirement for irrigation.
reservoir	Artificial lake where water is stored.
retarding basin	Area inundated temporarily. It reduces peak flood discharge.
revetment works	Facilities installed on slopes, steps and bank slopes of dikes to prevent and protect dikes and riverbanks from being scoured by running water and collapsing.
riffles and pools	Riffle is the place where the flow is fast and the depth is shallow in a river while Pool is the place where the flow is gentle and the depth is deep around the riffle.
riprap	Stones thrown to form a foundation or to weaken the flow velocity during civil engineering work.
riprap works	A method using ripraps for foot protection of dikes or construction of weirs without filling their gaps.
riverbank	The slope between the water surface and ground surface.
river bank erosion	Phenomenon where the riverbank is eroded by running water.
river basin	The area where rainfall or snowfall flows into the river. Summits of mountains are the boundaries of river basins.
river bed material	Sediments at the bottom of a river.
river channel	The river channel is the place where water flows in a river or the part where water flows safely. Also refers to the topography of rivers, etc.
riverside area	River side area of a dike.
rock crib	A kind of traditional river construction method used for water flow control.
rolling compaction	The method of compacting the soil using a roller or rammer.
rotative irrigation	Method of irrigation during drought. The irrigation area is divided into areas, and each area is irrigated in turn or rotationally for a limited time.

roughness coefficient	A coefficient that represents how strong the riverbed and river banks resist when the river flows. In general, if there are irregularities on the riverbed, the roughness coefficient is high, the flow rate is slow and the discharge rate is small.
rubber sponge	A material that can be used as a cushioning material for the case.
sand bar	The place that is formed with gravel in a river or near the mouth of a river.
sand basin	A pond for sedimentation and it removes sediment from running water.
sand drain gate	A gate installed on the sand basin, and it allows the sediment in the sand basin to flow down.
sand flushing ditch	A facility for discharging sediment accumulated upstream of the intake weir to the downstream.
sand mat method	An about 1.5m layer of sand and clay is laid to replace soft ground before constructing an embankment above it.
sandbank	Topography where sediments from the upstream are deposited in the river.
scouring	Phenomenon of soil or sediment being washed out of the riverbank, the shore or the riverbed due to waves and running water.
section modulus	A value that represents the cross-sectional performance.
sediment	Sand, stones or mud carried by water flow.
sediment discharge	The amount of sediment that moves due to the water flow.
sedimentation analysis	It is one of the riverbed material survey methods. Grain size is measured with the sinking speed by gravity.
sedimentation pool	Space for collecting mud at the bottom of a vertical shaft.
seepage line	The line indicating the range where river water penetrates the bank.
seepage water	River water and rainwater that infiltrate levees and soil.
Semi-overflow type spur dike	A spur dike structure where river water flows over it when water level rises.
shearing stress intensity	The force generated inside an object that shifts the object.
shrubification	The height of trees is remained not more than 2-3 meters by not growing the trunk due to densely planted.
silt	Silt is a kind of clastic which is smaller than sand and rougher than clay.
simple groin	A simple straight embankment or dike protruding from one side bank of a river.
single sand bar	A sandbar where the water flows in a straight line, with the ripple and pool appearing alternately in a vertical direction without forming multiple rows.
siphon	A water pipe installed under an obstacle when a waterway crosses the obstacle such as a river or a road.
slope gradient	The gradient of the slope. It is expressed by the ratio of the length of bottom and height.
soil cement	A mixture of local soil and cement for the purpose of soil improvement such as soil stabilization.
soil draw-out	A phenomenon in which soil leaks out at the back.
soil for dike embankment	Soil used to build an embankment.
span width	The width between fulcrums such as piers.
spillway	A passage for water to reduce the hydraulic pressure on the weir especially at flooding time.
spray irrigation	A method of irrigation in which pressurized water is sprayed from a nozzle to make it rainy or atomized.
spread and leveled	Refers to soil that is spread and leveled.
spread foundation	The concrete base that supports the weight of a building.
sprinkler irrigation	A method in which pressurized water is ejected in the form of raindrops from sprinklers attached at regular intervals, and water is sprayed on the soil surface.
steep gradient main irrigation canal	A waterway that leads to the sedimentation basin without depositing the sediment on the waterway.
stone masonry	A method of stacking only stones without using concrete or mortar.
stone pitching	In civil works, stones and cement are put on the surface of the embankment and riverbed in order to protect them from erosion.

stone spur dike	A type of flood control structure made of stones. A stone spur dike makes the river flow away from riverbanks.
stop log	Timber stacked on a floodgate to close it.
streamway	The line which ties the deepest point of each cross section where water usually flows.
subcritical flow	Flow with a Froude number smaller than 1.
surface irrigation	By surface irrigation, water slowly flows along the surface of cultivated land according to gravity, wets the ground and penetrates into the ground, e.g., furrow irrigation, border irrigation and basin irrigation.
surface loading	An index showing the capability of the settling tank.
suspended load	Sediment particles which settle slowly enough to be carried in flowing water. These particles are generally fine sand smaller than 0.2mm.
temporary works	Works related to temporary facilities/equipment that are provided to facilitate the construction work.
the PMS Method Irrigation Project	A series of projects for planning, design, construction, operation and maintenance of irrigation system consisting of PMS method irrigation facilities.
the PMS Method Irrigation Project Guidelines	Guidelines for disseminating PMS method irrigation projects.
torrential flow	Flow with a Froude number greater than 1.
tractive force	Power to move sand and gravel on the riverbed.
training dike wall	An embankment for the purpose of directing an unstable water flow to a particular direction.
transparent type	A type of spur dike with slits to let water flow through.
unit width discharge	Discharge per unit width.
unsteady flow calculation	A method of calculating chronic changes in longitudinal river discharge, water level and flow velocity.
unsupported excavation	When digging the ground, this method does not carry out any construction work to prevent the collapse of surrounding soil and to allow continuous digging works.
unwinding	Laying out sand, gravels and boulders as layers from a dump truck on site.
uplift pressure	The component of the force acting on an object in a fluid, the direction of which is perpendicular to the flow (from bottom to top).
vegetation works	The method to prevent erosion by surface water and preserve the natural environment by planting.
volumetric method	It is a standard method of riverbed material survey or the method of sampling gravel of 0.5m to 1.0m in depth of the riverbed and 0.5m in width and length after removing the surface sand and pebbles with thickness of 0.1 to 0.2 m.
wash load	It is the portion of sediment that is carried by fluid flow and does not settle. It consists of the finest particles, about 0.1 to 0.2mm or less.
water colliding front	The part where a strong river flow hits the river bank, mostly where the river is curved.
water distribution	The act of distributing water to water users.
water diversion gate	Gate for water diversion to distribute irrigation water and domestic water.
water transmission gate	Water supply gate provided in the sand basin.
water users' association	A public union established to carry out irrigation, drainage and civil engineering projects in the community.
water wheel	A water wheel provided with buckets that extracts water from running water.
waterlogging	Damage caused by excessive soil moisture in crops.
weir crest	The highest part of a weir.
weir height	Height of the weir from the riverbed to the weir crest.
weir length	Length of the weir from upstream to downstream.
weir width	Width of the weir from left side to right side.
wet stone masonry	A method of stacking stones using concrete and mortar.
wicker works	Vegetation works using willows. Used with gabion works for the protection of canal walls.
wing	Part of a weir attached to the left and right banks.

Yamada Weir	A stone-pitched weir on the Chikugo River in Japan. It is implemented diagonally against the flow of water in order to guide the water to the irrigation canal. It is a model of PMS method weirs.
Young's modulus	A kind of index that represents the hardness of a material.

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Appendix (3) SPECIFICATION OF INTAKE FACILITIES

Items	Detail	Marwarid Ⅰ Weir	Kama Ⅰ Weir	Kama Ⅱ Weir
	Construction Year	2003-2010	2008-2010	2010-2012
Intake Weir	Type	Bend oblique weir	Bend oblique weir	Bend oblique weir cum Partial movable weir
	Weir Width	Fixed weir: 280m (total width of Kashkot side: 505m)	Fixed weir: 200m	Total 200m (Fixed weir part: 180m, sand flush: 20m)
	Weir Length	Marwarid side: 20～60m Kashkot side: 65～100m	Fixed weir: 20～40m	Fixed weir; 45～135m
	Height	Water head difference on Low water level season: 2.2m	Water head difference on Low water level season: 1.2m	Water head difference on Low water level season: 2.2m
	Height from Intake Gate Floor	0.6m	0.5m	0.75m
	Weir slope (Water surface difference/Weir length)	Average slop: Marwarid side 0.044 Kashkot side: 0.088	Calculated with water head/weir length 0.03～0.06	Calculated with water head/weir length 0.0044～0.0133
	Weir Area	25,000㎡	4,000㎡	11,000㎡
	Water Level Condition	Average water level in the weir (= Intake gate floor depth) Winter (January-March 2018): 0.67m, Summer (June-August 2017): 1.47m	Average water level in the weir Winter: 0.49m, Summer: 1.45m	Average water level in the weir Winter: 0.69m, Summer: 1.82m
	Stone Diameter	0.5～2.0m	0.5～2.0m	0.5～2.0m
	Installation Angle of the Weir	—	about 30～45 degrees against river flow direction	about 45 degrees against river flow direction
	Elevation of the facility	—	Crest of weir slope : EL+551.080m ～551.310m Foot of weir slope : EL+549.780m ～550.030m	Crest of weir slope : EL+549.740m ～550.070m Foot of weir slope : EL+547.540m ～548.210m
Sand Flushing Ditch	Type	Construction by boulder	Construction by boulder	Partial movable weir of manual flush boards
	Width, Span	Width 2.0m x 5 span	Width 2.5m, Single span	Width 2.0m x 4 span
	Height	0.8m	Not retaining the original form As of March, 2018"	1.6m
	Bed Gradient	0.5/40＝0.0125=1.25%	Unknown	0.15/25＝0.006=6‰
	Flow Discharge	Unknown (Impossible to survey due to worsening security)	Scheduled to be rebuilt in October 2018	35m3/s at a depth of 1.5 m
	Elevation of the facility	—	Unknown	Crest of slope：EL+549.960m Foot of slope：EL+548.360m
Spillway		Construction by large boulder, width 30m	None	Construction by large boulder, width 15m
Intake Gate	Type	Double flush boards	Double flush boards	Double flush boards
	Gate Width, Span	Width 1.3m x 3 span	Width 1.45m x 3 span	Width 1.5m x 4 span
	Height	4.0m (include upper slab thickness 0.3 m)	3.5m (include upper slab thickness 0.3 m)	4.0m (include upper slab thickness 0.3 m)
	Intake Volume (m^3/s) Winter	2.0	2.2	4.0
	Intake Volume (m^3/s) Summer	4.0	4.4	7.0
	Water Level Condition	Up to now, there is no overflow damage.	No overflow damage.At the time of the large flood in 2010, the water level rose up to about 3m from the intake gate floor level.	At the time of flood in 2010,the water level jumped up to 3.5m and overflowed the top of old intake gate, but the breakage of intake gate was avoided.
	Intake Mouth Bed Elevation	—	EL+551.000m	EL+549.090m
	Elevation of the facility	—	Top of Intake Gate: EL+554.500m Bottom of Intake Gate: EL+551.030m	Top of Intake Gate: EL+553.890m Bottom of Intake Gate: EL+549.090m
	Others	—	—	—

Note: This table shows the information as of March 2018. [ ] shows the typical specification. [ ] shows constant condition regardless of the site condition.

Miran Weir	Marwarid Ⅱ Weir	Typical Specification	Consideration in case the typical values are applied to other rivers
2014-2016	2016		
Bend oblique weir cum Partialy movable weir	Bend oblique weir cum partialy movable weir	Bend oblique weir cum partialy movable weir	Constant condition regardless of the site condition
Total 444m (Fixed weir part: 401m, sand flush 1 (movable weir): 19m, sand flush 2 (movable weir): 24m)	Total 270m (fixed weir part: 250m, sand flush (movable weir part): 20m)	2 to 3 times of natural river channel width	Depend on the river width at the site
Fixed weir: 25～55m	Fixed weir: 35～40m (root of sand bar 70m)	25～50m	Depend on the unit width water discharge amount, height of the weir and river profile
Water head difference on Low water level season, sand flush 1 (fixed weir 1) : 0.9m, sand flush 2 (fixed weir 2) : 0.8m	Water head difference on Low water level season: 1.35m	Less than 1.5m	Constant condition regardless of the site condition
0.6m	0.7m	0.6～0.7m	Depend on the intake volume (water demand)
0.011～0.024 (Varies depending on the part)	0.0338～0.0386	around 0.02 (1/50)	Depend on the unit width water discharge amount, height of the weir and river profile
11,500㎡	10,500㎡	–	Depend on the weir width and length
Average water level in the weir Winter: 0.47m, Summer: 1.09m	Average water level in the weir Winter: 0.50m, Summer: 1.49m	Winter: approx. 0.5m Summer: approx. 1.5m	Depend on the river discharge amount
0.5～2.0m	0.5～2.0m	0.5～2.0m	Depend on the river discharge in case of flood
about less than 30 degrees against river flow direction	about 30 degrees against river flow direction	about 30～45 degrees against river flow direction	Constant condition regardless of the site condition
Crest of weir slope : EL+560.350m～560.440m / EL+560.110m～560.210m Foot of weir slope : EL+559.140m～559.190m / EL+559.610m～559.670m	Crest of weir slope : EL+587.030m～587.260m Foot of weir slope : EL+585.990m～586.780m	–	Depend on the elevation at the site
Partialy movable weir of manual flush boards	Partialy movable weir of manual flush boards	Partialy movable weir of manual flush boards	Constant condition regardless of the site condition
Sand flush 1: width 1.5m×4 span Sand flush 2: width 1.5m×6 span	Width 2.0m×4 span	Width 1.5～2.0m×4 span	Depend on the target particle size of the river bed material to be discharged.
Sand gate1: 1.0m, Sand gate2: 0.9m	1.55m	1.5m	Constant condition regardless of the site condition
(1) 0.1/28＝0.00357=3.57‰ (2) 0.07/24＝0.00292=2.92‰	0.15/25＝0.006=6‰	3～6‰	Depend on the target particle size of the river bed material to be discharged.
No survey result as of March, 2018	35m^3/s at a depth of 1.5 m	35m^3/s at a depth of 1.5 m	Depend on the target particle size of the river bed material to be discharged.
Crest of slope：EL+560.230m / EL+560.300m Foot of slope：EL+559.030m / EL+559.100m	Crest of slope：EL+587.130m Foot of slope：EL+585.580m	–	Depend on the elevation at the site
Construction by large boulder, width 10m	Construction by large boulder, width 15m	Construction by large boulder, width 15m	Depend on the river discharge amount
Double flush boards	Double flush boards	Double flush boards	Constant condition regardless of the site condition
Width 1.5m×4 span	Width 1.5m×4 span	Width 1.5m×4 span	Constant condition regardless of the site condition
3.0m (include upper slab thickness 0.3 m)	3.2m (include upper slab thickness 0.3 m)	3.5～4.0m (include upper slab thickness 0.3 m)	Depend on HWL
2.0	1.5	Depend on the intake volume	Depend on the intake volume (water demand)
4.0	3.5	Depend on the intake volume	
Erosion occurred at the time of construction in 2015, the bank line of proposed location for intake gate was moved about 50m toward landside.No spill or erosion damage after construction.	Flood season water level: 1.5 to 2.0m from the intake gate floor level;Large Flood in 2010: 2.5m from the intake gate floor level	–	Depend on HWL
EL+559.600m	EL+586.580m	–	Depend on the existing river bed elevation
Top of Intake Gate: EL+562.600m Bottom of Intake Gate: EL+559.600m	Top of Intake Gate: EL+589.780m Bottom of Intake Gate: EL+586.580m	–	Depend on HWL and LWL
–	Diversion gate, Kachara Ⅰ, was installed adjacent to the intake gate, height × width: 3m × 1.8m	–	–

Items	Detail	Marward I Weir	Kama I Weir	Kama II Weir
Main Irrigation Canal	Canal Width	4.5～10m	Existing canal width 4.0m	5.0m
	Revetment Height	Gabion mattress 1.8m	Excavation without timbering (about 2m)	Gabion mattress 1.6m
	Canal Length	25km	1,390m	1,040m
	Gradient of Canal	0.00125 to sedimentation basin (1.6km post), toward downstream 0.0005～0.0010	More than 0.0015	More than 0.0015
	Water Level / Flow Discharge Condition	–	–	LWL+0.6m (Q=5.73m^3/s) HWL+0.9m (Q=10.70m^3/s)
	Roughness Coefficient	0.012～0.016 (depend on the section)	Unknown	Water depth D<0.5m ; n=0.012, Water depth D>0.5m ; n=0.013
	Others	Canal bed: soil cement lining, Canal wall: gabion mattress, wicker works on landside	–	Canal bed: soil cement lining, Canal wall: gabion mattress, wicker works on landside
Sand Basin and Regulating Pond	Area	–	No sedimentation basin	–
	Depth	2m		2m
	Gradient of Sand Drain Canal	–		–
	Water Transmission Gate	–		–
	Drain Gate	–		–
	Number of Places	–		1 place
Dike and Revetment etc.	River Bed Height	–	Flood Plain EL+551.567m ～552.694m Deepest Riverbed EL+546.425m	Flood Plain EL+552.179m ～552.551m Deepest Riverbed EL+548.149m
	Dike Height	–	EL+555.003m 1.049m height from landside ground elevation	EL+554.180m 1.445m height from landside ground elevation
	Crest Width	–	8.439m	8.116m
	Dike Width	–	15.033m	18.759m
	Slope Gradient	–	River side: 1:3.01 Land side: 1:2.68	River side: 1:2.92 Land side: 1:2.47
Natural Condition (Additional)	River Width	–	176.010m (main channel part) 1711.155m (include flood plain)	289.308m (main channel part) 2264.856m (include flood plain)
	River Bed Gradient	1/357	1/357	1/357
	Farmland Ground Height (Cross section survey point)	–	EL+553.954m ～555.065m	EL+551.561m ～552.735m
	Farmland Ground Height (Beneficially farmland point)	–	EL+548.220	EL+547.010

Note: This table shows the information as of March 2018. [yellow box] shows the typical specification. [blue box] shows constant condition regardless of the site condition.

Miran Weir	Marwarid Ⅱ Weir	Typical Specification	Consideration in case the typical values are applied to other rivers
5.0m	5m width up to 1.5km post.	5.0m	Depend on the intake volume (water demand)
Gabion mattress 1.6m	Gabion mattress 1.6m	Gabion mattress Height=1.5～1.6m	Depend on the intake volume (water demand)
450m	4,920m	Depend on the distance to irrigation beneficiary area	Depend on the distance to irrigation beneficiary area
More than 0.0015	More than 0.0015	More than 0.0015	Constant condition regardless of the site condition
LWL+0.4m (Q=3.17m^3/s) HWL+0.6m (Q=5.97m^3/s)	LWL+0.4m (Q=2.38m^3/s) HWL+0.7m (Q=5.67m^3/s)	LWL around +0.5m HWL around +0.8m	Depend on the intake volume (water demand)
Water depth D<0.5m ; n=0.012, Water depth D>0.5m ; n=0.013	Water depth D<0.5m ; n=0.012, Water depth D>0.5m ; n=0.013	Water depth D<0.5m ; n=0.012, Water depth D>0.5m ; n=0.013	Constant condition regardless of the site condition
Canal bed: soil cement lining, Canal wall: gabion mattress, wicker works on landside	Canal bed: soil cement lining, Canal wall: gabion mattress, wicker works on landside	Canal bed: soil cement lining, Canal wall: gabion mattress, wicker works on landside	Constant condition regardless of the site condition
Width × Length = 27m ×40m	Width × Length = 20m ×82m	About 1100～1600m^3	Depend on the intake volume (water demand) and target particle size
2m	2m	2m	Constant condition regardless of the site condition
1/67 (15cm/10m)	1/100	1/100	Constant condition regardless of the site condition
2 places	2 places, width 1.5m ×1 span, width 1.5m ×3 span	2 places	Depend on the number of irrigation beneficially area for water transmission
1 place, gate: 1.7m ×1.7m, box culvert: 1.6m ×1.5m	2 places, gate: 1.7m ×1.8m, box culvert: 1.6m ×1.6m	2 places, gate: 1.7m ×1.8m, box culvert: 1.6m ×1.6m	Depend on the number of drainage point
1 place	4 places	1 site per 1km	Depend on the distance of main irrigation canal
Flood Plain EL+560.369m ～561.512m Deepest Riverbed EL+557.241m	Flood Plain EL+588.175m ～590.093m Deepest Riverbed EL+585.154m	–	Depend on the elevation at the site
EL+563.968m 2.234m height from landside ground elevation	EL+596.475m 7.868m height from flood plain	more than 1.2m freeboard	Depend on the flood discharge amount
10.292m	No dike due to digging shape of channel	more than 8.0m (min. 5.0m)	Constant condition regardless of the site condition
20.856m	–	approx. 20m	Depend on the dike height
River side: 1:1.65 Land side: 1:2.0	–	River side: 1:2.0 Land side: 1:2.0	Constant condition regardless of the site condition
244.104m (main channel part) 936.426m (include flood plain)	133.340m (main channel part) 1325.381m (include flood plain)	–	Depend on the river width at the site
1/357	1/357	–	Depend on the river gradient at the site
EL+562.010m ～564.032m	EL+595.927m ～597.302m	–	Depend on the ground elevation at the site
EL+558.700	EL+576.740	–	Depend on the ground elevation at the site

Appendix (4) CALCULATION SAMPLES

ANALYSIS METHOD FOR SANDBAR AND SCOURING USING HYDRAULIC PARAMETERS

1.1 Classifications of Sandbar

Sandbars are classified into alternate sandbars and double row sandbars as shown in Figure 1. Both of these sandbars have their own characteristics such as the location of erosion, and tend to move during floods. These sandbars can be classified by grasping their situation from satellite images as shown in Figure 2. In addition, as shown in Figure 3, sandbars can be classified by plotting the hydraulic parameters obtained by non uniform flow calculation. There are also sandbars that form inside bending or meandering curves (convex parts), and they are often suitable sites for intake weir since such sandbars tend to be fixed.

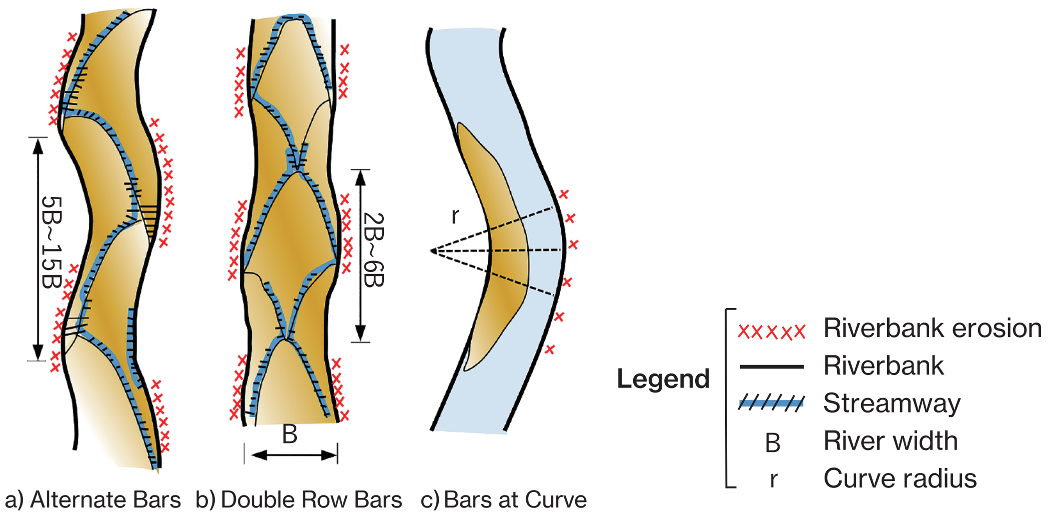


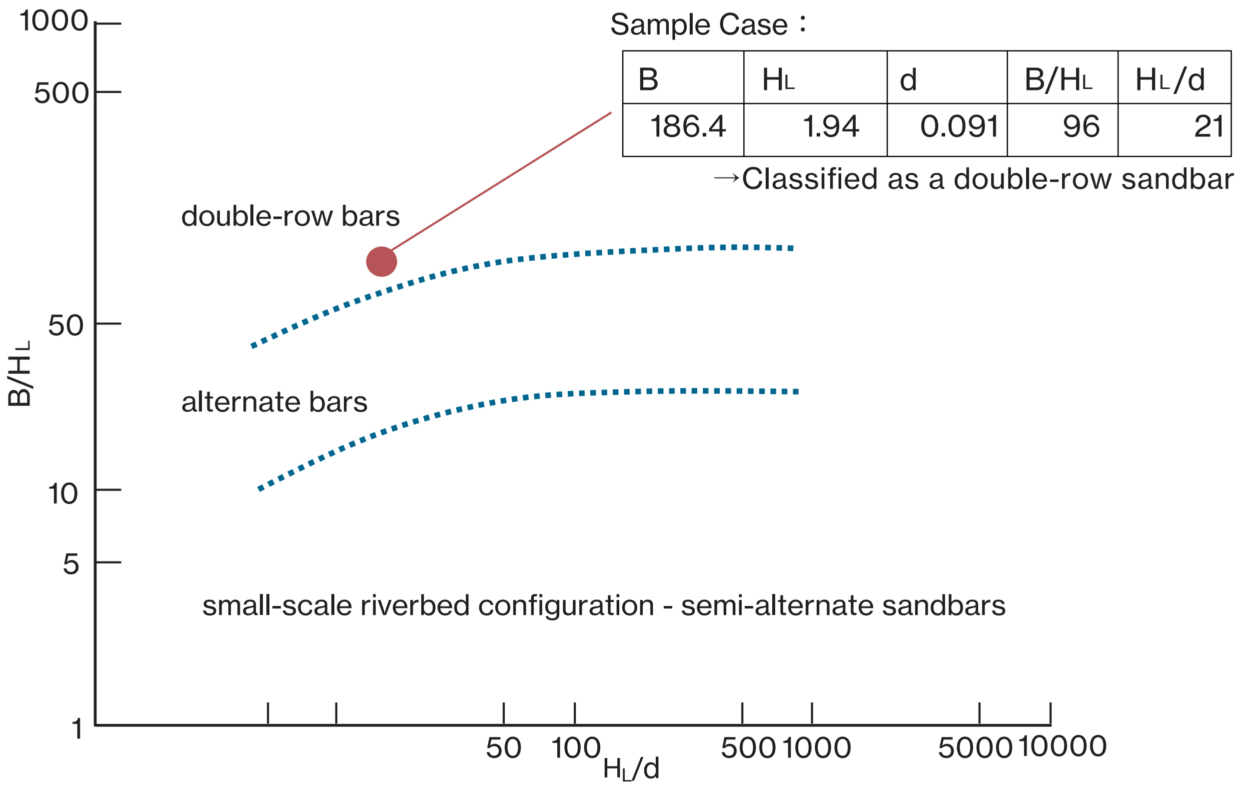
Figure 1 Classifications of Sandbar [2) ,see 12)]

Alternate Bars

Double Row Bars

Sandbars formed inside bending or meandering

Figure 2 Understanding Sandbars from Satellite Images [17)]



B: river width (m), HL: water depth during the flood of average annual maximum discharge (The average annual maximum discharge is the average discharge of each year's maximum discharge.) (m), d: representative particle size of riverbed material (m)

Figure 3 Classifications of Occurrence of Sandbar [2), see 12]

1.2 Analysis of Scouring

It is difficult to comprehend riverbed fluctuation patterns such as scouring and hence the evaluation is made based on the research results in Japan, although it is necessary to collect more data to improve the accuracy. Riverbed fluctuation patterns such as scouring are related to sandbars, and the scouring depth (Δ Z in the figure below) is evaluated using hydraulic parameters such as sandbar wave height and water depth, which are also shown in the figure below. The scouring depth Δ Z is the difference between the average riverbed height and the deepest riverbed height, and is a value indicating how much scouring has occurred from the average riverbed height.

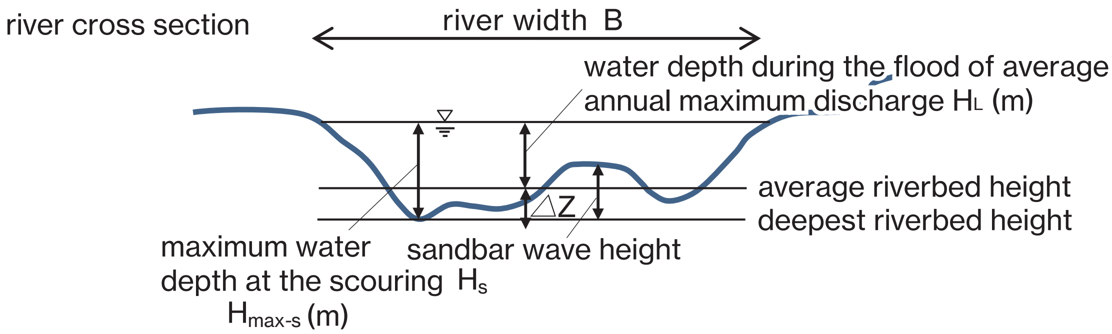


Figure 4 Hydraulic Parameters of Scouring [2), see 18)]

The scour depth has a value obtained from the actual cross section and a value estimated from hydraulic parameters by non uniform flow calculation as shown below. The value obtained from the cross section is the state at the time of survey. The values of hydraulic parameters are based on research results. For example, if the scouring depth obtained from the cross section is smaller than the scouring depth obtained from hydraulic parameters, the scouring depth can be deepened; that is, the sandbar can be raised or the deepest riverbed can be lowered (scouring). In this way, the riverbed fluctuation situation can be analyzed.
The planar shape of the river channel is unique to each segment, and scouring can be evaluated by the method shown in Table 1.

Table 1 Evaluation Method of Scouring for Segments and River Channel Shape [2), see 18)]

River Channel Shape	Segment 1	Segment 2	Segment 3
Straight River Channel	Evaluation by sandbar wave height using Formula 1.		no sandbar
(Single) Curved River Channel	Evaluation by ratio of curve radius and river width (γ /B) using Figure 6.		

(1) Straight River Channel

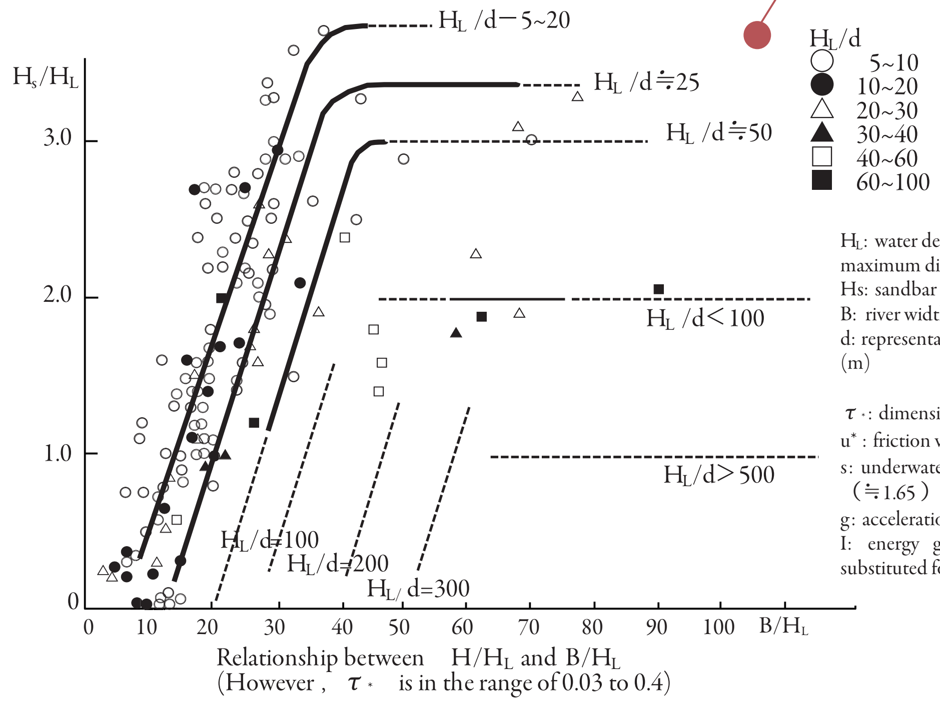
In the straight river channel, each segment has its sandbar fluctuation characteristics, and the sandbars formed by the river channels of Segments 1 and 2 which are commonly found in Afghanistan, move during floods(such as the alternate bars or double row bars in Figure 1). The scouring depth is governed by the sandbar wave height, and the sandbar wave height is governed by the water depth and river width at the average annual maximum discharge. The scouring depth can be estimated by the following formula:

$$\Delta Z = 0.8Hs \quad \text{(Formula1)}$$

ΔZ: scouring depth (m) (difference between the average riverbed height and the deepest riverbed height), Hs: sandbar wave height (m) (estimated from the figure below)

Sample Case：→Δ =0.8x6.99=5.59

B	H_L	d	B/H_L	H_L/d	H_s/H_L	H_s
186.4	1.94	0.091	96	21	3.6	6.99



H_L: water depth during the flood of average annual maximum discharge (m)
Hs: sandbar wave height (m)
B: river width
d: representative particle size of riverbed material (m)

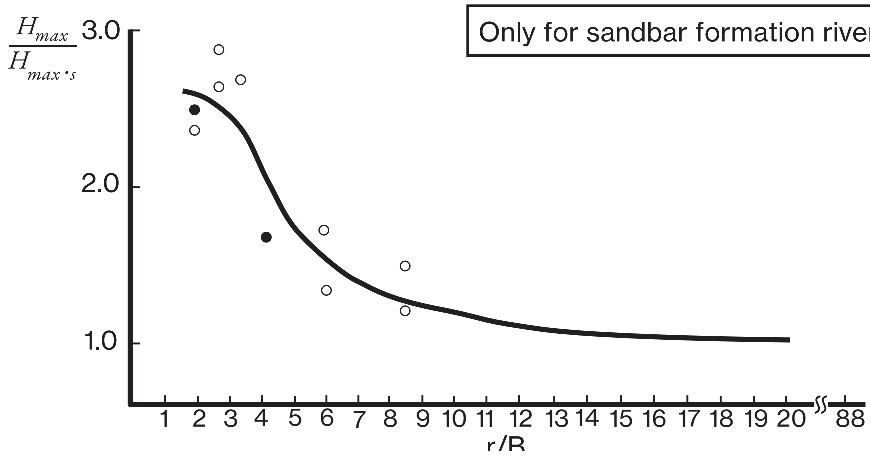
τ_*: dimensionless tractive force $(=u^{*}/(s \cdot g \cdot d))$
u^* : friction velocity $(=g \cdot H_L \cdot I)^{0.5}$
s: underwater specific gravity of riverbed material (≒1.65)
g: acceleration of gravity
I: energy gradient (Riverbed gradient can be substituted for segment 1 and 2 (partial) .)

Figure 5 Chart for Estimating Hs from Hydraulic Parameter [2), see 18)]

（2）(Single) Curved River Channel

The curved river channel of Segment 1 generally does not have a remarkable curve, but it is necessary to confirm scouring on site when it is forcibly curved due to bedrock. In addition, the curved river channel of Segment 2 is scoured by the secondary current or sandbar.

The scouring depth is governed by the water depth at the target discharge. The scouring at the average annual maximum discharge is estimated from the water depth of the maximum scouring part estimated from the figure below. The curve radius, river width, and water depth estimated in (1) are required. Although there are currently insufficient research results on the method of estimating the scouring depth at the target discharge, it is considered to evaluate the scouring depth at the average annual maximum discharge by adding extra value.



r: curve radius, B: river width, Hmax: maximum water depth at the scouring during the flood of average annual maximum discharge at curve, Hmaxs: maximum water depth at the scouring during the flood of average annual maximum discharge at straight river channel estimated from Formula 1

Figure 6 Evaluation of Scouring in Curved and Meandering River Channel [2), see 18)]

EXAMPLE OF DESIGN CALCULATION FOR IRRIGATION FACILITIES

1.1 Example Calculation for Stable Boulders

(1) Calculation Method for Stable Stone Size

The highest flow velocity among the critical flow velocities around the weir crest, in the weir apron part and at the overflow water depth (the area immediately downstream of the weir apron) is applied as the design flow velocity to calculate the required stone size corresponding to the design flow velocity using the "stability examination model for stone masonry with low integrity". When the weir apron gradient is low and the Froude number is F_r<1, no torrential flow, the critical water depth or critical flow velocity is applied. In this case, the required stone size is calculated using the flow velocity of normal flow in the weir apron part.

(2) Stability Examination Model for Stone Masonry with Low Integrity

Earth and water pressure will be the major causes of destruction when the slope gradient exceeds 1:1.5, while the fluid force will be a major cause of destruction when the gradient is lower than 1:1.5. Since the oblique boulder weir comprising stone masonry using natural boulders has a low gradient, the stone masonry is destroyed by the tractive force rather than the yield strength exerted from the rear by earth pressure. Accordingly, the stability of the oblique boulder weir shall be considered using the following "stability examination model for stone masonry with low integrity".

For stone masonry having low integrity with adjacent members, the key is whether the critical tractive force of all stone materials exceeds the tractive force of the river and remains stable.

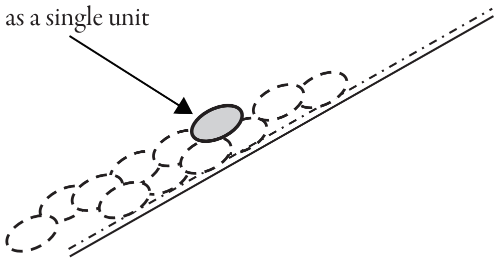


Figure 1.1.1 The Stability Examination Model for Stone Masonry with Low Integrity in which the Tractive Force of the River Causes Destruction

(3)Calculation Condition

Overflow Discharge Volume: $Q=1200m^3/s$

Weir Width: $W=105m$

Weir Height: $h=0.91m$

Weir Length: $l=30.7m$

(4)Calculation of Design Flow Velocity

a) Critical flow velocity at the weir crest

Gradient of weir apron : $I = h/l = 0.91/30.7 = 0.03$

Unit width discharge : $q = Q/W = 1200 \div 105 = 11.43 m^3/s$

Critical water depth : $hc = q/vc=(q/\sqrt{g})^{2/3} = (11.43/9.81^{1/2})^{2/3} = 2.37m$

Critical flow velocity : $vc = \sqrt{(ghc)} = (9.81*2.37)^{1/2} =$ **<u>4.82m/s</u>**

b) Calculation of flow velocity at the weir apron portion

Flow depth at the weir apron portion:

$h_2 = q/v_2 = (q/((1/n)*I^{1/2}))^{3/5} = (11.43/((1/0.035) \times 0.03^{1/2}))^{3/5}) = 1.66m$

Flow velocity at the weir apron portion:

$v_2 = q/h_2 = 11.43/1.66 =$ **<u>6.89m/s</u>**

Froude number of this case is $Fr = U / \sqrt{(gh)} = 6.89 / \sqrt{(9.81 \times 1.66)} = 1.7 > 1.0$ and since the flow velocity is faster than critical flow velocity, the flow condition is super critical flow.

c) Calculation of flow velocity at the area immediately downstream of the weir apron

Critical flow depth: h_c = 2.37m

Weir height: D = 0.91m

Flow depth immediately downstream of apron: h_2=1.66m

From the above, the relationship of hc + D> h2 is established, and since it is in a complete overflow state, the flow velocity at the immediate downstream part of the weir apron is calculated using the unit width flow rate q = 11.43m3/s at the time of design flood water discharge.

$$\begin{cases} \varphi = Z_1 + h_1 + \dfrac{Q^2}{2gA_1^{\ 2}} - \dfrac{n_1^{\ 2} l Q^2}{2R_1^{4/3} A_1^{\ 2}} & \cdots\cdots (1) \\ \psi = h_{1a} + \dfrac{Q^2}{2gA_{1a}^{\ \ 2}} + \dfrac{n_{1a}^{\ \ 2} l Q^2}{2R_{1a}^{\ \ 4/3} A_{1a}^{\ \ 2}} & \cdots\cdots (2) \end{cases}$$

To achieve $\phi = \psi$ in the above two formulas, the water depth at the edge of the downstream portion of the apron (h1a) is calculated from the critical water depth at the weir crest and the flow velocity (v1a) can be calculated using the following formula (3):

$$v_{1a} = \frac{Q}{h_{1a}} \quad \cdots\cdots (3)$$

Here, weir height: Z_1 = 0.91m, critical water depth: h_1 = 2.37m, unit width water discharge: q=11.43m^3/s, flow section area: A_1 = 2.37m^2 (area in unit width), hydraulic radius: $R_1 \fallingdotseq h_1$ = 2.37m (Approximate by water depth), roughness coefficient: n_1 = 0.035, n_{1a}=0.035

Therefore, when $\phi = \psi$, the water level at the immediately downstream end of the weir apron (h_{1a}) is h_{1a} = 1.5m.

Flow velocity at the area immediately downstream of the weir apron : $v_{1a} = q/h_{1a}$ = 11.43/1.5 = 7.62m/s

Among the above a), b), and c), the flow velocity v_{1a} = 7.62 m/s at the immediate downstream part of the weir apron where the flow velocity is highest is applied as the representative flow velocity.

Correction coefficient by curve of the river alignment: α = 1+B/2_r = 1.05

Here, river width: B = 105m, radius of curvature of the river channel : r = 1km

Design flow velocity : $V_o = \alpha * v_{1a}$ = 1.05*7.62 = 8.00m/s

(5) Setting of Stone Diameter

Design flow velocity : V_o = 8.00m/s

Stone density: ρs = 2650kg/ m³

Water density: ρw = 1000kg/ m³

Experimental coefficient showing the turbulence intensity : E1 = 1.2

Average particle diameter of stones : D_m=Vo^2/($E1^2$*2*9.81*($\rho s/\rho w$ − 1))=8.002/(1.2^2*2*9.81*(2650/1000 − 1)) = 1.37m 1))=8.002/(1.22*2*9.81*(2650/1000 -1))=1.37m

Correction coefficient by slope angle : K = 1.001

Stone diameter: D = K・D_m = 1.001*1.37 = 1.38m or more.

1.2 Example Design Calculation of Flush Board for Intake Gate

(1) Calculation Method of Flush Board

The flush board applied in PMS method irrigation project has a structure in which one side of Himalayan cedar with a length of 1.7 m, a height of 20 cm, and a thickness of 5 cm is reinforced with 4 mm thick steel plates.

Flush boards at the intake gate are checked from the viewpoints of a) bending, b) shearing, and c) deflection. The formulas for each calculation are shown below.

Figure 1.2.1 Flush Board with Reinforced Himalayan Cedar

a) Bending

Bending stress intensity : $\sigma = M/Z \leqq fb \times Cf$

σ : Bending stress intensity (N / mm²) = M／Z

M : Maximum bending moment (N・mm) = $w \times L^2/8$

Z : Section modulus (mm³) = $b \times h^2/6$

fb: Allowable bending stress intensity (N / mm2)

(Wood : 28.2N/mm², Steel plate : 140N/mm², Synthetic stress intensity : 36.5N/mm²)

Cf : Dimensional effect factor = $(300/h)^{1/9}$

W: Water pressure per unit length of flush board (N / mm)

L : Length of flush board=1700mm

B : Thickness of flush board=50mm

H : Height of flush board=200mm

b) Shearing

Shearing stress intensity: $\tau = 1.5 \times Q/A \leqq fs$

τ : Shearing stress intensity (N / mm²) = $1.5 \times Q/A$

Q : Maximum shear force (N) = $w \times L/2$

A : Cross-sectional area (mm2) = $b \times h$

Fs : Allowable shear stress intensity (N / mm²)

c) Deflection

Deflection: $\delta \times 2 \leqq L/250$ (Allowable deflection)

δ : Deflection (mm) = $5 \cdot w \cdot L^4 / 384 \cdot E \cdot I$

I : Moment of inertia (mm⁴) = $b \times h^3/12$

E : Young's modulus (N / mm²)

(2) Example of Flush Board Design Calculation

A calculation example is shown under the conditions of Marwarid II case.

a) Design Condition

HWL : EL+589.05m

Base elevation of intake gate: EL+586.58m

Design water level: Base elevation of intake gate + 2.47m
Flush board height per sheet : h=0.2m=200mm
Water pressure per unit length of flush board : w = 2.47 × 9.81 × 0.2 = 4.8 N/mm

b) Stable verification of the flush board for bending

Bending stress intensity : σ (N/mm²) = M/Z = 1,361,588 ÷ 360,000 = 3.8 < fb × Cf = 36.5 × 1.05=38.2 ----**OK**
Maximum bending moment:M (N・mm) = w × L²/8 = (4.8 × 1500²)/8 = 1,361,588 N・mm
Distributed load : w (N/mm) = 4.8 N/mm
Beam length : L (mm) = 1500mm
Section module : Z (mm³) = b × h²/6 = ((50+4 × 1) × 200²)/6 = 360,000mm³
Allowable bending stress intensity : ffb (N/mm²) = 36.5N/mm²
∵Allowable bending stress intensity (Wood : 28.2N/mm2, Steel plate : 140N/mm², Synthetic stress intensity : 36.5N/mm² / Board thickness 50mm + steel plate 4mm × 1)
Dimensional effect factor : Cf = $(300/h)^{1/9}$= $(300/200)^{1/9}$= 1.05

c) Stable verification of the flush board for shearing

Shearing stress intensity : τ (N/mm²) = 1.5 × Q/A = 1.5 × 3,631 ÷ 10,800 = 0.50 < fs = 8.9 ----**OK**
Maximum shear force : Q (N) = w × L/2 = (4.8 × 1500)/2=3,631 N
Distributed load : w (N/mm) = 4.8 N/mm
Beam length: L (mm) = 1500mm
Cross-sectional area : A (mm²) = b × h = (50+4 × 1) × 200 = 10,800
Allowable shear stress intensity:fs (N/mm²) =8.9N/mm²
∵Allowable shear stress intensity (Wood : 2.4N/mm², Steel plate : 90N/mm², Synthetic stress intensity : 8.9N/mm² / Board thickness 50mm + steel plate 4mm × 1)

d) Stable verification of the flush board for deflection

Deflection : δ (mm) = 5wL⁴/384EI=(5 × 4.8 × 1500⁴) ÷ (384 × 24,266 × 36,000,000) = 0.37
δ x 2 = 0.37 × 2 = 0.73< L/250 =6 ----**OK**
Allowable deflection：L/250 (mm) = 1500 ÷ 250 = 6
Distributed load : w (N/mm) = 4.8 N/mm
Beam length : L (mm) = 1500mm
Moment of inertia : I (mm⁴) = b × h³/12 = ((50+4 × 1) × 200³)/12=36,000,000mm⁴
Young's modulus : E (N/mm²) = 24,266N/mm²
∵Young's modulus (Wood : 9,807N/mm2, Steel plate : 205,000N/mm², Synthetic stress intensity : 24,266N/mm² / Board thickness 50mm + steel plate 4mm × 1)

1.3 Calculation Example of Sand Flushing Capacity of Sand Flushing Ditch

(1) Calculation of Objective Particle Size for Sand Flushing

The flow velocity V and hydraulic radius R at the designed flood discharge in the target river are calculated using the Manning equation (1) to determine the critical friction velocity U*c using formula (2). Using this value allows the particle size of sands to be flushed at the ditch to be calculated as the critical particle size for sediment movement from Iwagaki's formula as shown in Chapter 3. It is expected that gravel of size smaller than the critical particle size flows from upstream during flooding and is accumulated in the sedimentation pool immediately upstream of the intake weir.

Manning equation : $V = \frac{1}{n} R^{\frac{2}{3}} I^{\frac{1}{2}}$ ………… (1)

Formula for the critical particle size for sediment movement: $U_{*c} = \sqrt{gRI}$ ………… (2)

Iwagaki's formula (see Chapter 3): the critical particle size for sediment movement is determined by an empirical formula concerning the relation between the critical friction velocity and critical particle size for sediment movement.
Here: V: flow velocity (m/s), R: hydraulic radius (m), g: gravitational acceleration (m/s²), I: riverbed gradient, n: roughness coefficient, U*c: critical friction velocity
The following is an example calculation of the critical particle size of sediment movement at the time of flood discharge Q =

$2{,}050m^3/s$ near the Marwarid II Weir. According to the calculation using Manning formula, the flow velocity and hydraulic radius when the flood discharge is applied to the river cross section at the Marwarid II Weir are V = 1.53 m/s and R=1.01. The riverbed gradient is I = 1/357. Therefore, the friction velocity is as follows.

Friction velocity $U_{*c} = \sqrt{gRI}$, $U^* = \sqrt{9.81 \times 1.01 \times (1/357)} = 0.17$

From the results of the riverbed material survey, it is known that the representative particle size is about 3cm or more. Therefore, the critical particle for sediment movement is calculated as follows applying the formula of U*2=80.9d.

$d = U^{*2}/80.9 = (0.17 \times 100)^2/80.9 \times 10 = 34.1mm$

From the above, gravel smaller than this particle size may be washed away during floods and deposited behind the intake weir.

(2) Confirmation of Sand Flushing Capacity of Sand Flushing Ditch

The longitudinal gradient of the bottom of the sand flushing ditch is set so that the tractive force for discharging the accumulated gravel in the sedimentation pool immediately upstream of the intake weir can be secured. If the critical particle size for sediment movement calculated from the tractive force at sand flushing ditch is larger than the objective particle size in the preceding paragraph, the gravel below the objective particle size can be flushed out. The following is an example calculation of the critical particle size for sediment movement at the Marwarid II weir. The calculation conditions are as follows.

a) Calculation condition

Width・number of gates : 2.0 m × 4 Span
Height of sand flushing ditch : 1.5 m
Longitudinal gradient of sand flushing ditch : 1/166

b) Confirmation of sand flushing capacity

Based on the above calculation condition,

Hydraulic radius is $R = A/S = (1.5 \times 2 \times 4)/(1.55 \times 8 + 2 \times 4) = 0.6$
Friction velocity is $U_{*c} = \sqrt{gRI}$, $U^* = \sqrt{9.81 \times 0.6 \times (1/166)} = 0.19$

From the results of the riverbed material survey, it is known that the representative particle size is about 3cm or more. Therefore, the critical particle size for sediment movement is calculated as follows applying the formula of $U^{*2}=80.9d$.

$d = U^{*2}/80.9 = (0.19 \times 100)^2/80.9 \times 10 = 43.6mm > 34.1mm$

The flow velocity in this case is $V = 1/0.035 \times 0.6^{2/3} \times (1/166)^{1/2} = 1.57m/s$ from the Manning formula.
In this result, since the diameter of the particle size flushed out by the sand flushing ditch is larger than the objective particle size of 34.1mm obtained in the previous section, it is possible to flush out the deposited sand and gravel.

1.4 Examination of Cross-Sectional Area of Underground Pipe of Siphon

(1) Calculation Formula of Head Loss by Underground Pipe of Siphon

The head loss at siphon is calculated as follows.

$$H = i \cdot L + \beta \cdot \frac{V^2}{2_g} + \alpha \quad (1)$$

Here, H: siphon head loss (m), i: hydraulic gradient to the flow velocity in the siphon underground pipe, L: siphon underground pipe length (m), g: gravitational acceleration ($=9.81m/s^2$), α : 50 to 80mm, β : 1.5 as the standard.

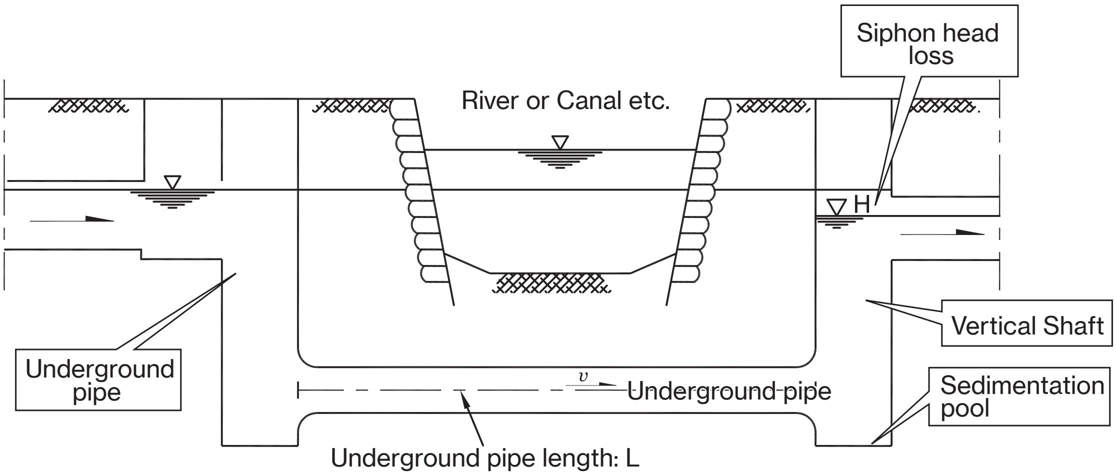


Figure 1.4.1 Structure and Water Level of the Siphon

(2) Calculation Example of Underground Pipe Design of Siphon

Under the following conditions, the canal bottom elevation of the downstream canal is determined.
The water level in the upstream canal is calculated from the following:

- Upstream canal bottom elevation EL+0.00m
- Underground pipe length of siphon ℓ =18.00m
- Section of upstream canal bottom width 5.0m, wall height 2.0m
- Upstream canal gradient i=0.0008
- Roughness coefficient n=0.012
- Discharge amount q=2.0 m^3/s

From the above conditions, the following can be derived using the Manning formula:

- Velocity v=1.095m/s
- Water depth h=0.36m

The water level in the upstream canal is as follows:

- The water level in the upstream canal＝EL+0.00 + 0.36＝EL＋0.36m

Next, the head loss (H) due to the inverted siphon is calculated.
The flow velocity in the inverted siphon shall be set to about 20% higher than the flow velocity in the upstream canal.

- Flow velocity for inverted siphon v = 1.095 × 1.2 =1.314m/s

From the above, the actual flow velocity is calculated in some cases of cross sectional area of inverted siphon. Based on the formula of Q＝AV, it is calculated as follows:

□1.1 × 1.1 : V= q/A = 2.0 / (1.1 × 1.1) = 1.653m/s
□1.2 × 1.2 : V= q/A = 2.0 / (1.2 × 1.2) = 1.389m/s
□1.25 × 1.25 : V= q/A = 2.0 / (1.25 × 1.25) = 1.280m/s
□1.3 × 1.3 : V= q/A = 2.0 / (1.3 × 1.3) = 1.183m/s

Therefore, it is appropriate to set the cross sectional area of the inverted siphon to about □ 1.25 x 1.25.
From the following Manning formula,

$$V = \frac{1}{n} R^{\frac{2}{3}} I^{\frac{1}{2}}$$

The hydrodynamic gradient I of the inverted siphon is calculated.

V : Velocity 1.28 m/s
I : Gradient
R : Hydraulic radius WA/WP = 0.313m
WA : Flow sectional area 1.25 × 1.25 = 1.56 m^2
WP : Wetted perimeter 1.25 × 4 =5m
n : Roughness coefficient 0.013

From the above, the hydrodynamic gradient is I = 0.0013.
From the following siphon head loss formula,

$$H = i \cdot L + \beta \cdot \frac{V^2}{2_g} + \alpha$$

H : Head loss (m)
i : Hydrodynamic gradient with respect to the flow velocity in the inverted siphon
ℓ : Underground pipe length of siphon (m)
v : Flow velocity in underground pipe of siphon (m/s)
g : Gravitational acceleration (9.81m/s^2)
α : Usually set to 5～8cm

Based on the above, the head loss is calculated as follows:

$$H = 0.0013 \times 18.0 + 1.5 \times \frac{1.280^2}{2 \times 9.8} + 0.05 = 0.198\text{m} \fallingdotseq 0.2\text{m}$$

The water level in the downstream canal is as follows:

EL+0.36 (water level in the upstream canal)−0.2 = EL+0.16m

Since the cross-sectional shape of the downstream canal is the same as that of upstream canal, the water depth is the same and is 0.36 m.

Therefore, the bottom elevation of the downstream canal shall be set to the elevation equal to or less than the following value:
EL+0.16−0.36 = EL−0.2m

1.5 Example Calculation for Sand Flushing Capacity of Drain Gate

(1) Operation Method of Drain Gate

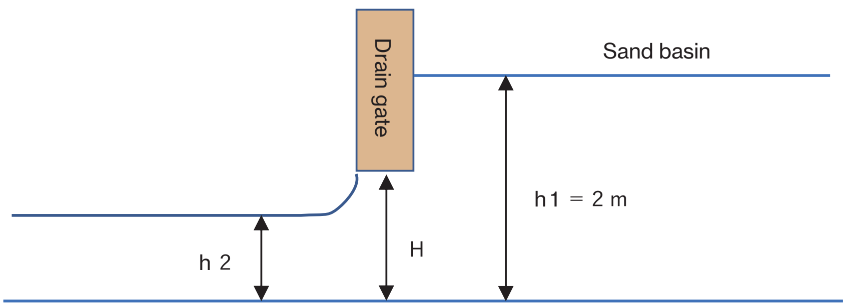
The PMS operation method of the drain gate of the sand basin is as follows:

▶The drain gate is fully closed from December to March (in winter) when the amount of water intake is low, and is open at all other times. Therefore, the drain gate is opened and closed twice a year, opened at the end of the dry season and closed at the end of the flood season.

▶The height of the gate opening of the drain gate is about 30 cm, and drainage is performed from the bottom of the drain gate.

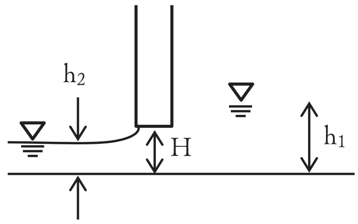
▶The water depth in the sand basin is always kept at about 2 m during operation for drainage and sediment removal.

Figure 1.5.1 shows an image of sand flushing from the drain gate in the sand basin. The sand deposited in the sand basin is discharged together with water from the opening at the bottom of the drain gate acting like an orifice, which flushes the sediment deposited on the bottom of the sand basin.



(2) Calculation of Sand Flushing Capacity of Drain Gate

The drainage discharge amount at the bottom of the drain gate is calculated by the following formula which is applied to calculate the drainage discharge amount from the sluiceway and culvert. An example calculation on sand basin at Miran is shown as follows:



Submerged outflow : $h_2 \geqq H$ $Q = CBH\sqrt{2g(h_1 - h_2)}$ C=0.75 .... (1)

Subsurface outflow: $h_2 < H$ and $h_1 \geqq 3/2H$ $Q = CBH\sqrt{2gh_1}$ C=0.51 .... (2)

Free outflow : $h_2 < H$ and $h_1 < 3/2H$ $Q = CBh_2\sqrt{2g(h_1 - h_2)}$ C=0.79 .... (3)

However, when free outflow is $h_1 / h_2 \geqq 3/2$, it is replaced into $h_2 = 2/3\ h_1$.
Here, H: height of sluice gate/culvert, B: width, h1: deeper water among those measured from the outflow base elevation, h_2: shallower water depth
Since the water depth of the sand basin is about 2 m and the opening height of the drain gate is about 30 cm, the intermediate outflow formula is applied among the above formulas.

Drainage discharge amount: $Q = CBH\sqrt{2gh1} = 0.51 \times 1.6 \times 0.3 \times \sqrt{2 \times 9.81 \times 2.0} = 1.53 m^3/s$
Drainage flow velocity: V=Q/A=1.53 / (1.6 × 0.3) =3.2m/s
Drainage gradient: I=1/67
Hydraulic radius: R=A/S= (1.6 × 0.3) / ((1.6+0.3)× 2) =0.126
Friction velocity: $U^* = \sqrt{(gRI)}$, $U^* = \sqrt{9.81 \times 0.126 \times (1/67)} = 0.136$

From the results of the riverbed material survey, it is known that the representative particle size is generally less than 1 mm. Therefore, the critical particle size for sediment movement is $d = U_*^2/55 = (0.136 \times 100)^2 / 55 \times 10 = 33.6mm$ from the formula of $U_*^2 = 55.0d$, and sand with a particle size of less than 1 mm can be discharged.