Manual for Examination to Develop Rural Infrastructure

February, 2025

Agricultural Development Consultants Association (ADCA)

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Contents

1. Types of rural infrastructure and the scope of the Manual

Rural infrastructure is divided into infrastructure related to the agricultural production base as public works and infrastructure related to agricultural production by farmers or farmer organizations.

(1) Rural infrastructure as public works

Rural infrastructure as public works include the following:

- Irrigation and drainage facilities
  - Irrigation and drainage: dams, head works, intake works (gates), pumping stations, regulating reservoirs, main canals, main drainage canals, other irrigation and drainage canals, management roads, water management facilities (TM[1], TC[2], SCADA[3], etc.)
  - Agricultural fields: field consolidation (including underdrainage), farm roads
- Renewable energy: small hydroelectric power generation
- Market facilities: distribution infrastructure such as market buildings, market equipment, storage facilities, etc.

(2) Infrastructure for agricultural production by farmers or farmer organizations

Rural infrastructure to be developed by farmers or farmer organizations includes the following:

- Irrigation and drainage facilities: wells, small pumps for fields, underdrainage, in-field irrigation facilities (sprinklers, drip irrigation, etc.), ICT[4] equipment for field management
- Agricultural facilities: agricultural machinery, composting facilities
- Renewable energy: agricultural solar power generation, biogas facilities, biomass use facilities
- Post-harvest facilities: drying and storage facilities, agricultural product processing facilities

This Manual describes the items that should be considered when developing irrigation and drainage facilities, which require the largest project cost than others and the main infrastructure for rural development.

2. Characteristics of irrigation and drainage projects

Irrigation and drainage projects have the following three characteristics:

(1) Just developing irrigation and drainage facilities will not immediately lead to an expansion of irrigated area or irrigated agriculture. There are several steps between the development of facilities and achieving outputs,

[1] TM (Telemetry) is a remote measurement method that observes the target from a distance.
[2] TC (Telecontrol) is the act of controlling and operating equipment remotely using communication systems.
[3] SCADA (Supervisory Control and Data Acquisition) is a type of industrial control system that uses computers to monitor systems and control processes.
[4] ICT (Information and Communication Technology) is a general term for technology that transmits digitized information using the Internet and other communication methods.

and it is important to combine this with soft support such as strengthening farmer organizations as necessary. Setting high goals without taking this into account increases the risk of not achieving the expected goals.

(2) Even if irrigation facilities are developed, it takes time to create the conditions for spreading irrigated agriculture to farmers. This tendency is particularly strong when new irrigation development projects are carried out.

(3) Creating the conditions for irrigated agriculture requires a multifaceted approach that goes beyond just developing irrigation facilities, including organizing water users' associations and providing guidance on improving farm management. In order to achieve the desired irrigated agriculture, it is important to respond appropriately to the various stakeholders.

The information required to formulate an irrigation and drainage project is as follows (underlined parts are technical information):

- Implementing agency (project owner)
- Location (province, city, town, village, GPS[5] location information)
- Expected area of benefit (ha)
- Project type (new development, renovation, expansion, etc.)
- Irrigation method (gravity, pump, open canal, pipeline, sprinkler, drip irrigation, etc.)
- Expected project or construction cost
- Expected completion date or construction period
- Target crops (rice, vegetables, fruit trees, etc.)
- Number of direct and indirect beneficiaries (households, people, population of administrative district)
- Main target facilities (dams, head works, main canals, secondary canals, pumps, farm roads, storage facilities, drying facilities, meeting places, etc.), if existing facilities are to be used, their condition (usable, unusable)
- Consistency with government development policy
- Farmer economy, intentions (main source of income, needs)
- Information on water resources (river name, groundwater, annual precipitation, meteorological and hydrological data, presence of water rights, etc.)
- Special geographical and natural conditions (landslide areas, topography, etc.)
- Maintenance and management of irrigation and drainage facilities after completion, division of roles and capabilities of the management body (budget, personnel, experience, etc.)
- Impact on the environment (necessity of Environmental Impact Assessment (EIA), conflicts between ethnic groups or communities, possibility of social friction, etc.)
- Extent of resident relocation and land expropriation
- Other issues

Planning irrigation and drainage projects requires a lot of information. In particular, technical information is the foundation of the project, and there are some items for which it takes a long time to gather.

The world's irrigated area increased 2.2 times in the approximately 50 years from 1961 to 2008, but in developing countries in the Asian monsoon region, where the "Green Revolution" has been taking place since the late 1960s,

[5] GPS (Global Positioning System) is a satellite positioning system that can determine the current location and time on Earth.

the irrigated area increased 2.4 times during the same period, exceeding the world average (Onimaru, 2012). At present, the proportion of new irrigation projects has decreased, and repair/ renewal of existing irrigation project has become the mainstream. When planning a project to repair and renew facilities that were developed in past irrigation projects and are now dilapidated, information can be collected more easily than for new projects, since information on existing beneficiary areas and on past projects can be used. In addition, with the remarkable development of ICT technology in recent years, it has become possible to collect information in a short period of time using new technology.

This Manual, in appendices A to F, provides the following information on how to use new technologies and how to evaluate economic viability of the projects.

A. Function diagnostic technology for existing facilities (asset management technology)
B. Labor-saving technology for on-site survey using UAV[6]
C. New technology for repairing irrigation facilities
D. ICT water management technology
E. Project evaluation using LCC
F. Reducing methane emissions from rice paddies through intermittent irrigation

3. The matters to be considered in irrigation and drainage projects

In planning an irrigation and drainage project, the following should be considered in outline:

- Strength of need from the expected beneficiaries
- Estimated project cost range
- Affiliation of the facilities to be developed
- Estimated construction period of the project

(1) Strength of need from the expected beneficiaries

It is important to determine whether there is a strong need from the beneficiaries in the proposed project area. Beneficiaries who have no experience with irrigated agriculture may not understand the need for water management on their own farmland and the labor required for it, the fair distribution of water in communal facilities, proper maintenance of the facilities, and the additional costs involved, and may end up abandoning the facilities they have invested in in the future. The project is expected to be effective in areas where people are making efforts to secure the little water they currently have, making efforts to improve crop production and quality even if only slightly, and are desperate for irrigation facilities.

(2) Estimated project cost range

Consider the expected project cost through a rough economic evaluation. If the expected project cost is large, consider the priority of facility development, development level, alternatives, etc. so that adjustments (reductions) can be made later. For the method of rough economic evaluation, see **Appendix E**.

[6] UAV (Unmanned Aerial Vehicle) is an unmanned aircraft. It is commonly called a drone.

(3) Affiliation of the facilities to be developed

If the facilities to be developed are owned by individuals or specific companies and ownership is unclear after the project, the realization of the project's effects and the scope of benefits will depend on the intentions of the individuals or specific companies, so these will be excluded from the development target. Also, check for the risk that the implementation of the project will cause social friction, such as conflicts within the irrigation area preventing fair water distribution or the project becoming the cause of new friction.

(4) Estimated construction period of the project

There is a standard flow for projects, but if it is shortened for some reason, investigations may become insufficient or the construction period may have to be compressed. As a result, the quality of the outputs and the project's effectiveness may be compromised. If the target completion date is set from the beginning to be significantly different from the standard schedule, consider narrowing the scope of the project or changing the implementation method.

4. Consideration for the implementation of irrigation and drainage projects

Consider important points for implementing irrigation and drainage projects, categorizing them into socio-economic conditions, technical feasibility, capacity of the implementing agency, operation and maintenance, validity as a project, and environmental impact.

4.1 Socio-economic conditions

(1) Agriculture is the main source of household cash income for the beneficiary farmers

When beneficiaries have a nearby source of cash income unrelated to agriculture (such as factory work), they tend to avoid heavy agricultural labor, especially the younger generation, and this can lead to a shortage of workers. In addition to obtaining information on the beneficiaries' main source of income from the local office of the project implementing agency, the planner will also interview around 10 farming households in the target area. However, it is important to take into consideration that the income structure of beneficiaries is complex. For example, beneficiaries include a wide variety of people, from small to large landowners, tenant farmers, and seasonal workers. Some landowners have developed businesses that were started using agricultural income as capital, and their main source of income is non-agricultural income. Tenant farmers and seasonal workers also have a wide variety of agricultural and non-agricultural incomes.

(2) There is no risk of conversion of the target area to non-farmland, as is the case in urban fringes.

If some farmland is converted, the flow of water and maintenance will be cut off, and the irrigation effect may be significantly reduced. For example, in an irrigation district near the Cambodian capital of Phnom Penh (the Prek Thnot River basin), factories and housing developments have progressed in a "piecemeal" manner, causing a loss of

continuity of irrigation water in some areas. Furthermore, coupled with water shortages caused by inadequate maintenance and rising land prices, people are moving away from agriculture. Thus, the conversion of farmland to housing and other land, especially in urban fringes where population pressure is high, is a natural progression and cannot be prevented. Although the location is favorable from the perspective of "proximity to the market," in the case of a relatively large-scale gravity irrigation system, attention must be paid to the possibility of farmland conversion within the target area. It is also necessary to check the state of development of land use control laws related to farmland, such as Japan's Farmland Act.

(3) The selected target crops meet the needs of farmers.

It is necessary to consider crop planning centered on the crops that actually support the household. Even if the government policy is to promote vegetable cultivation, if farmers want to grow rice, it is desirable to promote vegetable cultivation as a secondary crop while increasing rice production (supply of materials, dissemination of technology, etc.). There are cases where farmers were interested in livestock and vegetable cultivation, but facilities development projects were carried out to promote irrigated rice cultivation in line with government policy, but in the end, rice cultivation did not take root (JICA. 2019a).

In terms of accurately grasping the needs of farmers, the SHEP[7] approach undertaken by JICA is a useful reference.

(4) The purpose of increasing production of the target crop is clear.

There are cases where "the construction of irrigation facilities that allow double cropping has been completed, but the second crop is not being grown." Some small-scale rice farmers, in particular, think that "it is enough as long as we can secure for our own consumption." In contrast, farmers with relatively large areas of land (for example, 1 hectare per household) are proactive about increasing income through double cropping, as they sell rice excluding the amount they consume as a source of cash income. It is necessary to confirm whether beneficiary farmers are willing to increase production even if it means increased working hours, and to create a reasonable plan that reflects the beneficiary farmers' goals and desire to increase production.

(5) There is a market to absorb the increased production.

Even if irrigation projects increase production, it is meaningless if the produce cannot be sold, and farmers will lose motivation to increase production. What is required is the existence of a market, access to the market (roads, means of transportation), storage facilities for shipping during off-season periods when market prices are high, and processing facilities to increase added value and profits. It is advisable to check at least farm roads (within the district, connecting to main roads) in advance and incorporate them into the project if necessary.

(6) There is currently a sufficient labor force available.

[7] The SHEP (Smallholder Horticulture Empowerment and Promotion) approach is a market-oriented agricultural extension method that was developed in 2006 through technical cooperation between JICA and the Kenyan government, aiming to increase incomes by strengthening the farming capabilities of small-scale farmers. It is an approach that promotes "profitable agriculture" as a business that "produces to sell" rather than the traditional passive agriculture of "produce and then sell".

In the case of paddy rice farming, unless mechanization has become widespread, the maximum cultivation scale per household is approximately 1 hectare (guideline). In the case of field crops, which involve a high workload due to pest and disease control and weed management, the limit is even smaller (guideline is 0.5 hectares or less). Furthermore, when irrigation is introduced, the annual workload increases due to fertilization and increased cropping rate. Usually, there is a lot of abandoned farm land in existing irrigation areas that are the subject of rehabilitation. If people can earn a stable cash income outside of agriculture, there is no guarantee that they will return to risky agriculture. It is necessary to confirm that "there is currently a large amount of surplus labor (unemployed)" and "the possibility of covering labor through self-farming, tenant farming, or locally hired labor."

4.2 Technical feasibility

(1) Location of water source (water intake point)

If the irrigation area is far from the water intake point, a long headrace canal is necessary. The longer the distance of the headrace, the greater the risk of leakage and the difficulty of maintenance. If the headrace is too long compared to the irrigation area, such risks must be taken into consideration.

A simple method for on-site survey using UAVs to grasp the water source and existing water usage status is shown in **Appendix B**.

(2) Stability of water sources

Even if the annual runoff is the same, if it flows out all at once in a short rainy season, it cannot be used unless a reservoir such as a dam is constructed. Conversely, a river that flows without drying up, even if it is a small amount, is an excellent water source. For surface water such as rivers and springs, it is necessary to determine the period of water shortage and the minimum flow rate. There are cases where the river basin is degraded due to farming and tree cutting due to the increase in population pressure, and floods and sediment runoff are increasing. It is desirable to plan by assuming future flow conditions and changes in the river basin and the effects of climate change (such as the amount of rainfall in the past few years) rather than simply using past hydrological data.

On the other hand, it is also necessary to consider the laws regarding water rights, the existence of water rights related to the water source, and the existence of competing water rights holders who use the same water source. Even if the legal system is not yet established, it is desirable to confirm by interviewing whether there are any water users upstream and downstream and whether there are any plans for use. Since plans will change significantly depending on water source development (construction of dams, reservoirs, etc.), it is necessary to clarify whether water source development is included in the target plan or whether there are such plans in the future.

(3) Availability of meteorological and hydrological data within or near the area

Irrigation planning requires meteorological data to calculate the amount of water consumed by crops, and hydrological data such as rainfall, river water level and flow rate. When considering dam construction, it is important to determine the amount of water that can be stored if the annual rainfall is less than 1,000 mm, especially since the planned irrigation area is large. Confirm whether there is a daily rainfall and river water level observation station that have been observing for the past five years or more near the expected water intake point (within about 10 km).

If there is not, determine the distance to the nearest daily rainfall and river water level observation station. If there is no meteorological and hydrological observation station at all, it is desirable to conduct hydrological observation for at least one hydrological year (dry season-rainy season-dry season, rainy season-dry season-rainy season). If necessary, consider installing a new observation facility.

Appendix D shows an example of meteorological and hydrological observation using TM.

(4) Beneficiaries' experience with irrigated agriculture

The benefits of irrigation cannot be achieved by simply providing water. Appropriate cultivation and water management, such as fertilization, the introduction of high-quality seeds, and the supply of oxygen to the root zone through mid-season drainage, are required. For farmers who have only experience with rain-fed farming, it is necessary to assess their capabilities and provide guidance and dissemination of farming techniques and inputs associated with the development of irrigation facilities. Financial resources and services (seeds, fertilizer sales, etc.) to provide agricultural inputs are also necessary. After identifying the institutions and organizations that provide these agricultural support services, the planner will consider providing technical cooperation in disseminating farming techniques in parallel with the project, if necessary.

(5) Balance of facilities

When considering the installation of headworks on a river 50 m wide, even when the irrigation area is small at only a few tens of hectares, the scale of the intake works will be large to cope with floods. This work will be inefficient. Furthermore, when the headrace canal is long, a great deal of effort will be required to maintain the facilities until it reaches the irrigation area, which will be an obstacle to achieving sustainable effects. Furthermore, irrigation and drainage are inseparable and should be considered as one entity, and drainage facilities must also be considered, particularly in low-lying paddy field irrigation areas. It is important to consider a balance between irrigation and drainage facilities (intake works, headrace canal, irrigation canal, drainage canal). Furthermore, when considering the use of facilities, equipment, and materials that are not used in surrounding areas, the difficulty of maintenance (spare parts, repair personnel, etc.) must also be taken into consideration.

In the past, when irrigation facilities that were dilapidated or severely damaged were rehabilitated, a full-scale renovation project was undertaken. However, because renovation projects are expensive, it is necessary to continue using facilities that are still functioning for as long as possible in order to reduce the cost of repairs and rehabilitation. To this end, it is important to periodically diagnose the functionality of existing irrigation and drainage facilities as a whole, evaluate the priority, importance and repair/renewal costs, and carry out the most effective repair/renewal works to maintain the functionality of the irrigation facilities.

Appendix A shows the functionality diagnosis techniques for existing facilities.

(6) Realization of benefits from the development of target facilities

Irrigation facilities consist of canals and ancillary facilities that run from the intake facility to the fields. However, due to the complexity of land acquisition and route selection, many project plans make farmers pay for the development of terminal canals, or only target the replacement of pumps in pump irrigation areas. In such cases, the project will not be effective if the condition of the canals and facilities that are not subject to development remains poor. To address this, there are methods of limiting the effects, such as setting low irrigation efficiency, limiting the

irrigated area, and setting low target yields. Once surveys for implementation have begun, it becomes difficult to "limit the effects." It is important to determine the scope of the effects from the preliminary survey stage.

(7) Presence of geological problems

If geological problems are of concern based on information from local parties, etc., it is necessary to take measures such as conducting a preliminary survey by a geological expert as necessary. For example, if there is a landslide area on the route of the headrace canal, countermeasure work will be enormous, and the project cost may deviate significantly from the estimated cost, which may make the project itself unfeasible.

4.3 Capacity of the implementing agency

(1) Implementing agency of the anticipated project

At the project implementation stage, coordination becomes difficult when there are multiple implementing agencies. For example, dams may be managed by the Ministry of Water Resources, irrigation facilities by the Ministry of Agriculture, and farm roads by the Ministry of Public Works. In preliminary surveys, appropriate project implementation agencies should be selected after understanding the legal system and the jurisdiction of each organization. If it is determined that cooperation between organizations will be difficult in light of past performance, etc., it is desirable to create a project plan that "avoids having multiple implementing agencies."

(2) Implementing and Managing Agencies

There are many cases where the project implementation agency and the agency that manages the project after completion are different. In the case of relatively small-scale irrigation districts, the project implementation agency may be the main ministry, but the relevant department within the local government (such as the provincial agricultural department) may carry out maintenance after completion. In such cases, it is necessary to confirm the legal basis, authority, and responsibility of the relevant agencies in facility maintenance. Regarding matters to be discussed at the project implementation stage, it is also necessary to confirm the capabilities (personnel, budget) of the management agency. It is also effective to hold discussions about project implementation and management after completion from the time of project formation, including with ministries and agencies responsible for budget management such as the Ministry of Finance.

(3) Role of management agencies in facility maintenance

Normally, the main irrigation system is maintained by public institutions (implementing agencies, local governments, etc.). However, there are cases where government policy transfers the maintenance of all facilities to water users' associations (WUAs). In such cases, the construction of large-scale irrigation facilities increases the difficulty of operating the facilities, increases maintenance costs, and results in inefficient management by the WUAs. It is necessary to review the project to an appropriate scale and change the management method, including involving public institutions.

(4) Organization and personnel of the management agency responsible for facility maintenance

It is necessary to confirm the appropriateness of the maintenance organization, personnel, and budget of the management agency planned after the completion of the project. In some cases, the management agency is responsible for multiple irrigation districts, has only a few staff members, and has a small budget other than personnel costs. With such organizational capacity, it is difficult to smoothly maintain the target irrigation districts or coordinate with the WUAs. Since it is not easy to increase the budget or personnel, it is necessary to consider that the project will be of a scale appropriate to the current organization.

4.4 Operation and maintenance

(1) Characteristics of maintenance of irrigation and drainage projects

Unlike social infrastructure projects such as roads, which directly benefit many people, the direct effects of irrigation and drainage projects are limited to the land and its users. Therefore, it is assumed that users will also take the initiative in maintenance. Generally, users form organizations such as WUAs to carry out maintenance, but in the case of new projects, new organizations must be created. With regard to water management, wasteful use by a small number of users often causes water shortages downstream, preventing the expected effects from being achieved. In the case of irrigation and drainage projects, 100% effectiveness is not guaranteed even after the facility construction is completed. The establishment and strengthening of maintenance systems should be considered as part of the facility construction, and it is necessary to consider the presence of problems that may be a major obstacle to maintenance and measures from the preliminary survey stage. Particular attention is required in areas where there is no WUA or the existing WUA is not functioning.

(2) Existence of laws, systems and guidelines regarding water users' associations

It is important that WUAs have a clear legal status and that their establishment process and functions are clearly indicated in guidelines, etc. If such a system has not been established, an approach to construct facilities on the assumption that users will maintain them should be avoided. In cases where this is unavoidable, it is necessary to consider separately promoting technical cooperation for the establishment and strengthening of WUAs.

(3) Existence of WUAs in the target area

If there are laws and systems relating to WUAs, such as one that states "water management in all irrigation areas is carried out by WUAs," WUAs must be established in new irrigation areas. However, it is extremely difficult to establish and support WUAs within the project period. Support for strengthening WUAs must be through "plan, do, check, act (PDCA[8])" approach during at least two cropping seasons, otherwise farmers will not have the "experience and feeling of success," and sustainability cannot be expected. Even if there is an existing WUA in a rehabilitation project, it is meaningless if it is not actually functioning. If there is no WUA in the target area, or it is not functioning, support for establishing and strengthening the association through separate technical cooperation, etc. will be considered.

[8] PDCA is a concept that aims to improve the quality of management by circulating a hypothesis-verification process of Plan, Do, Check, and Action.

4.5 Validity as a project

(1) Appropriateness of project costs

One guideline for the appropriate initial investment at the preliminary survey stage is 1 million JPY per hectare. Conversely, projects that cost less than 200,000 JPY per hectare are likely to have overestimated the irrigation area or underestimated costs.

Points to note are: (i) when project costs are estimated by the host country, if foreign aid is received, the cost can be 1.5 to 2.0 times higher, as the facilities will be made more robust in accordance with foreign design standards and sufficient auxiliary facilities will be provided; (ii) in the case of facility development of 3 million JPY/ha or more, it is assumed that the recipient government will not be able to update or maintain it; (iii) the amount of investment per area will be higher than that of other donors, and the recipient government may not be convinced; (iv) in areas where the capacity of the implementing agency and the capacity of the farmers are low (inexperienced), concentrated investment in a small area from the water source to the end and field development is risky (lack of maintenance will result in early deterioration of functionality).

Appendix C shows repair techniques for irrigation facilities, and **Appendix E** shows the methodology for project evaluation.

(2) Number of beneficiaries

The benefits of irrigation projects are limited to the land and its users. Even if a certain amount of land is secured, the direct benefits of the project may be concentrated in a few areas, for example, if there are a lot of large landowners or landless farmers (hired labor). Furthermore, if the project cost per unit area is high, the number of beneficiaries will decrease relatively (the project cost per beneficiary will be high). Possible ways to widen the scope of benefits are such as including farm roads and drainage improvement projects that benefit an unspecified number of people in the project, and, rather than improving all the facilities in a specific area (core to peripheral facilities), for example, targeting only the rehabilitation of water intake structures in multiple areas with the outcome of "restoring water intake functions."

(3) Burden of maintenance costs

In the case of new pump irrigation, it is necessary to determine whether users can bear the electricity and fuel costs. Even if the yield increases due to irrigation, it is difficult to collect pump operation costs if all of the costs are consumed by the user. Even if the cash income increases, whether to pay or not is a separate issue. In many cases, water fees are not calculated backwards from necessary expenses, but are set as an amount that can be paid.

It is more practical to reach an agreement on pump operation costs as an increase in the current water fee, rather than as a percentage of the increase in income. In the case of "pump irrigation of rice" and "project costs of 3 million JPY or more per hectare (without dams)," there is a concern that the maintenance costs will be too high for the WUA and management organization, or that the facility's functionality will decline due to the inability to maintain the facility. There are two types of pump irrigation: (i) "electric pumps" that operate the motor by receiving electricity directly from a grid line, and (ii) "generator pumps" that operate the pump while refilling the generator with diesel fuel. In particular, with pumps that are powered by electricity (i), basic charges are incurred even when the pump is not in operation, which can lead to increased operating costs.

(4) Appropriateness of the work to be carried out by the host country

In irrigation projects, some of the construction work required for the development of terminal canals to produce effects may be borne by the recipient. In new irrigation projects, there are also cases where the creation of farmland (opening of fields, terrace construction, etc.) is borne by the recipient. The main reasons for bearing the costs are to "reduce project costs" and "avoid land disputes." Generally, in order to achieve project effects, the recipient's construction work is to be completed before the completion of the main construction work. There are cases where the recipient's construction work is delayed or not performed, significantly impairing the project effects (Example 1: There is a diversion work but no terminal canals, and there is no farmland. Example 2: The recipient's construction work for terrace construction was delayed, so the drainage work for the main construction work was carried out first, but the completed terrace construction significantly changed the catchment area of the drainage work, and some drainage facilities were damaged due to insufficient capacity). As part of the study in the recipient's responsibilities, the planner will check the host government's subsidy system, etc., and then present the recipient with an estimate of the necessary expenses and time. In some cases, the planner will need to incorporate the recipient's responsibilities into the main construction work, and form the project assuming an increase in project costs.

4.6 Environmental impact

(1) Extensive land acquisition and resettlement

Regarding the environment and land acquisition, confirm whether the host country has sufficient legal provisions, whether the relevant institutions have sufficient capacity and experience to deal with these issues, and whether they have secured a budget. On the other hand, farmers are extremely averse to losing the amount of farmland they currently cultivate, regardless of whether they own the land or not. In the case of new irrigation projects and projects that include terminal canal development, there are many cases where the canal has to be run through existing farmland. Basically, the other party is responsible for arranging the land, but the procedures take a long time and often affect the construction. Even in the case of "illegal occupation" where houses or stores are built on canal land, which is public land, if it continues for a long period of time, some kind of compensation procedure is required as a vested right. In the case of rehabilitation projects, there are relatively few problems related to land acquisition, but in cases where there is no management road on the existing main canal, new land for the road is required. Some countries have rules that say "farmers are obligated to provide land for tertiary canals" or "beneficiaries must construct tertiary canals," but in reality, tertiary canals are not constructed and water is distributed through secondary canals over rice fields in many cases. In such cases, it is possible to set the effect lower and make a reasonable plan. Since land provision agreed upon at the time of planning may be refused at the construction stage, it is desirable to assume the corresponding difficulty of land acquisition from the preliminary survey stage for new irrigation projects and projects including terminal canal construction.

It is also necessary to pay attention to the gap between the JICA guidelines and the laws and environmental guidelines of the host country. At the implementation stage, compensation for residents who illegally live on public land and residents who illegally cultivate land becomes an issue. It is desirable to confirm the extent of the gap between the JICA guidelines and the laws of the host country at the preliminary survey stage and to confirm whether the host government is willing to accept the JICA guidelines (and provide support to illegal residents).

(2) Presence of nature reserves or national parks in the vicinity of the target area

In some countries, if the target area is located in a nature reserve or national park, development activities may not be permitted. The requirements for environmental impact assessments may be high. Check with not only the implementing agency but also the agency in charge of the environment regarding the status of nature reserves within the target area.

(3) Environmental impacts of canal and reservoir construction

When irrigation facilities are developed, stagnant water is likely to occur in the target area, which could become a breeding ground for malaria mosquitoes and schistosomes. In the preliminary survey, the presence of water-related pests and diseases in the target area will be confirmed.

(4) Climate change measures

Paddy fields are a major source of greenhouse gas (GHG) emissions in the agricultural sector. By shifting water management methods from continuous flooding to intermittent irrigation, it is possible to reduce the anaerobic conditions in paddy fields and reduce GHG (methane) emissions from paddy fields. For this reason, consideration will be given to promoting the development of irrigation and drainage canals for paddy fields in the beneficiary areas so that intermittent irrigation is possible.

Appendix F shows the reduction of methane gas emissions from paddy fields through intermittent irrigation.

(5) Possibility of social conflict

Because the beneficiary area of irrigation projects is limited, if residents in the surrounding areas feel that something is not fair, it could become a cause of social friction. Furthermore, even within the beneficiary area, if conflicting religions or ethnic groups coexist, disputes over water may arise over the route of irrigation canals or the location of diversion works. Once the target area has been decided, such problems cannot be avoided, so it is necessary to identify the presence of social problems from the preliminary survey stage.

(6) Gender Consideration

The roles of men and women in agriculture differ from country to country, so it is necessary to clarify the relationships and roles of men and women in agriculture. For example, in some countries, weeding for irrigation canals is considered "women's work." If new irrigation canals are constructed in areas with such cultural customs without proper consideration, the burden on women who are already busy with housework and childcare will increase even more.

5. Participatory water management and facility management

5.1 Significance of participatory water management

In order to make up for food shortages caused by population growth, developing countries have expanded agricultural land and are developing modern irrigation and drainage facilities. However, the maintenance of these expanding irrigation and drainage facilities requires a huge amount of money and manpower, so there are limitations to what each government can achieve through maintenance alone. As a result, the concept of Participatory Irrigation Management (PIM) was proposed around 1990, and efforts are being made to encourage farmers, who are the beneficiaries of irrigation facilities, to maintain and manage the facilities themselves. Participatory water management aims to achieve proper maintenance and management of irrigation facilities, and sustainable water use through the participation of farmers, who are the beneficiaries of irrigation projects.

A key requirement for successful participatory water management is "active participation of farmers in irrigation management." There are two prerequisites for meeting this requirement: (i) fair water allocation, and (ii) ensuring stable profitability from irrigated agriculture. When promoting participatory water management, it is necessary to consider action plans that fully take these two prerequisites into account. Since "vitalizing WUA activities" is the foundation for successful participatory water management, it is also important to strengthen organizational management capabilities and expand the system for collecting irrigation fees.

5.2 Development of laws and regulations related to participatory water management

If laws, ministerial ordinances, and regulations related to the transfer of irrigation facility management and WUAs are not in place, the inputs from the host country necessary for establishing, ensuring sustainability, and spreading participatory water management will not be guaranteed. Activities under such circumstances will ultimately fail. Since it is not possible to promote "participatory water management" when the relevant laws are insufficient, it is necessary to confirm the state of their development in advance. If they are not in place, it is appropriate to start with technical cooperation through the dispatch of policy advisors, etc. The transfer of irrigation facility management is classified based on the area size of the irrigation district and the type of facility, such as (i) full management transfer to the WUA, or (ii) the government agency manages the core facilities and transfers management of the end facilities. Since the standards for this classification differ from country to country, the standards of the country in question will be investigated. It is also necessary to understand whether the WUA has legal status, whether it has been granted the authority to collect water fees, and granted property rights and management rights over the canals. It is also necessary to check the memorandum of understanding for the establishment of the WUA and understand the relationship with the national laws, etc.

5.3 Coordination between implementing agencies

In many countries, the Ministry of Agriculture is in charge of facility maintenance and water management at the field level. In such cases, the Ministry of Irrigation and the Ministry of Agriculture are the project implementing agencies, and appropriate coordination between them is essential for efficient implementation. In some cases, under "decentralization," the central government and local governments are the implementing agencies. If coordination is

not smooth, time and effort will be spent on coordination, which will have a negative impact on the entire activity, so it is advisable to discuss in advance with the relevant agencies what an appropriate coordination system should be. Furthermore, since coordination becomes more difficult if multiple implementing agencies are positioned on the same level, it is appropriate to narrow down the implementing agency to one and make the remaining agencies cooperating organizations. Furthermore, when there are multiple implementing agencies, it is effective to have them conclude an agreement between the agencies that clearly states their responsibilities and roles, as well as the division of activity funds.

5.4 Formulation and dissemination of a participatory water management model

In the case of cooperation for "participatory water management," the strategy is generally to form a model in a pilot irrigation district within the cooperation target area, and to disseminate the model to other areas through the self-help efforts of the country after the cooperation is completed. There are many cases where the results of cooperation are not "expanded from a point to an entire area," and model dissemination is merely set as a formal upper goal. To solve this problem, it is important to accumulate information from the pre-stage, such as by examining the project contents with related organizations, with the "model dissemination" after the cooperation is completed positioned in the roadmap. It is necessary to confirm whether the implementing organization of the cooperation is in a position to take on the post-project dissemination system. For the sustainability of the project, it is necessary to strive to make it possible to institutionalize the model dissemination at the initiative of the implementing organization. Specifically, it is desirable that the model dissemination is positioned as a strategy of the organization, and that articles of incorporation and job regulations are also prepared to realize it.

If the cooperation target area (area for model dissemination) is large, it may be appropriate to have multiple pilot (model) districts for future model dissemination. It is important to keep this in mind when deciding the number of pilot districts.

5.5 Irrigation methods

In the case of pump irrigation areas, there are cases where irrigated agriculture is temporarily suspended or abandoned because farmers are unable to cover the costs of fuel and facility renewal. It is desirable to select gravity irrigation areas as pilot areas where such risks are low. If a pump irrigation area is a candidate pilot area, it is desirable to carefully analyze sustainability in terms of farm income, expenditure, and government support systems, and make a decision based on the results. In such cases, a farm income and expenditure analysis, including pump operating costs, should be conducted, and if necessary, cooperation should be extended to include farm improvement activities aimed at increasing income.

5.6 Functional status of irrigation facilities

A prerequisite for participatory water management is that irrigation facilities are functioning, with facilities maintained in a state that allows water to be taken, conveyed, and distributed as planned. For example, if water intake weirs and diversion gates are inoperable or no longer functioning properly due to deterioration or damage, or if there are problems with water leaks from canals, this will result in the inability to deliver water to end-user fields,

and farmers' motivation to improve participatory water management will inevitably be low. It is fine if water conveyance problems can be resolved through simple repairs and replacement that can be carried out with cooperation from farmers, but if fundamental repair work is required, the area will not be selected as a pilot area. Furthermore, if facilities are currently under construction in the target area, cooperation regarding the establishment of a WUA will first be considered.

5.7 Existence of full-time farmers

In irrigation districts where the majority of farmers are part-timers with more income outside of agriculture, the motivation to improve irrigated agriculture is low. Because farmers are the main actors in "participatory water management," this situation becomes a bottleneck in implementing project activities. Pilot districts are selected that have as many full-time farmers as possible who make agriculture their main source of income and who basically live in the irrigation district.

5.8 Division of management duties between the government and the WUA

The starting point for forming a "participatory water management model" in areas jointly managed by the government and WUAs is to have the division of responsibilities clearly defined by law or ministerial ordinance. If the division of roles is unclear, it will be unclear what kind of model to form, and the activities themselves will go astray. In the case of joint management, in many countries, government agencies are responsible for the operation and maintenance of intakes, main canals, and secondary canals up to the diversion gates, while WUAs are responsible for the management of end-user facilities from the secondary canals onwards. It is important to clarify the division of roles and responsibilities for the maintenance of the irrigation system, confirm the property rights and management rights of the facilities, and clarify who will be responsible for repairing the extent of future damage. In addition, the policy for "Irrigation Management Transfer (IMT)" will also be confirmed.

5.9 Clarifying the challenges of participatory water management

The starting point for all cooperation is the awareness of the problems faced by the host country parties. When providing cooperation in "participatory water management", it is necessary that the implementing agency and WUA members have a clear awareness of the problems. Through discussions with the government and WUA members, it is possible to confirm what issues exist in "water management," "facility maintenance and management," "WUA activities," and "coordination between the government and WUAs." Examples of issues related to participatory water management are shown in Table 5.1.

Table 5.1 Examples of challenges in participatory water management (JICA. 2019b)

Item	Examples of challenges
Water management	- Due to excessive water withdrawal by upstream farmers, irrigation water does not reach the end fields. - Unbalanced water distribution between upstream and downstream.
Facilities maintenance management	- Regular maintenance of canals (e.g. weed removal in the case of earth canals) and gates (e.g. lubricating oil injection) is not being carried out. - Damaged parts of facilities that can be repaired on-site are not being repaired. - Proper maintenance of facilities is not possible due to a lack of water use fees.
WUA activities	- Low membership rate. - Low collection rate for water fees. - Low unit price for water fees. - Underfunding of water fees makes it difficult to carry out proper WUA activities.
Cooperation between the government and WUAs	- Due to budget and manpower shortages, the operation and maintenance of key facilities managed by government agencies is not being carried out properly, causing major disruptions to water intake and supply. - There is no written agreement on the division of responsibilities between the government and the WUAs, and it is based on verbal agreements, so there are some unclear aspects regarding "responsibilities and roles regarding the operation and maintenance of facilities." - Irrigation plans are drawn up solely by government agencies without consulting the WUAs, and do not meet the water demand of farmers.

Since the purpose of activities in the pilot area is to form a model for dissemination, it will be confirmed through discussions with government officials whether the issues are common to other irrigation areas. If issues specific to the pilot area are taken up as cooperation items, the applicability of the model will be lost.

5.10 Securing water rights necessary for irrigation

The right to use irrigation water (water rights) must be properly secured in accordance with the rules of the country. Even if water rights are secured, if there are disputes over water use with upstream and downstream areas, it will take time to resolve the dispute.

5.11 Existence of WUA

(1) Establishment of WUAs

Since participatory water management is carried out by WUAs, it is necessary to confirm whether WUAs have been established in the pilot candidate areas. If WUAs have not been established, it is necessary to add support for

establishing WUAs to cooperation activities. It is necessary to confirm the conditions for establishing WUAs and registration procedures (including related laws and regulations) set by the host government.

(2) Duties of a WUA

The functions that a WUA must fulfill are as shown in Table 5.2.

The duties of a WUA include water management through the operation of irrigation facilities, maintenance and management of the facilities, provision of services necessary for carrying out these duties, collection of water fees which serve as the source of facility management, and acquisition of subsidies necessary for facility repairs that exceed the WUAs capacity to bear. Other functions of a WUA include dispute resolution and external coordination.

Table 5.2 Functions of WUAs (JICA 2019b)

Functions		Contents
Operation	Water distribution planning	Formulating plans for water distribution prior to the cropping season
	Water distribution adjustment	Adjusting water distribution during the cropping season
	Facility operation	Water intake, operation of diversion gates, etc.
Maintenance	Cleaning	Weeding and sediment removal from canals that can be carried out by water users
	Repairs	Repairing facilities, etc.
Cost recovery	Service provision	Mobilizing the labor of water users to maintain and operate the facilities
	Water fee collection	Collecting water fees from water users
	Subsidies	Obtaining subsidies from government agencies
Dispute settlement		Mediating conflicts between upstream and downstream farmers due to uneven water distribution, etc.
Coordination with external parties		Coordinating with the government, donors, other WUAs, etc.

(3) Participatory Water Management Model in Cooperation

Because the "model" for cooperation was not clearly defined, its interpretation differed among the parties involved, which resulted in a lack of consensus on the direction of cooperation and inability to operate the project efficiently.

The "participatory water management model" that cooperation aims to achieve is "the realization of sustainable irrigated agriculture with the participation of beneficiary farmers." Cooperation related to participatory water management aims to "achieve sustainable irrigated agriculture" by forming a model and disseminating it. Sustainable irrigated agriculture can only be achieved when four elements are met: (i) fair water allocation through improved water management, (ii) appropriate facility maintenance and management, (iii) WUA activities that provide a sense of benefit, and (iv) improved agricultural profitability. The details of each element are as shown in Table 5.3. It is important to investigate and analyze the current situation in the target area from the perspective of the four elements and develop activities that focus on the shortcomings.

Table 5.3 Elements and contents of participatory water management model (JICA. 2019b)

Elements	Contents
● Fair water distribution through improved water management	- If there is an imbalance in water distribution between upstream and downstream farmers, dissatisfaction will lead to an increase in non-payers of water fees, i.e., free riders, making it difficult to secure the water fees necessary for irrigation district management. Furthermore, if this situation is left unchecked, it will lead to problems such as inappropriate facility maintenance caused by insufficient water fees, which will put the sustainability of irrigated agriculture itself in jeopardy. - The only prescription for this problem is "realization of fair water distribution." Specifically, the condition for realizing sustainable irrigated agriculture is to achieve fair water distribution through a series of water management activities: "formulation of appropriate water distribution plan → water distribution implementation → monitoring → water distribution correction based on monitoring results." Furthermore, the effects of fair water distribution are multifaceted, as it is directly linked to "maximization of agricultural production" and "effective use of water resources." - In addition, in order to achieve fair water distribution, it is also necessary to take hardware measures, such as installing water measurement facilities at the water distribution points.
● Proper facility maintenance and management	- If proper maintenance is not carried out, it will not be possible to address facility deterioration or repair damaged parts, which will result in a decline in facility functionality and serious hindrance to water management. - Problems caused by the improper maintenance will create a negative spiral of "inappropriate water allocation → increase in those who have not paid water fees → difficulty in securing necessary water fees → difficulty in proper facility maintenance → decline in facility functionality," which will ultimately lead to the serious problem of a decline in the irrigated area. - Proper facility maintenance is one of the essential elements for realizing sustainable irrigated agriculture. Proper facility maintenance requires the implementation of a series of activities: "planning (annual, medium to long term) → implementation → monitoring."
● WUAs activities giving benefits to members	- A prerequisite for an active WUA is that it carries out organizational activities that members feel are beneficial. Before the introduction of participatory water management systems, irrigation district management in developing countries was entirely carried out by the government. As a result, some farmers still have the mindset that they are being forced to pay water fees and that they do not understand the need for a WUA. Developing activities that allow members to feel that they are benefiting from being members will eliminate such mindsets, increase their sense of participation, revitalize WUA activities, and ultimately lead to the realization of sustainable irrigated agriculture. - In order to create a WUA that feels beneficial, it is necessary to strive to diversify organizational functions, not only in water management and facility maintenance, but also in taking advantage of the benefits of group size in the joint purchase of agricultural equipment and materials, joint shipping of agricultural produce, and holding agricultural technology training sessions.

● Improving agricultural profitability	- Low agricultural profitability not only makes it difficult to set appropriate water fee, but also affects the collection rate of the fees. Improving agricultural profitability for beneficiary farmers is one of the essential elements for realizing sustainable irrigated agriculture. In order to increase agricultural profitability, efforts to improve farming practices are required with the aim of increasing productivity and the selling price of agricultural products. - When agricultural profitability is low in pilot areas, it is desirable to address farming practice improvement as one of the cooperation components.

(4) Participation rate of WUA

The participation rate of WUAs is one of the important indicators showing the current state of participatory water management in the irrigation district. If the participation rate is low, there is a high possibility that serious problems exist behind it. If the reason for the low participation rate is conflicts between farmers or communities, etc., which cannot be resolved through cooperation, the district will not be selected as a pilot district.

(5) Organizational structure of WUA

In terms of organizational structure, it is common for small irrigation areas to have a single WUA, while for large irrigation areas to have a multi-layered structure with water users' groups (WUGs) at the tertiary canal level, WUAs at the secondary canal level, and a federation of WUAs for the entire area. In the case of a multi-layered structure, it is important to understand the roles and responsibilities of each level of organization, and use this information to consider approaches to "participatory water management." It is also important to obtain relevant information such as which administrative districts the pilot irrigation areas cover and whether the chief has a strong influence over the WUAs.

(6) WUA articles of incorporation, rules and regulations

If there are rules for the WUA, check whether they clearly state the rules necessary for ensuring transparency in the organization's management and fair water distribution. Even if there are rules and regulations, there may be cases where the members are not aware of them and they have become a mere formality, so check the compliance status.

(7) Unit water fee and collection rate

If the water fee collection rate is low, it is highly likely that the reason is due to technical cooperation issues (e.g. uneven water distribution, low farm income, etc.), so this should be checked. Determining the appropriateness of the current unit water fee requires expert knowledge, so this will be analyzed and reviewed after the start of technical cooperation. In advance, information about the current unit water fee and whether it is over or under rated can be obtained from members of the WUA. Also, the execution rate of water fee, their use, and the existence of an auditing system are indicators of the appropriateness of the water fee collection system. It is also important to check whether the water fees are set by the farmers themselves, and whether they are based on an "area-based" system according to the irrigated area, or a "metered-rate" system in which a fee is levied according to the amount of water used.

(8) WUA activities and the benefits of joining a WUA

In areas where WUA activity is sluggish, members may not see any benefit in joining the WUA. For example, if there is an imbalance in water distribution between upstream and downstream areas, downstream farmers will hesitate to pay water fees, and if they do not feel that the compensation they receive is commensurate with their obligations, their motivation to participate in WUA activities will decrease. The basis for revitalizing WUAs is to "develop activities that make members feel there are benefits." Specifically, it is important to not only stabilize agricultural production through fair water distribution, but also to work to improve agricultural profitability for members by diversifying WUA functions, such as through "joint purchasing of agricultural equipment" and "joint shipment of agricultural produce" that take advantage of the WUA's economies of scale.

(9) Organizational evaluation of WUAs

Regarding the WUA, the planner will evaluate the overall governance of the organization, such as the position of the WUA representative, the fairness of water distribution and burden, and the identification of beneficiary areas. To supplement the organizational evaluation, the planner will interview WUA officials and others to understand the details and background of the major issues identified in the evaluation results.

(10) The way and frequency of electing WUA officials

Generally, WUAs are run by officers such as the chairperson, vice-chairperson, business officers (facility maintenance and management, water management, etc.), accountant, and auditor, who are elected from among the members. WUA officers are generally elected by a method that reflects the consensus of the members, such as at a general meeting. If officers are nominated by a government agency that does not reflect the consensus of the members, or if the frequency of elections stipulated in the WUA regulations is not followed, the WUA may be run without transparency.

(11) Meeting frequency and participation rate

WUAs are managed based on the results of discussions at various meetings so that their activities reflect the consensus of the members. Annual plans and budgets are reviewed and approved at regular general meetings, and emergency responses and dispute resolution are reviewed and resolved at extraordinary general meetings. The frequency of such meetings and the participation rate of members are one indicator for measuring the functioning of the WUA, so it is important to keep them as data.

(12) Participation rate of members in facility maintenance and management work

Proper maintenance of irrigation and drainage facilities that have been transferred to the management of WUAs requires cooperative work by the members, such as raising sediment in canals, removing weeds, repairing damaged parts of facilities, and maintaining farm roads. If these maintenance tasks are not carried out properly, the facilities will not only malfunction, resulting in an inability to achieve fair water distribution, but the facilities will also deteriorate. As a rule, these maintenance tasks should be carried out jointly by all WUA members. If the participation rate of the members in these tasks is low, there is a high possibility that there is a problem with WUA activities in general. Furthermore, if the issue of non-participation in facility maintenance tasks is left unattended, it will foster

a sense of unfairness among the members, which could ultimately lead to the WUA's dysfunction, so there is a need to establish and apply punitive provisions for non-participation.

5.12 Support for irrigated agriculture

(1) Profitability of irrigated agriculture

When the profitability of irrigated agriculture is low, problems arise such as the inability to set appropriate unit water fee and low collection rates. These problems lead to the deterioration of facilities due to a constant lack of funds, which ultimately leads to an increase in the number of people who do not pay water fees, and the problem of facility management becomes increasingly serious. It is necessary to investigate the profitability of irrigated agriculture in advance, and if there is a high possibility that low profitability will hinder sustainable irrigation district management, cooperation activities for improving farming and distribution will also be incorporated.

(2) Government support for irrigation district management

Responding to major damage to irrigation facilities due to disasters or large-scale repairs due to deterioration generally exceeds the financial capacity of WUAs. Even though it is participatory water management, it will be difficult to maintain the sustainability of irrigated agriculture without government support for damage and repairs. The planner will check the existence and content of such government support systems, and if there are any deficiencies, the planner will provide advice on expanding the systems as part of cooperation activities.

(3) Agricultural guidance system

In many developing countries, for example, irrigation is managed by the Ministry of Water Resources and Irrigation, while agriculture is managed by the Ministry of Agriculture. In recent years, as part of the trend toward decentralization, the Ministry of Agriculture has taken over agriculture, but on-site agricultural guidance may be the responsibility of local governments. Improving agricultural profitability is a prerequisite for the success of participatory water management funded by water fees. If the results of the preliminary survey indicate that it is necessary to incorporate agricultural guidance activities aimed at improving agricultural profitability as part of the cooperation, it is necessary to understand the agricultural guidance system in the target area and hold prior consultations with the relevant agencies.

5.13 Utilizing the SHEP approach

(1) SHEP approach to improve irrigated agriculture

Although traditional cooperation was touted as participatory development, prescriptions were made by outsiders (such as government officials in the host country or donor agencies), and beneficiaries tended to participate in the activities passively. Such a situation was one of the causes of the problem of "lack of sustainability after the end of cooperation." The SHEP (Smallholder Horticulture Empowerment and Promotion) approach is very helpful in solving this problem and developing sustainable cooperation. The SHEP approach consists of four steps: (i) sharing

the purpose, (ii) creating opportunities for farmers to become aware, (iii) farmers to make decisions, and (iv) providing technical "solutions."

When applying these steps to irrigated agriculture technical cooperation, the beneficiary farmers will take the lead in conducting a "participatory baseline survey" to grasp the current situation and issues of irrigated agriculture, and based on the results, the farmers themselves will formulate action plans for improvements in water management, facility maintenance, WUA activities, farming, etc., and then the technical "solutions" necessary for improvement activities will be provided.

Furthermore, a series of activities based on these steps will also enable the intrinsic motivation of beneficiary farmers, which is the foundation of the SHEP approach: autonomy (the desire to do something of one's own volition, without feeling like one is being forced to do it), competence (the desire to feel a sense of accomplishment in one's actions), and relatedness (the desire to have a sense of trust in others).

(2) "Profitable irrigated agriculture" through the introduction of the SHEP approach

One of the prerequisites for promoting participatory water management is the realization of profitable irrigated agriculture. The problems of low water fee collection rates and inappropriate unit water fee arise from a complex set of factors, including uneven water distribution, lack of ownership among farmers in facility maintenance, and low farm income. Therefore, cooperative activities aimed at resolving each of these factors will lead to the promotion of participatory water management and the creation of sustainable irrigated agriculture.

To promote irrigated agriculture under participatory water management, it is necessary to create a virtuous cycle of "improved farm income → appropriate unit water fee setting/high water fee collection rate → appropriate facility maintenance → fair water distribution → increased agricultural production." And if, through the creation of this cycle, all beneficiary farmers come to realize that "appropriate facility maintenance and fair water distribution are essential to maintaining the sustainability of profitable agriculture," then participatory water management will naturally be successful. If even one piece of this cycle is missing, it will be difficult to achieve sustainable participatory water management. In that sense, improving farm income is essential. However, the problem is how to link increased agricultural production to increased farm income. In that respect, SHEP's approach, which has shifted from "produce and then sell" to "produce to sell," is effective as a tool for technical cooperation related to the "promotion of participatory water management," which is the foundation for improving farm income.

Annex

A Function diagnostic technology for existing facilities (asset management)

Asset management (AM) in irrigation sector is defined as project management to provide good irrigation services sustainably based on the role of irrigation projects in response to social needs. AM is composed of systematic activities to maintain the functions of irrigation facilities (assets) within various constraints, albeit detailed work and actions of AM are not defined.

The problems of irrigation projects in general when AM is not implemented are summarized in Figure A.1.

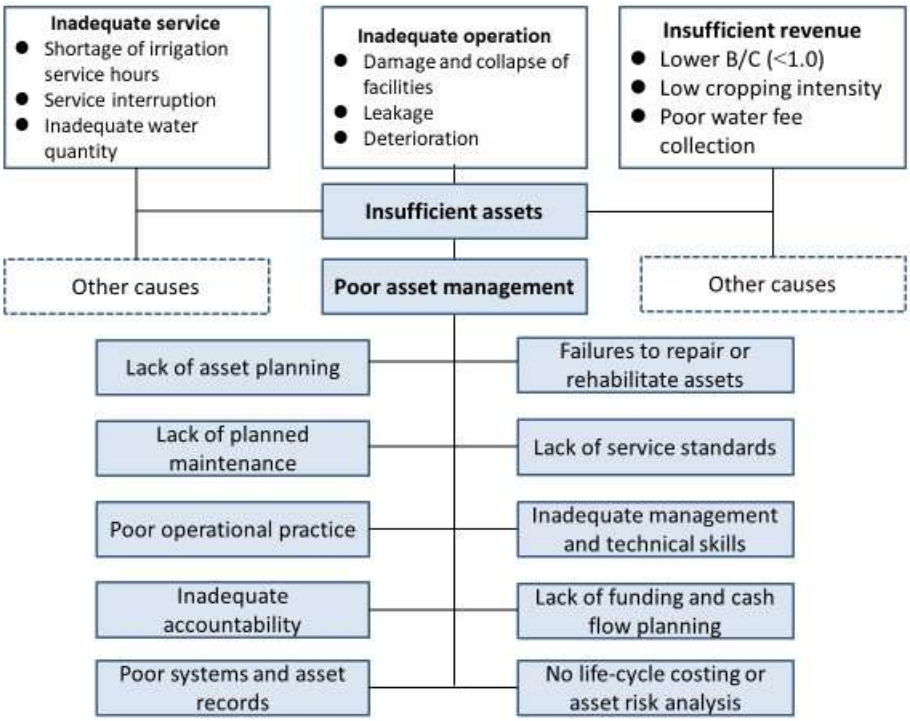


Figure A.1 Problems when AM is not implemented (ADB. 2013)

The core component of AM is stock management (management of physical facilities). AM includes fund management and human resource management in addition to stock management. This manual focuses on stock management of irrigation facilities.

The AM process for irrigation facilities focusing on stock management is as follows (Figure A.2).

(1) Daily check and repair of facilities by local engineers in charge
(2) Regular function diagnosis by regional engineers
(3) Prediction of deterioration based on diagnosis results, comparison of countermeasures, formulation of function maintenance plan
(4) Facility monitoring based on facility monitoring plan
(5) Implementation of countermeasures based on the function maintenance plan and monitoring results
(6) Accumulation of data on survey and examination results as well as results of countermeasure work

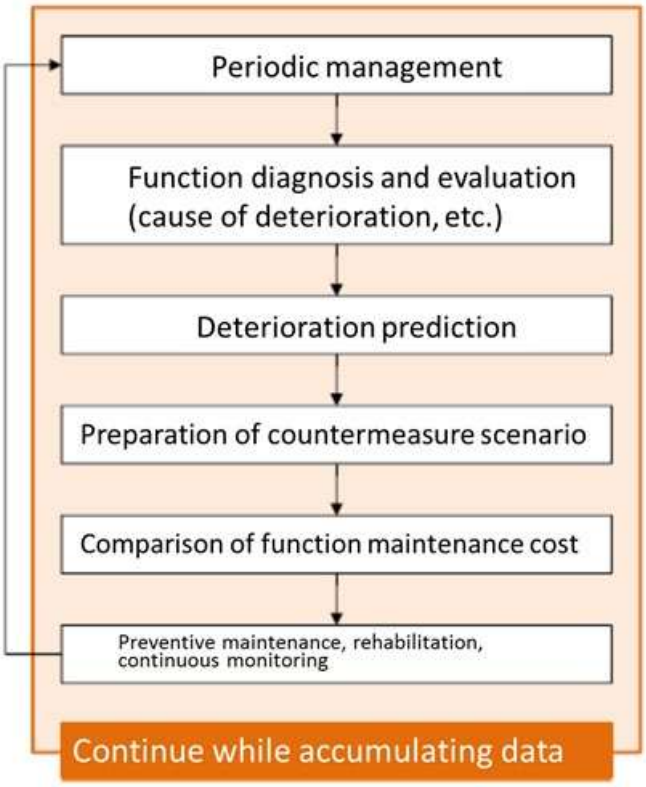


Figure A.2 Irrigation asset management cycle

Irrigation facilities will deteriorate over time after construction is completed, and the functions of the facilities will gradually be lost. In order to maintain the functions of irrigation facilities, appropriate maintenance is required, however, the budget for maintenance is usually limited and the repair / reinforcement of important structures tends to be postponed. Until now, when the lowest limit of the functions of important structures has been reached, renewal of the entire irrigation system has been carried out at a high cost. As investment in irrigation projects progresses, the number of irrigation facilities and the amount of maintenance / renewal cost increases.

In order to maintain the constructed irrigation system under the limited national budget, the irrigation facilities should be regularly evaluated and the budget required for maintenance / repair / reinforcement / renewal should be distributed appropriately. This will result in the extension of service life of the entire facilities. For this purpose, it is necessary to conduct a function diagnosis of facilities for each irrigation system and create a function maintenance plan. The function maintenance plan includes results of function diagnosis, deterioration prediction, priority setting for repair / reinforcement / renewal, method / implementation scenario of countermeasures, calculation of function maintenance cost, and facility monitoring plan.

By introducing AM (stock management), it becomes possible to properly maintain functions of irrigation facilities, extend service life of the facilities, and reduce costs required to maintain functions of facilities. Figure A.3 shows a comparison between the conventional full renewal work and the function maintenance work through AM.

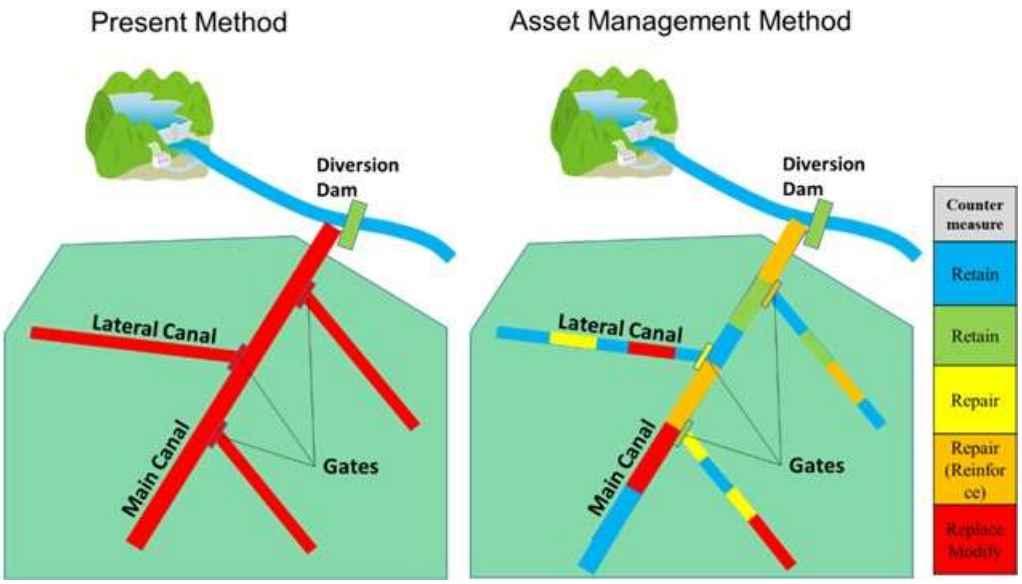


Figure A.3 Comparison between conventional renewal and asset management

Function diagnosis results are usually divided into five soundness levels according to the degree of deterioration: that is, S-5 for no countermeasure required, S-4 for observation required, S-3 for small-scale repair / reinforcement, S-2 for medium-scale repair / reinforcement, and S-1 for renewal. The facilities are classified into three levels based on the importance of the facility: that is, A for high, B for medium, and C for low importance. As for priority setting to implement countermeasures, the magnitude of risk caused by deterioration of function of facilities should be evaluated based on the degree of deterioration and the importance of facilities. The facility with higher risk is given priority. Figure A.4 shows a conceptual diagram of risk analysis.

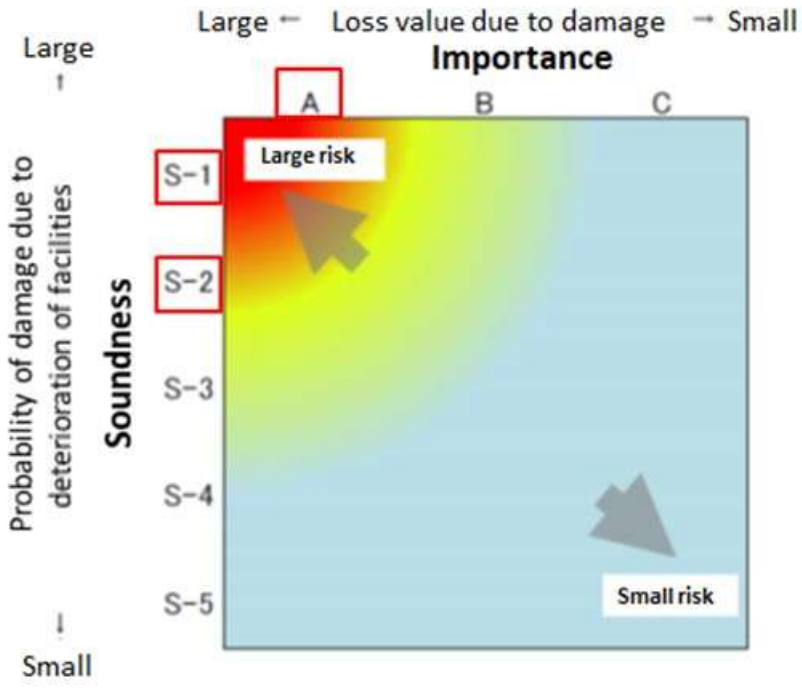


Figure A.4 Conceptual diagram of risk analysis

Table A.1 shows an example of criteria for determining repair / renewal by soundness / importance. This table is tentatively based on the following ideas, but since irrigation projects are highly regional, it is necessary to set guidelines for repairs and renewals that suit actual conditions of a country / region.

- In principle, the facility with S-1 should be renewed as soon as possible. If funding or renewal is difficult, temporary important emergency repairs should be carried out to restore functionality.
- The one with S-2 should be renewed within 5 years, and temporary important / normal emergency repairs should be carried out.
- The one with S-3 should be carried out emergency or regular repairs provisionally, with the principle of conducting important repairs within 5 years.

Table A.1 Image of repair / renewal judgment by soundness / importance

Soundness		S-1			S-2			S-3		
Importance		A	B	C	A	B	C	A	B	C
Renewal	Emergency renewal	◎								
	Normal renewal		◎							
	Renewal within 5 years			◎	◎	◎	◎			
Important repair*	Important emergency repair	◎	◎	◎	◎	◎				
	Important normal repair				○	○	◎			
	Important emergency repair within 5 years						○	◎	◎	◎
Regular repair	Emergency repair	○	○	○	○	○	○	◎		
	Normal repair							○	◎	◎
	Repair within 5 years								○	○

Note) “Important repair” is a large-scale repair that greatly exceeds the “regular repair” level.

Irrigation facility cost should be evaluated by life cycle cost which includes not only construction cost, but also maintenance, repair / reinforcement / renewal cost, and residual value (See **Appendix E**).

AM does not require special additional work when introducing and implementing it. The new work to be introduced by AM is almost limited to the accumulation of data, its analysis, and use of the analyzed results. One of the benefits of AM is evidence-based planning and implementation of irrigation work that can be clearly explained to external stakeholders. The basis for this AM benefit is various information and data collected and accumulated during operation and maintenance (O&M) work. The analysis and use of those data is the key to AM.

Information and data obtained through the implementation of irrigation projects need to be systematically linked and utilized when practicing AM. Furthermore, it is important to collect and accumulate data in order to practice AM more effectively for the future. Expansion of existing ledgers (computerization, addition of input items, etc.) and establishment of a new database is necessary. When establishing, it is desirable to organize information and data by considering ‘what purpose and how much to use’ and ‘how / who will continue to update / input data’.

Figure A.5 shows an example of a system module that should be built by AM.

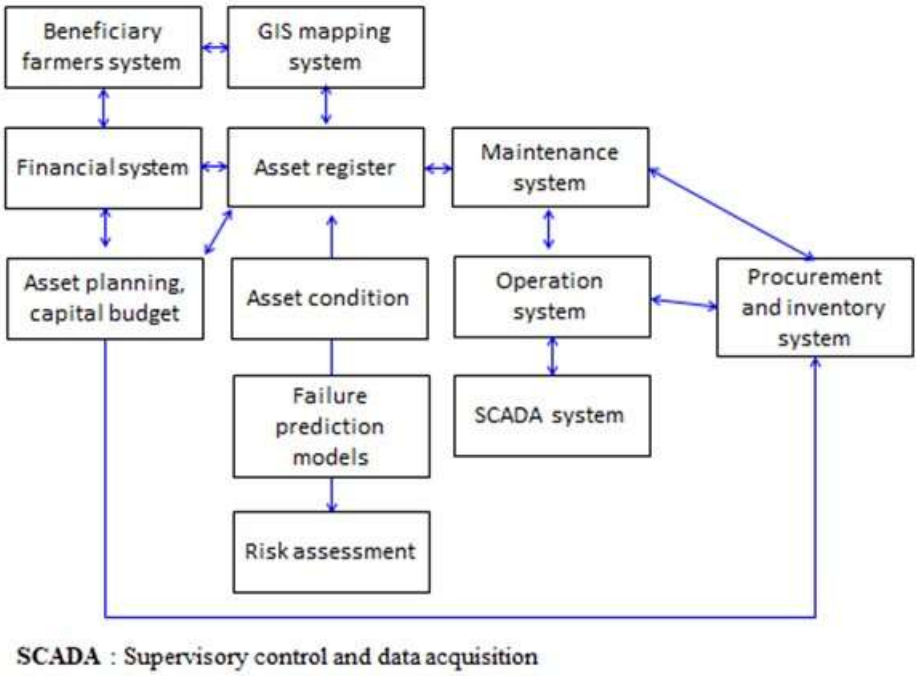


Figure A.5 Asset management system modules

The irrigation stock management database system accumulates information on irrigation and drainage facility specifications, maintenance and repair history, and function diagnosis results etc. as a system to provide a centralized understanding of facility conditions and to support appropriate function maintenance measures. Figure A.6 shows a conceptual diagram of the information collection and database of irrigation facility stock management that should be developed before implementing AM of irrigation project.

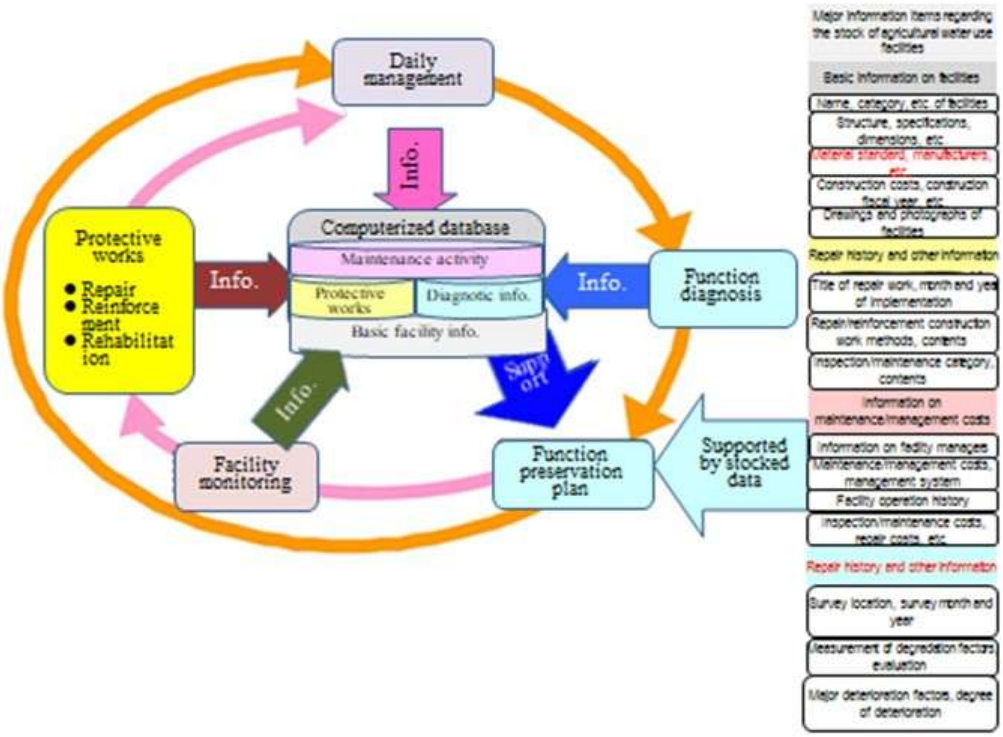


Figure A.6 Conceptual diagram of database for stock management of irrigation facilities

Based on the digitized data base, decision makers can decide budget allocation appropriately according to the priority which will be set by soundness and importance evaluation accumulated in the data base (Figure A.7). If the domestic resources for repair / reinforcement / rehabilitation / renewal is insufficient, foreign resources should be requested based on the digitized data base through due procedures, in order to avoid function breakdown of irrigation system. The digitized data base will provide an objective material quite useful for explanation to external stakeholders.

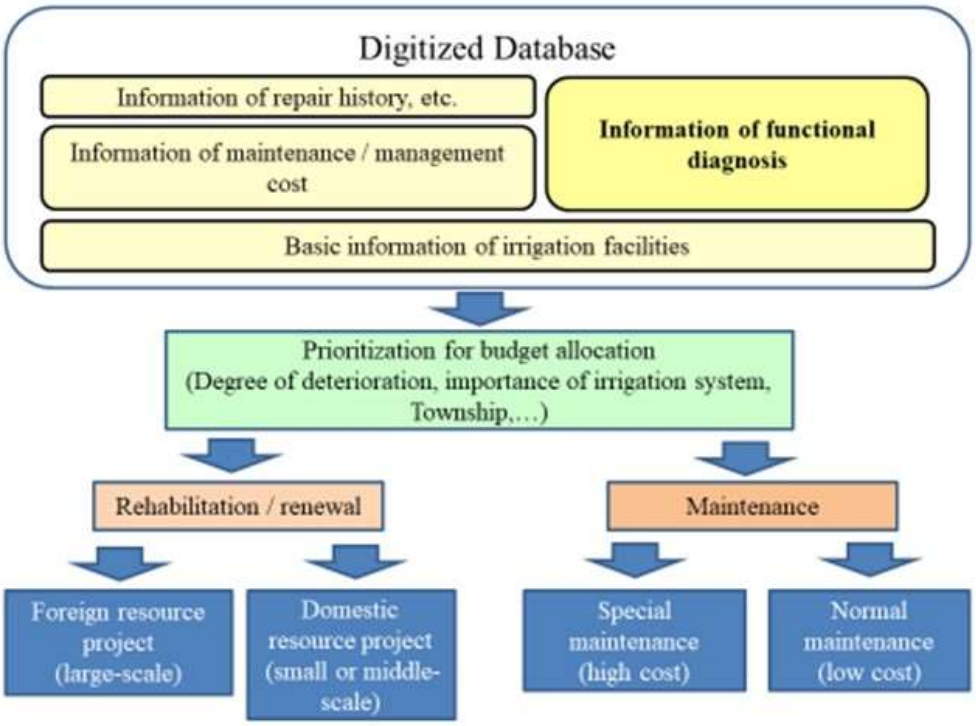


Figure A.7 Prioritization and project planning through asset information

When planning an irrigation project that mainly involves repairing and replacing irrigation facilities, it is important to diagnose the functionality of existing facilities. ADCA has developed an Asset Management System, which is license-free and available to anyone, as an effective tool for visualizing the results of function assessments (Figure A.8).

The features of the AM system are as follows:

- Since the main terminal equipment is a smartphone, the number of other devices such as PCs can be minimized.
- The GPS function makes it easy to determine the location of the survey point, and location information is automatically entered, reducing the possibility of human error.
- Input items include the type of irrigation facility, main material of the facility, soundness of the facility, importance of the facility, facility name (change the automatically entered name), photos (up to three), video (up to 20 MB), and description of the facility status (text input, and there is no limit to the number of characters and possible in any language). Data input is easy because everything except the name, photo, video, and description of the facility status is selective.
- Photos taken with a smartphone are reliably linked to location information.
- Data can be easily searched, displayed, output, updated, and deleted.

- Data registration date and data update date are automatically entered and cannot be changed.
- Input data is automatically registered in the database. When moving to a new fiscal year, the previous year's data is saved as the previous year's database and cannot be changed, and the previous year's data is automatically copied to the new fiscal year, making it easy to change, delete, and add. In this way, the database is accumulated by year, making it easy to analyze data over time.
- Data can be output to PDF and Excel, and when outputting to Excel, the linked photos are output at the same time.
- The use of a cloud service company's server is recommended, so there is no limit to the number of survey locations. If the amount of data entered exceeds the amount of data contracted with the cloud service company, users can continue to use it by changing the contract to the next level of data. However, an increase in the contract amount of several dollars to several tens of dollars per year is required.
- The map is based on the free OpenStreetMap, but users can switch to free Google maps such as Google Satellite, which makes it easy to see the survey locations.
- The markers on the map are color-coded by facility name and soundness level. Facilities with a high priority for repair and renewal are displayed in red as S1, intermediate S3 is displayed in yellow, and S5, which is almost the same as a new construction, is displayed in blue, so by searching for the red locations, the locations of facilities that should be repaired with the highest priority can be easily identified. In addition, by touching the display selection icon on the map with a smartphone, users can display locations on the map that are narrowed down according to classification, such as displaying only S1 locations.
- The system has minimal operating costs (the only expense an entity has to pay to operate an AM system is the cloud service fee, so it is impossible to operate a similar system at a lower cost).

-

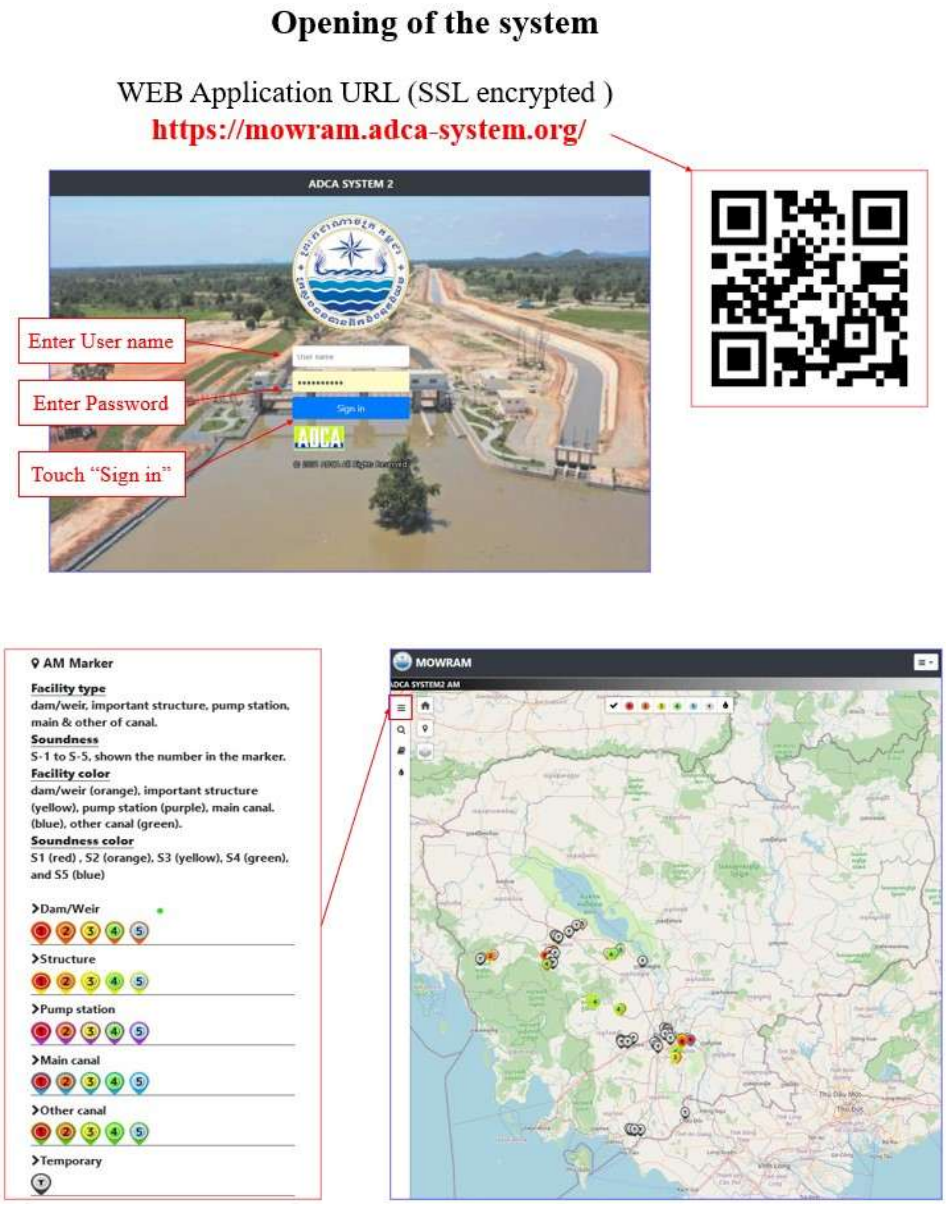


Figure A.8 Top page of the ADCA's AM system (MOWRAM system) (with displaying comments)

B Labor-saving field survey using UAV

1. Overview of UAVs

UAV (Unmanned Aerial Vehicle) refers to a general term for small unmanned aircraft that are remotely controlled without a pilot on board. Drones, radio-controlled aircraft, small helicopters for spraying pesticides, etc. fall into this category, and they are broadly divided into fixed-wing and rotary-wing aircraft. Since most new UAV technologies are still in development, there is no standardization of which technologies to apply and how they should be applied, and many new technologies are being explored depending on the conditions of the field where the UAV will be used. Normally, UAVs with a certain size can fly stably for a long time compared to small UAVs, and since they have a larger loading capacity, they can be used in a wider range of applications, such as changing the devices that can be mounted.

A digital camera is generally integrated with the aircraft. By using a gimbal (a camera mount that corrects camera shake), it is possible to mount a commercially available compact digital camera or a single-lens reflex camera. The gimbal is designed with consideration for weight balance for stable flight. In addition, the camera function and flight program are linked, so photos and videos can be taken in the same way as with the UAV's built-in camera.

Simply taking a video makes the purpose of the shoot unclear, so video editing is essential. There are many video editing software programs on the market for computers such as Windows and Mac, ranging from advanced software to software with simple interfaces that are easy for beginners to use.

In addition to directly using videos and photos taken with a UAV, SfM[9] can be used to create three-dimensional data, enabling more advanced analysis and quantitative measurements of length, area, etc.

2. Applications of UAV

2.1 Public surveying

In Japan, it is possible to create digital topographical maps and three-dimensional point clouds using aerial photographs taken by UAVs for public surveys.

A "digital topographical map" is a representation of map information related to terrain, features, etc., in a state that can be processed numerically, such as coordinate data showing position and shape. Standard digital topographical maps created by UAVs are map information levels 250 (within 0.12 m standard deviation of horizontal position) and 500 (within 0.25 m standard deviation).

A "three-dimensional point cloud" is a representation of the horizontal position and elevation of terrain-related information, as well as the color information of aerial photographs, in a state that can be processed numerically (Figure B.1).

[9] SfM (Structure from Motion) is a technology that restores the shape of an object from multiple photographs of the object. It automatically extracts "feature points" that can identify positions in multiple photographs, and determines the relationship between the position and orientation when the photographs were taken.

Figure B.1　3D point cloud data created from aerial images
(Source: https://www.ad-hzm.co.jp/solution/construction_dx/detail_03/)

2.2　Survey of water storage and sediment volume

Sedimentation in dams and reservoirs is a major management issue, as it not only reduces the effective storage volume, but also induces flooding damage at the upstream end due to rising inflow water levels. Measurement of the volume of stored water and sedimentation is essential to maintain the functionality of dams and reservoirs, and 3D point cloud data captured by UAVs is an effective survey tool for this purpose. Furthermore, by setting up survey markers (permanent markers) on-site, it is possible to compare data with previous years using the same standards.

2.3　Use in function diagnostic surveys

Function diagnostic surveys of irrigation facilities are mainly carried out by humans, but there are many cases where it is difficult to enter or get close to the survey location, which means that the condition of the facility cannot be fully understood. UAVs can be used to conduct close-up surveys at high altitudes or in difficult-to-reach locations, and by recording the condition of the facility in detail, it is possible to more appropriately evaluate the soundness of the facility (described in detail in 3 below).

2.4　Use in disasters and sudden accidents

Approaching the scene of a natural disaster or sudden accident is accompanied by many dangers and can be difficult due to road closures, etc. Aerial photography using UAVs allows for a quick understanding of the damage or accident situation, which allows for an appropriate initial response to be implemented. To this end, it is important to prepare for emergencies by acquiring UAV operation skills that can respond immediately to disaster or accident scenes, and to make organizational efforts to create an emergency system.

2.5　Use in agricultural surveys

By taking photos and videos from the air using a normal visible light camera, it is relatively easy to check the agricultural status of widespread farmland or the land use status of difficult-to-access mountainous areas. In addition, by using infrared thermal cameras and multispectral sensors mounted on UAVs, it is possible to investigate the growth of agricultural crops and the occurrence of pests and diseases.

3. Function diagnosis method by UAV

3.1 Function diagnostic survey using UAV

Function diagnostic surveys using UAVs are based on the assumption that photographic images taken by a digital camera mounted on the UAV will be used, and are carried out using the work content shown in Table B.1, using single photographs, ortho-images[10] processed by SfM, or three-dimensional models. In addition, the use of videos taken by UAVs or still images processed from videos is also effective for function diagnostic surveys. The use of infrared cameras (thermos-sensors) is also considered promising.

Table B.1 Overview of function diagnostic work using UAV

Work process	Work overview
1. Preliminary survey	(1) Identifying the cause of changes in the facilities to be surveyed and setting the objectives of the UAV survey 1) Identifying the causes of abnormalities in normal preliminary surveys (2) Checking constraints on UAV flight 1) Basic standards for permits in restricted flight areas 2) Airspaces where permission to fly UAVs is required 3) Other restrictions under relevant laws and regulations (3) Other things to check 1) Existing control points (GCP: Ground Control Point) 2) Collecting the latest information on UAVs
2. On-site survey	(1) Confirmation of site conditions for on-site survey using UAV At the site, focus on checking points to note when taking aerial photographs, such as obstacles that may hinder a safe flight, takeoff and landing locations, and areas that cannot be measured. 1) Check for obstacles that may hinder UAV flight and image acquisition ・Check weather conditions, obstacles, satellite positioning conditions, radio wave conditions, third party intrusion, and the presence of living creatures that may hinder safe flight. 2) Checking the working conditions ・Check the shape and location of the surveyed facility, takeoff and landing locations, personnel allocation, and reference point (target) installation locations (2) Test flight Test flight the UAV to understand the flight conditions and check the captured videos and images. (3) Understanding the changes in the facilities surveyed 1) Identify as many changes as possible to the facilities surveyed on-site 2) Consider the need for supplemental photography

[10] Ortho-image is an image created by converting an aerial photograph into an image that is displayed in the correct size and position, without any tilt, as if viewed from directly above, just like a map.

Work process	Work overview
3. Planning a field survey using UAVs	(1) Planning a field survey using UAVs 1) Organizing the results of checking constraints ・Aviation law, general matters, other regulations, flight permits and approvals 2) Setting the purpose and required accuracy of on-site survey using UAV (2) Grasping the state of change and setting fixed ranges Set fixed ranges to assess the soundness of the facility after grasping the abnormality of the entire facility 1) Grasping the abnormality situation ・Identify abnormal conditions from videos and images without performing image processing 2) Setting fixed point range ・Group the identified abnormalities, and set fixed-point survey areas (3) UAV work plan 1) Flight method (autonomous flight / manual flight) 2) Equipment and materials used (4) UAV flight plan 1) Implementation system for filming work 2) Check takeoff and landing locations and weather conditions 3) Determine the shooting distance 4) UAV shooting plan ・Set shooting distance, shooting course, etc.
4. Field survey by UAV	(1) Setting the reference point ・Allocation of reference points, etc. (2) Flow of UAV photography ・Based on the field survey plan, photographs will be taken using a UAV. 1) Checking UAV, etc. ・Before the flight, immediately before the flight, during the flight, after the flight, and other matters to be confirmed 2) Items to check on-site ・Meteorological conditions (weather, wind speed), consistency with photography plans, checklists, communication systems, record management of operation results 3) UAV filming 4) Important points to note when taking off and landing 5) Things to check after shooting
5. Image processing using SfM	(1) SfM (SfM :Structure from Motion) 1) SfM image processing 2) 3D model development 3) Input/Output data format 4) Outputs and their use
6. Infrared camera (thermo-sensor)	(1) Infrared survey methods ・Installation of contact thermometer ・Image analysis
7. Function diagnostic evaluation	(1) Automatic crack extraction software (2) Function diagnostic evaluation procedure

In terms of actual work results, the use of UAV measurement has reduced the labor required for on-site work by 20-30%, while the labor required for indoor work has increased by about three times compared to conventional methods. Compared to conventional methods, UAV measurement has shifted the work content from on-site work to indoor work, and the total amount of work has been reduced by about 20% (Kanto Regional Agricultural Administration Office, 2023).

3.2 Preliminary survey

In addition to grasping the causes of deterioration of the facility, UAVs also collect and organize information on the constraints on UAV flight and obstacles that affect flight and photography. By using a deterioration factor estimation table to estimate the expected deterioration and range of the facility, the measurement accuracy of each deterioration required for the soundness evaluation is considered, and this is used as basic information for formulating the on-site survey plan.

Regardless of the location, the following rules must be observed when flying a UAV.

- Do not fly if consumed alcohol or other substances.
- Fly only after making sure that all necessary preparations for flight are complete.
- If there is a risk of collision with an aircraft or another UAV, have it descend to the ground.
- Do not fly in a manner that causes unnecessary noise or inconvenience to others.
- Fly during the day (from sunrise to sunset).
- Fly while constantly monitoring the UAV and its surroundings within visual range.
- Fly while maintaining a distance of 30m or more between people (third parties) or objects.
- Do not fly over events where many people gather, such as festivals.
- Do not transport explosives or other dangerous materials.
- Do not drop objects from UAV.

When carrying out a function diagnosis using a UAV, it is necessary to predict the cracks, wear, and other abnormalities occurring in the target facility, clarify the objectives, such as grasping the crack width and degree of wear required for the soundness evaluation, and determine the resolution of the images to be taken by the UAV and the accuracy of the 3D model. Since function diagnosis using a UAV targets facilities that are high up or difficult to access, it may be difficult to visually confirm abnormalities on-site. It is necessary to use a deformation factor estimation table, etc., to estimate the expected abnormalities and their range in the target facility from the information obtained in the preliminary survey (finished form drawings, repair history, years in service, environmental conditions, etc.). Based on the results of the assumed abnormalities and range, the survey objectives, such as detecting uneven settlement and cracks, are roughly determined, the measurement accuracy of each abnormality is understood, and a field survey plan is formulated to ensure the required accuracy.

3.3 On-site survey

In the on-site survey for the function diagnosis using UAV, in addition to the usual on-site survey contents, the focus will be on checking the points to be noted when formulating the UAV on-site survey plan, such as checking obstacles that may hinder UAV flight, take-off and landing locations, and areas where photography is not possible.

(1) Check for obstacles that may hinder UAV flight and image acquisition

Weather conditions

Because UAVs are flying objects, they are more susceptible to weather conditions than ground operations, and depending on the situation, operations may be interrupted or unable to continue. During site reconnaissance, a detailed survey of local conditions, such as weather, at the time of the scheduled flight is conducted.

Obstacles

There may be cases where trees between the survey target and the UAV, or vegetation grows thickly or covers the area near or on the surface of the target, making it impossible to capture the surface shape of the structure. In such cases, remove as much of this as possible during the on-site survey. Also, images captured of moving objects such as smoke or waves around the target make it difficult for SfM to process them correctly, and good results are often not obtained. Trees around the target may have a similar effect, so the type, height, shape and location of the trees should be understood in advance. Note that there is a water surface near the impact points around headworks and other hydraulic structures and coastal embankments, and the effects of this are often unavoidable.

Satellite positioning conditions

General UAVs are equipped with a care-free (CF) function and a position hold (PH) function to maintain the stability of the aircraft. These functions receive satellite radio waves to assist the aircraft's status and operation, but if the number of satellites captured decreases, the auxiliary functions are ineffective and control of the aircraft becomes difficult. Therefore, when conducting site reconnaissance, be sure to check the GNSS[11] capture number taking into consideration the trees and undulations around the takeoff and landing site. The GNSS capture number should be six or more as a rule, and UAV flights during site reconnaissance should be avoided during times when the number of GNSS captures is five or less. Note that if the number of GNSS captures is low, the application's control function may activate and the UAV may not be able to fly. Note that the GNSS signal may be cut off under the monitoring bridge of a headworks or the eaves of a building roof, increasing the risk of crashing. Note that investigations are not possible inside buildings because the GNSS signal cannot reach them.

Third party access

Regarding flight rules when third parties are present, it is mandatory to fly at a distance of 30 m or more between third parties, buildings, third party vehicles, and other objects. In areas where third parties are expected to enter, access restrictions and management by safety guides are required. When conducting on-site surveys, it is necessary to check whether third parties are entering the area.

(2) Checking the working conditions

Shape and location of the surveyed facility

The points to note specific to irrigation and drainage facilities are as follows: Whenever possible, measure wind speed during on-site surveys and obtain detailed information on the location and sunlight conditions.

- When the target area is wide for a function diagnosis of a headworks, etc., check the time periods when shadows occur for each facility.

[11] GNSS (Global Navigation Satellite System) is a general term for satellite positioning systems that use artificial satellites to measure positions on Earth.

- When photographing the vertical (curved) surfaces of dam columns, elevated water tanks, etc., please note that there are currently no programs that allow autonomous flight, so photography will have to be done by manual flight.
- Headworks and other facilities are intertwined with small facilities. The facilities which have uneven surfaces and are structurally prone to air current disturbances make the conditions for flying a UAV quite difficult. Securing space to fly a UAV is an issue, especially when flying a large UAV.

Confirmation of take-off and landing locations

To safely take off and land a UAV, a large, flat area appropriate to the size of the UAV must be secured, so a site survey is conducted to confirm a location that meets these conditions.

The UAV calibrates its gyro (an inertial sensor for the aircraft's attitude and speed) immediately before starting the motor at takeoff. If this calibration is performed on an uneven surface, the tilted attitude of the UAV will be determined to be the horizontal attitude, resulting in an angled takeoff. Also, if the UAV is hovered with altitude hold turned on, it will drift in the tilted direction (impairment to the attitude control function: depends on the model).

Even if the surface is level, locations on or near steel structures are not suitable for takeoff and landing due to the risk of radio interference.

Staffing

For UAV surveys, pilots, aircraft monitors and security personnel will be assigned, and personnel composition and deployment will be confirmed to ensure the safety of third parties.

Check the location of the reference point

In order to determine the exact positional relationship of the aerial photographs taken by the UAV, it is necessary to set up at least three control points within the shooting range. For setting the control points, confirm the locations where they can be set up during the on-site survey, or investigate alternative points in case it is difficult to set them up.

(3) Test flight

The purpose of test flights is to grasp the overall on-site condition of the facility. They will be conducted only when there are no flight restrictions, and safe flight is possible. It is desirable to check images taken during test flights on-site. If the survey area or the scale of the target facility is large, shooting will be conducted to create orthoimages for formulating a field survey plan.

(4) Understanding the changes in the facilities surveyed

In the on-site survey, understand as much as possible about the changes to the facility that were assumed in the preliminary survey. When constructing a vertical model, depending on the SfM used, there may be cases where the number of photos is small or the target facility has a similar color, making it impossible to recognize the characteristic points and constructing a model. Therefore, check the condition of the facility so as to understand the changes, and consider the need to take supplementary photos in addition to the usual photos.

3.4 Planning for field survey using UAV

There are two flight methods for UAVs: autonomous flight using GNSS along a pre-programmed flight course, and manual flight where the pilot visually controls the UVA using a control lever. When using UAVs for function diagnosis, it is necessary to select the flight method most suitable for the survey based on the results of on-site reconnaissance surveys. Regardless of the flight method, it is important to avoid flying in a direction that will confront mountain slopes or structures.

(1) Autonomous flight

Autonomous flight, which allows the flight course and shooting intervals to be set in advance, is effective in cases where a high shooting lap rate and surveying accuracy are required, such as for creating 3D models or orthoimages. Specialized equipment and a flight planning application are used to fly a UAV autonomously. Flight planning is usually done on orthoimages, but it should be noted that there may be errors in location information, etc. When setting the flight course, it is necessary to avoid terrain (mountains, valleys, cliffs, etc.) and obstacles (structures, overhead lines, etc.) within the flight range. Autonomous flight is performed by a program, allowing for stable flight, but care should be taken not to neglect monitoring during flight.

(2) Manual flight

Manual flight is a method in which the pilot operates the UAV using the control lever while visually observing the UAV. When it is difficult to set the flight course in advance, when the shooting location cannot be specified in advance, or when autonomous flight is not possible, the UAV is flown manually. In this case, if the distance between the pilot and the UAV becomes large, the sense of perspective disappears and the distance between obstacles and the UAV becomes unclear, so it is necessary to maintain a sufficient distance between obstacles and the UAV.

(3) Equipment and materials used

Considering the required accuracy when carrying out facility function diagnosis, select a device to be installed on the UAV, such as a digital camera that can obtain the required photo resolution. Then, select an UAV with sufficient payload (total load weight), flight time, and endurance.

<u>UAV</u>

The UAV used is a multicopter type that is battery-powered and capable of autonomous flight, and as long as it meets the conditions, it can be of any type, including industrial (medium to large commercial UAV), general-purpose UAV, and hobby UAV. Normally, UAVs of a certain size are capable of more stable flight and longer flight times than smaller UAVs, and have a wider range of application in function diagnosis, such as having more room for loading and being able to change the devices that can be mounted on them. Note that when using a UAV weighing more than 10 kg, it is essential for the pilot to have sufficient flight experience and operating skills to ensure safety.

<u>Digital camera</u>

In function diagnostic surveys using UAVs, it is assumed that a dedicated camera or a commercially available compact digital camera or single-lens reflex camera that can be mounted on the UAV will be used, and equipment that can obtain the necessary photo resolution (ground pixel size) depending on the purpose of the survey will be used. In addition to the camera performance of the image sensor, the shooting range will vary depending on the type of lens, such as a wide-angle lens with a different focal length or a normal-angle lens. Note that while a wide-angle lens has a wider shooting range than a normal-angle lens, there will be more blind spots on uneven surfaces, etc.

(4) Flight plan

Implementation system for UAV flight

When carrying out safe work, it is important to clearly define the roles required and create a work structure in which each person can devote themselves to one role. Depending on the content of the role, the same person may take on multiple roles. Also, for the safe flight of a UAV, it is necessary to simultaneously check the surrounding conditions and weather for safety, operate the UAV, and monitor the equipment status. In preparation for unforeseen circumstances, it is advisable to have a spare UAV. Spare batteries and propellers should also be prepared.

Take-off and landing points

The takeoff and landing area for a UAV must be a large, flat area appropriate for the size of the UAV. Any slope should be avoided as it increases the risk of the UAV tipping over during landing, which could lead to damage to the UAV. It is also advisable to lay a special mat to prevent pebbles, debris, etc. from getting caught in the propellers.

Setting the shooting distance

When using the same camera to take pictures, the longer the shooting height (distance to the subject), the wider the shooting range will be, and the shorter the shooting time per unit area will be. Also, since the number of photos taken will be reduced, the data volume will be smaller, and the analysis time will be shorter, resulting in a more efficient plan. On the other hand, the resolution of the imaged subject will be lower, and in some cases, the required accuracy for deformation measurement will not be met.

(5) UAV shooting plan

Flight time

The flight time in the shooting plan should be set with some leeway to land using about 50% of the battery's total capacity, taking into account the fact that winds are stronger in the sky than on the ground, troubles during flight, and returning to the landing site. If the flight distance is extended, try to increase the number of flights to reduce risk as much as possible. In that case, prepare spare batteries.

Battery

Note that batteries are easily affected by temperature, and the time it takes for the battery to drain will vary depending on the temperature at the time of shooting. If the battery becomes cold, it may not be possible to fly the UAV.

Shooting time

Regardless of whether the flight is autonomous or manual, a PC (usually a tablet device attached to the transmitter) is generally used as a UAV monitor. As this is also battery-powered, the shooting time at one location is limited by the battery life of the PC (approximately 3 hours). Shooting plans are made with a standard shooting time at one location of 3 hours or less. However, this does not apply if a dedicated charger for the PC is prepared.

Flight speed calculation

The flight speed of a UAV is about 60 to 80 km per hour. These figures assume no wind and will vary depending on weather conditions and the condition of the UVA. There may also be individual differences. For each survey, calculate the flight speed of the UAV based on the flight method (autonomous flight, manual flight), the specifications of the camera used, the shooting altitude that ensures the photo resolution of the desired subject, and shooting conditions such as overlap rate and side lap rate.

Shooting method

There are many types of irrigation facilities, and each facility has a different shape, so photography must be carried out in a way that suits its shape. The required accuracy of the images varies depending on the function diagnosis survey items, such as crack width and rust, so photography must be carried out under conditions that satisfy these. It is necessary to keep the shooting conditions as consistent as possible in order to minimize differences due to the resolution of the camera and environmental factors such as sunlight. Depending on the content of the function diagnosis survey, videos or single photographs may be used directly. When measuring the length of the deformation or crack width, measurement photography must be carried out taking into account the photo resolution, and the camera's zoom function must not be used when taking the photographs.

- Photographing the facility

  If the main purpose is to create an orthoimage, then vertical measurement photography is performed. If a 3D model of the entire facility is required, photography from all directions is required (Figures B.2 to B.3). For shadowed areas during photography, supplementary photography is performed separately from the normal photography. By taking these supplementary photographs, subsequent processing in SfM becomes easier.

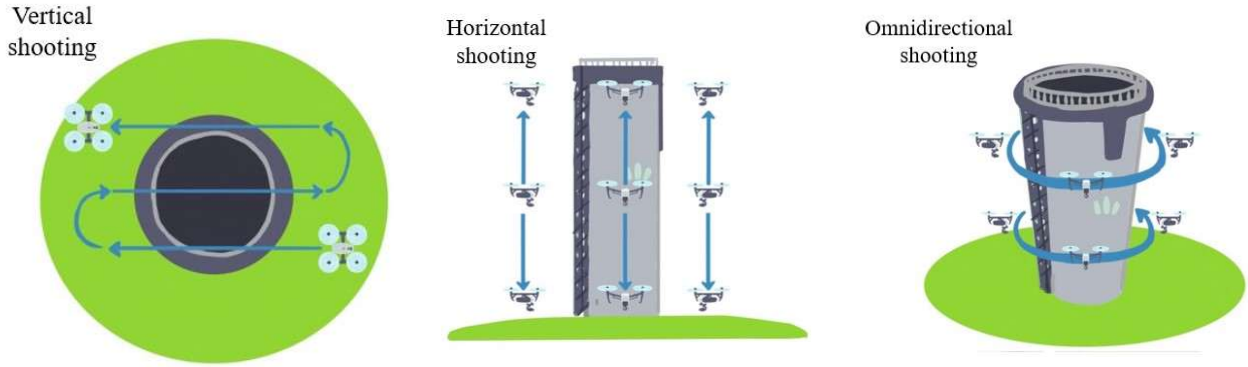


Figure B.2 Image of the shooting method

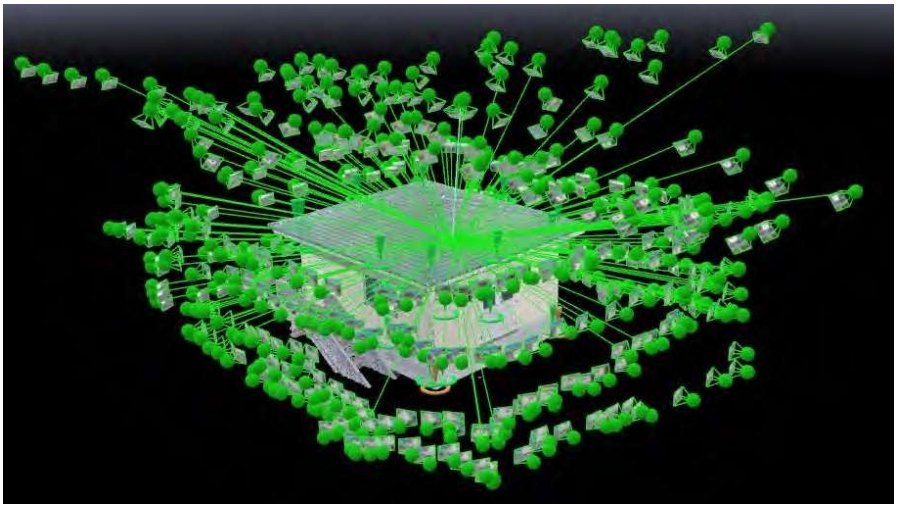
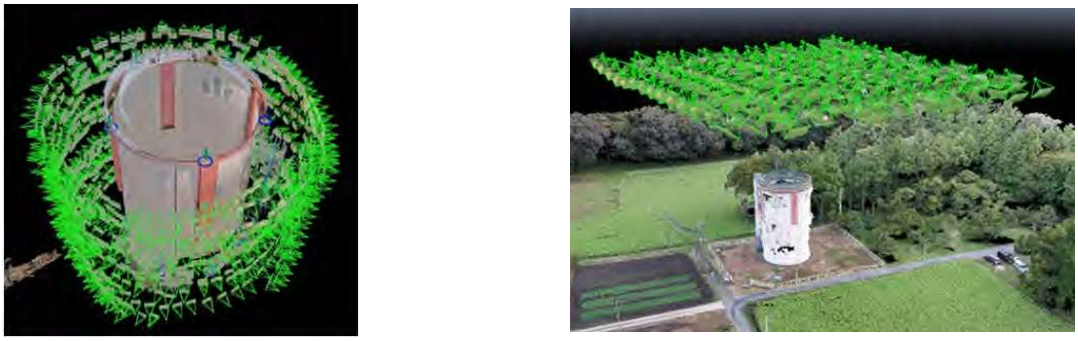


Figure B.3 Example of photography method for a building

Note: When creating a 3D model of a building, images are taken from various positions and directions to eliminate missing images (blind spots).

- Omnidirectional shooting

Omnidirectional shooting (circular mission) may be conducted on the side of a cylindrical facility such as an elevated water tank. Omnidirectional shooting is a special type of shooting in which the UAV is always facing the facility and shooting it, so the appropriate UAV flying technique is required (Figure B.4).



Photographing the wall Photographing the entire facility

Figure B.4 Photographing the elevated water tank for the purpose of creating a 3D model. The walls and the entire facility were photographed separately.

Setting the shooting course and overlap rate between images

The measurement photos taken by UAVs can be either overlap (OL) in the direction of travel or side lap (SL) between courses (Figure B.5). When UAV photos are processed using SfM, the greater the OL rate between images, the higher the accuracy of the output 3D model. The standard OL rate within the same course is 80% or more, and the SL rate is 60% or more. The photography course is set taking into account the planned overlap rate between images.

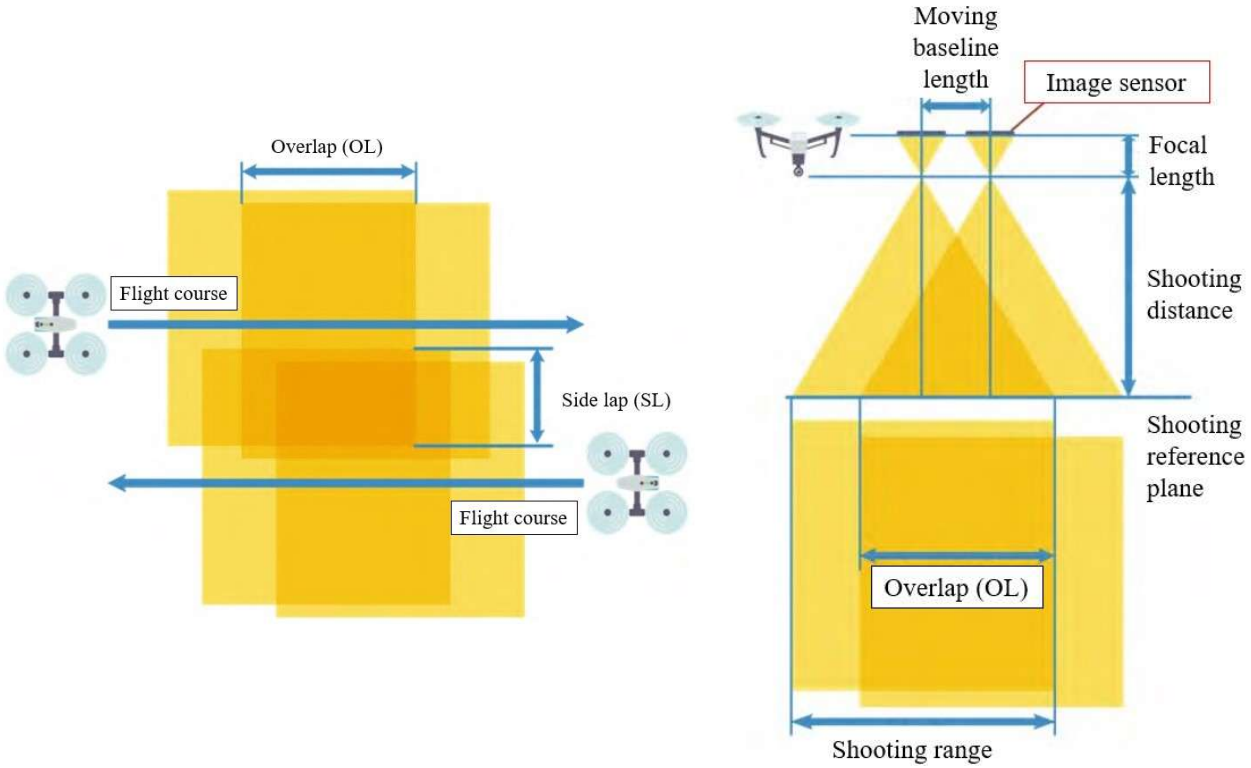


Figure B.5 Photograph image overlap

Photo shoot planning

Based on the flight course determined, a UAV shooting plan is created based on the OL and SL ratio of the captured images (Figure B.6), the focal length, angle of view, and other camera specifications of the digital camera. As shown in Figure B.7, when shooting a tall facility such as an elevated water tank vertically, some parts of the facility may not be visible in the photo due to the difference in height between the facilities, so a shooting plan is created that takes the height of the facility into consideration.

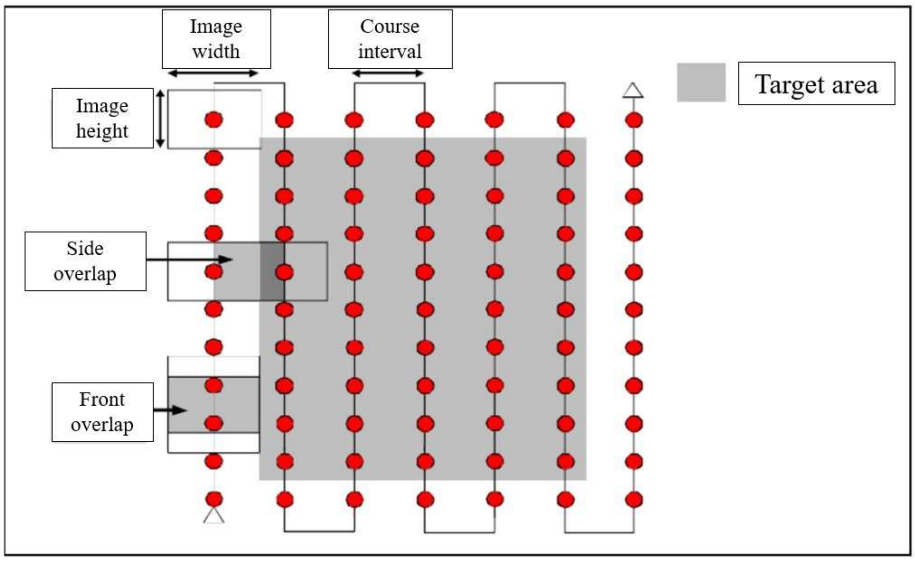


Figure B.6　Relationship between overlap and side lap ratio (flat surface)

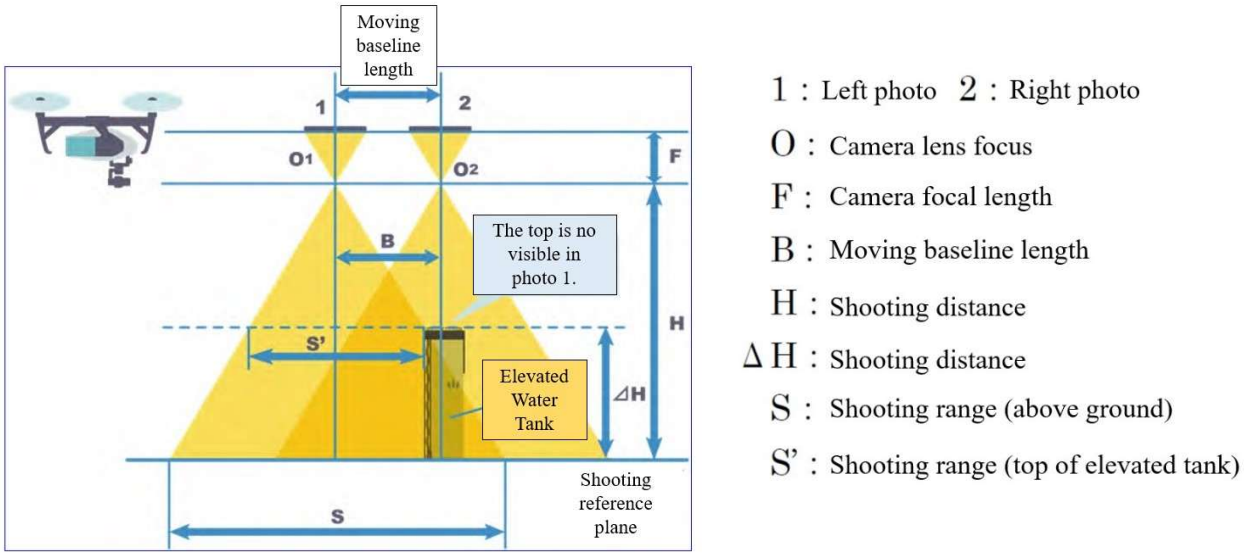


Figure B.7　Relationship between overlap and side lap ratio (cross section)

3.5　UAV field survey

For on-site surveys using UAVs, control points will be set up based on the survey plan, and then photographs will be taken using the UAV. Photographing will be done with due consideration to safety, and after photographing, the images will be promptly inspected to ensure the quality of the images.

(1)　Reference point

Control points are set up on-site in accordance with the field survey plan, coordinate values (X, Y, Z) are measured, and the location information is added during SfM image processing. Note that it may not be possible to set control points depending on the site conditions and the shape of the facility, in which case structures on the ground whose positions can be identified in the photographs or points of change in the shape of the facility can be

used instead. Control points are set up according to the required positional accuracy, and surveying must be carried out according to that accuracy. Note that control points should be set up in places that can be clearly distinguished from the surrounding area and are visible from the UAV. Incidentally, targets of about 10 cm square can be seen even at a shooting distance of more than 100 m.

(2) UAV shooting process

In order to operate a UAV safely, it is necessary to comprehensively consider the UAV inspection, local conditions (weather, wind, etc.), shooting plan, personnel allocation, and the pilot's skill.

Inspection of aircraft, etc.

Equipment inspection is important for the safe operation of UAVs. In addition to performing maintenance on a daily basis, check the following items before and after a flight. In addition, recommend replacing consumables when the number of flights or flight time specified by the manufacturer is reached.

- Before flight
  - Are there any abnormalities such as damage, distortion, or detachment in the appearance of the UAV, propellers, cables, etc.?
  - Is each device (battery, propeller, gimbal, camera, etc.) securely attached?
  - With the propellers removed, check for any abnormalities in the motor noise, heat, rotation speed, odor, etc.
  - Are the batteries for the transmitter and UAV fully charged? Also, are there an adequate number of batteries, including spares?

- Immediately before flight
  - Is each device securely attached? Are there any loose screws?
  - Are the LEDs lit normally?
  - Are the motors making any strange noises?
  - Are the propellers free of scratches or wear?
  - Is the battery fully charged?
  - Is the payload within the appropriate range?
  - Are there any problems with communication with the transmitter or with linking with the photography planning software?
  - Are there any problems with meteorological conditions such as weather and wind speed?
  - Are there any power lines, trees, or other objects nearby that could impede safe flight?
  - If there are, is it possible to fly the UAV while maintaining a sufficient distance from them?
  - Are there any metal plates or objects nearby that could cause compass errors?
  - Are the settings for altitude limit, distance limit, obstacle detection function, etc. correct?
  - Are there any third parties nearby or standing in the area? Can the operator fly the UAV while maintaining a distance of more than 30 m from third parties?

- In flight
  - Is the attitude stable during takeoff and landing?

- Is the hovering and flight stable?
- Is the GNSS (GPS) sensitivity stable?
- Is the overall movement of the UAV normal?
- Are the propellers rotating normally?
- Are there any status abnormalities?
- Is the UAV approaching any obstacles or third parties, or birds, etc.?
- Is there sufficient battery power remaining to return?
- Are there any changes in the weather or wind volume?

- After flight
  - Is there any dust or debris on the UAV?
  - Is there any equipment that is generating heat?
  - Is there any damage to the propellers, such as cracks or chips?
  - Is there any abnormal heat being generated by the motor or battery?

- Other matters to be confirmed
  - Make sure the device's OS, app, UAV, transmitter, and battery versions are up to date.
  - If change flight locations, recalibrate the compass.
  - Check the UAV for the following items every 20 hours of flight.
    - ✓ Are there any parts that need to be replaced?
    - ✓ Is each device securely attached (no missing or loose screws, etc.)?
    - ✓ Is there any damage or distortion to the UAV (propeller, frame, etc.)?
    - ✓ Are the communication, propulsion, power, and automatic control system operating normally?

Items to check on-site

The following items must be checked before flying a UAV. Failure to check these items may lead to serious accidents.

- Weather

  Check the local weather information for the planned flight time to ensure there will be no sudden changes in the weather. The weather conditions best suited for flying are "sunny" or "cloudy," but care must be taken as too much light can cause halation, and too little light can make the captured image too dark. Generally, when flying a UAV during rainfall, rainwater and debris can get into the motor and other parts of the UAV, causing breakdowns. In the worst case scenario, there is a risk of the UAV crashing, so avoid flying in the rain. Also, if hear thunder, immediately cease flying.

- Wind speed

  The UAV's performance includes information on how much wind speed it can withstand. For safety reasons, flight is suspended if the ground wind speed is 10 m/s or more. This is because wind speeds are often stronger in the air than on the ground, and there is a risk of the flight deviating from the set flight route. There is always the possibility of sudden weather changes or gusts of wind, so check wind direction when necessary to make the decision to suspend operation.

- Consistency between UAV shooting plan and site

  Is the flight route created in accordance with the shooting specifications? Also, are there any obstacles (trees, power lines, etc.) on the created flight route that may impede automatic flight? A final check is made on-site to ensure consistency with the shooting plan.

- Check sheet

  In order to operate UAVs safely, a checklist will be created and safety management of the UAV will be performed before each flight.

Things to check after shooting

The quality of the captured images is checked immediately, and if there are any defects such as image distortion or missing shots, the cause is identified and necessary measures are taken before re-capturing. It is necessary to consider the capture method taking into account the orientation of the target facility, depending on the requested content and the weather on the day. For example, if want to measure the side of a facility, must re-capture the image at a time when the target surface will not be obscured by shadows.

3.6 Image processing using SfM

The results of the photographs are assumed to be used for detecting abnormalities in the function diagnostic survey, so they need to be processed by SfM and processed into a format suitable for checking abnormalities. In the survey, abnormalities are detected based on vertical photographs. These photographed images are imported into SfM, and image processing is performed. Then orthoimages are generated to grasp the rough shape of the facility, the deterioration state and the damage scale of the entire facility in a planar manner. From the 3D model obtained by SfM, the abnormalities of height (unevenness, height difference, etc.) that are difficult to judge from photographic images are grasped in a planar manner for the entire facility.

The 3D model obtained by SfM is information on relative positional relationships, and geospatial coordinates are not defined. Therefore, geospatial coordinates are defined by relating the coordinates of multiple reference points on the model. In this procedure, the photographed range is reproduced as a 3D model from the images taken by the UAV, and the shape of the facility structure is generated. If necessary, colors generated from the captured images can be applied to the 3D model to create a more realistic model (DSM: Digital Surface Model) or to create an orthoimage.

3.7 Infrared camera

Currently, there are several types of infrared cameras (thermo-sensors) that can be mounted on UAVs, including cameras that can be attached to general-purpose UAV, and the use of infrared cameras in function diagnostic surveys is also seen as promising.

Infrared function diagnosis is an analytical technique that takes advantage of the fact that the rate of change in surface temperature of an object varies depending on the material and thermal properties that make up the facility structure, and extracts and judges the difference in temperature between abnormal parts such as cavities and leaks and healthy parts from thermal images. The maximum depth of abnormalities that can be detected is about 5 cm, and the investigation targets include floating, peeling, and falling of concrete with air spaces inside, and floating and

peeling of paint films. It is expected to be effective in function diagnostic surveys of concrete structures such as water tanks and dams.

Installation of contact thermo-meter

When taking infrared images, it is desirable to measure the temperature environment at the same time, so a thermo-meter is installed.

Analysis by combining infrared images

The facility data photographed and recorded on-site is processed, and thermal images are used to identify water leaks, floating, and peeling areas, while visible images are used to check for abnormalities such as cracks, exposed rebar, rust, free lime, and peeling paint.

Analysis by differential processing

By calculating the difference between the two joined images, the temperature change at the two times is visualized. The difference processing involves joining and synthesizing the images taken at different times onto different layers, calculating the difference between overlapping pixels in the software, and outputting the result as an infrared image.

3.8 Function diagnostic evaluation

Function diagnosis evaluation using UAVs is carried out using a facility condition evaluation sheet based on the results of image processing such as damage diagrams that meet the required accuracy. The results of function diagnosis surveys will be compiled into a database to enable information sharing and monitoring of the progress of abnormalities. Note that software such as automatic crack extraction software also has accuracy limitations depending on the shooting conditions, and in some cases is less accurate than visual inspection. As only superficial judgments can be made, it is desirable to use it in conjunction with traditional inspection methods such as palpation and percussion.

(1) Crack analysis using automatic crack extraction software

Cracks captured in digital images can generally be extracted by converting the captured image to black and white binary and extracting the crack width and length, or by converting the captured image to 256 colors (gray gradations) from white to black and extracting the crack width and length. With the latter method, by using a gray color scheme (256 colors), it is possible to extract cracks that are difficult to extract by binarization due to stains or differences in the color tone of the concrete surface. In binarization, the density is divided into two values, and values above a certain level are expressed as black and anything below that is white, so the cracked parts that were displayed in the original image may become white.

(2) Creation of damage map using ortho-images

Using ortho-images of a fixed range, the cracks are traced. The work procedure is as follows:

- Create an ortho-image using SfM for the fixed-point range.
- Import the ortho-image, which contains location information, into CAD. At that time, import the location information of the ortho-image (which has a scale).
- Enlarge the ortho-image in CAD and check for cracks.
- Trace the cracks confirmed in CAD.

After that, the usual damage map creation process will be carried out.

(3) Crack width estimation using crack scale sheet

The crack width is estimated using a crack scale sheet. The procedure is as follows:

- Affix the crack scale to the target facility and take a photograph.
- If it is difficult to attach it to the target facility, attach it to a similar facility and observe how it appears in the photograph.
- Create a line type with a line width that matches the crack scale photographed.
- Trace the cracks identified on CAD with lines, and the crack width of the line type that hides the crack will be the estimated crack width.

(4) Understanding the extent of wear using ortho-images

Using ortho-images of fixed areas, the degree of wear is grasped. The work procedure is as follows:

- Create an ortho-image using SfM for the fixed-point range.
- Import the ortho-image, which contains location information, into CAD. At that time, import the location information of the ortho-image (which has a scale).
- Measure the size of standard-sized aggregates in the worn range in CAD.

(5) Understanding the extent of deformation using ortho-images

Using ortho-images of a fixed range, the degree of deformation is grasped. The work procedure is as follows:

- Create an ortho-image using SfM for the fixed-point range.
- The ortho-image, which contains position information, is imported into 3D CAD. At that time, the position information of the ortho-image is also imported (it has a scale).
- Set two arbitrary perpendicular points on the 3D CAD and measure the angle between them.

(6) Identifying uneven settlements, etc. using 3D point clouds

Using ortho-images of fixed points, the degree of uneven settlement is grasped. The work procedure is as follows:

- Create an ortho-image using SfM for the fixed-point range.

- Import the 3D point cloud with location information into 3D CAD (with scale).
- Create a cross-section of any cross section in the 3D CAD and check the degree of subsidence, etc.

(7) Image judgment by AI

Studies are underway to use image diagnostic AI for function diagnosis work. Photos are taken using UAVs or cameras, and appropriate images are selected to create ortho-images, which are then input into the image diagnostic AI, which outputs each abnormality. Image processing and machine learning are then performed on the output data, and the desired facility condition table is created. Note that the following points should be noted when creating ortho-images to be used with image diagnostic AI.

- Dividing processing units: Divide the flat area into smaller units for processing with the SfM software.
- Setting tie points: In order to improve the curve phenomenon, tie points are set when processing with the SfM software, and the positions where images match are determined by human judgment, and calculations are then performed.
- Taking photos with a high degree of overlap: Increase the degree of overlap and side lap, and increase the number of shooting courses.
- Taking photos from a direct angle: To prevent image distortion, photos should be taken from a direct angle to the facility in order to derive accurate measurement values.

C New technology for repairing irrigation facilities

Irrigation facilities are consisting of various types and materials, but the target types of structure are earth dams, head works, open canals, and revetments, and the materials are soil materials, concrete, precast concrete, and other related materials. Machinery such as pumps and metal structures like steel gates are not included here.

(1) Earth dam countermeasures

In cases of restoration and repair methods for existing earth dams, damaged areas of the embankment, such as cracks at the top and sliding and bulging of the upstream and downstream slopes, are often removed and re-filled.

When reinforcement work is required, Table C.1 shows the combination of reinforcement methods for deformations occurring in fill dams and the causes of the deformations.

Table C.1 Reinforcement methods for deformation of fill dams (MAFF. 2020)

Cause	Deformation	Embankment hold-down work	Surface water-proofing work	New drain construction work		Improvement work	
				Horizontal drain	Vertical drain	Embankment/ ground improvement	Cut-off drain
Lack of required safety factor	Sliding failure of embankment	○	△	△	△	○	△
Special characteristics of ground and embankment zoning	Sliding failure of embankment	○	△	△	△	○	△
	Deformation other than sliding failure	○				○	
Deterioration of filter function (permeable side)	High infiltration line and unstable	○	○	○	○	○	○
Change in groundwater condition of surrounding ground	High infiltration line and unstable	○	○	○	○	○	○
Change in infiltration line (rising, lowering)	Occurrence of leakage from downstream face of embankment and boundary with ground	○	○	○	○	○	○
	Piping		○	○	○	○	○
Deterioration of filter function (piping side)	Occurrence of leakage from downstream face of embankment and boundary with ground		○	○	○	○	○
	Piping		○	○	○	○	○
Lack of strength (low resistance to liquefaction)	Large deformation due to liquefaction	○	○	○	○	○	○

When using the fill embankment method, materials may be obtained by excavating the ground inside the reservoir. If materials from under the reservoir are used, they have a high water content and problems with strength and workability, so a certain proportion of good quality soil such as crushed stone is often added to adjust the grain size.

Figures C.1 to C.3 show schematic diagrams of fill dam reinforcement methods (MAFF. 2020).

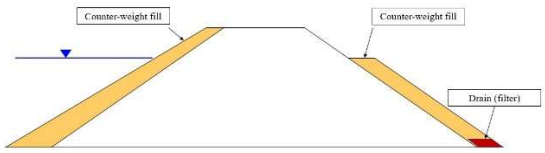
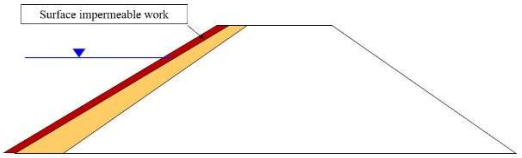
	Embankment method	Surface impermeable wall construction
Overview		
Constr. method overview	To improve stability, fill the upstream and downstream slopes of the embankment to reduce the slope gradient. Drains or filter materials will be laid at the boundary between the downstream fill and the existing embankment to prevent cracks from occurring and the rise of the seepage line.	After excavating and removing the surface layer of the upstream slope of the embankment, a waterproof zone (made of good quality soil, asphalt, rubber sheet, etc.) is constructed to lower the seepage line inside the embankment and suppress the rise in pore water pressure.
Effects	The main purpose is to reinforce the embankment against sliding and the resulting subsidence, and little effect in reinforcing the embankment against liquefaction can be expected.	This is to reinforce the embankment body against liquefaction, but does not have a reinforcing effect against liquefaction of the foundation. In order to promote the lowering of the seepage line, drainage from the drain is necessary.

Figure C.1 Embankment construction and surface impermeable wall construction

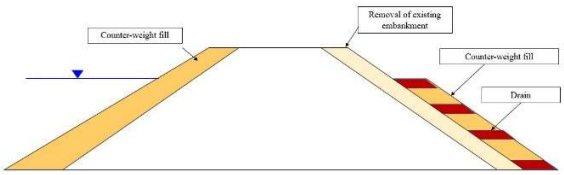
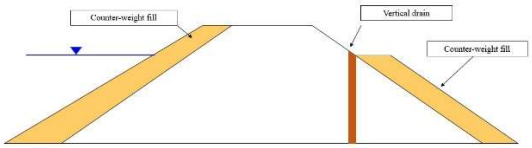
	Horizontal drain	Vertical drain
Overview		
Constr. method overview	Install a horizontal drain downstream of the embankment to lower the seepage line inside the embankment and suppress the rise in pore water pressure. If the installation of the drain causes damage to the embankment, replace the embankment material and install a new drain. Use a filling embankment as well if necessary.	Install a vertical drain downstream of the existing embankment to lower the seepage line inside the embankment and suppress the rise in pore water pressure. If necessary, use a filling embankment in combination.
Effects	This is intended to reinforce the embankment body against liquefaction, but does not have any effect on reinforcing the foundation against liquefaction.	This is to reinforce the embankment body against liquefaction, but does not have a reinforcing effect against liquefaction of the foundation. Drainage is necessary to promote lowering of the seepage line.

Figure C.2 Drain installation work

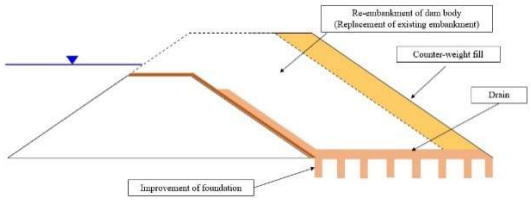
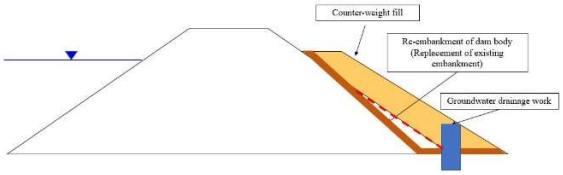
	Ground improvement + embankment replacement (pressure embankment)	Cut-off drain + pressurized embankment
Overview		
Constr. method overview	Liquefaction of the foundation can be suppressed by ground improvement (sand compaction, vibro compaction, etc.) of the sandy ground. Depending on the ground improvement method, there is a possibility that the embankment may be damaged, so it may be necessary to replace part of the embankment (including filling with soil) and re-build the embankment after ground improvement.	Install groundwater drainage works such as cut-offs in the sandy ground to prevent liquefaction of the foundation. If necessary, perform grouting of the foundation and filling embankment work on the upstream and downstream slopes of the embankment. If there is a difference in particle size between the old embankment, new embankment, and drainage material, and the difference in permeability coefficient becomes large, a phenomenon occurs in which the descending infiltrating water is blocked at the top of the interface (capillary barrier), the filling embankment becomes easily saturated, and the stability of the slope may be affected.
Effects	This is intended to reinforce the foundation of the embankment against liquefaction, but depending on the scale of replacement of the embankment, it is also possible to reinforce the embankment against liquefaction.	This is intended to reinforce the foundation against liquefaction, but depending on the scale of the embankment replacement, it is also possible to reinforce the embankment against liquefaction.

Figure C.3 Improvement works

Other methods for repairing earth dams or reservoirs include the bentonite sheet method, the bentonite mixed soil method, and the sandbag layering method.

Bentonite sheet method

The bentonite sheet method is a method for repairing reservoir embankments that uses a bentonite-based waterproof sheet to achieve water impermeability. Bentonite-based waterproof sheets are essentially made of bentonite, an inorganic natural clay mineral, and have excellent long-term durability, with published research results indicating durability for tens of thousands of years. While there are differences in the structure and bentonite shape of each product, they are produced in factories as waterproof sheets in which bentonite is held together by woven or

nonwoven fabric or high-density polyethylene resin using needle punching, stitch bonding, adhesives, etc. (Figure C.4).

Bentonite mixed soil method

This is a method of forming a water-impermeable layer by mixing and stirring bentonite with sandy soil and compacting it. It is also used as a water-impermeable layer at the bottom of landfills at waste disposal sites and as a buffer material for geological disposal of radioactive waste. Although the bentonite needs to be stirred, the compaction work is the same as that of general earthworks. The formed water-impermeable layer has excellent water-impermeability and durability like a bentonite sheet, and since it is a soil water-impermeable layer of the same quality as the construction base, it blends well with the construction base. A water-impermeable layer with a certain thickness is expected to reduce the risk of the water-impermeable layer breaking due to earthquakes or subsidence, along with the self-repairing properties of bentonite. In repairing the embankment of an earth dam or a reservoir, in addition to using clay as an alternative to the water-impermeable filling material, a new, more simplified water-impermeable method has been developed in recent years (Figure C.5).

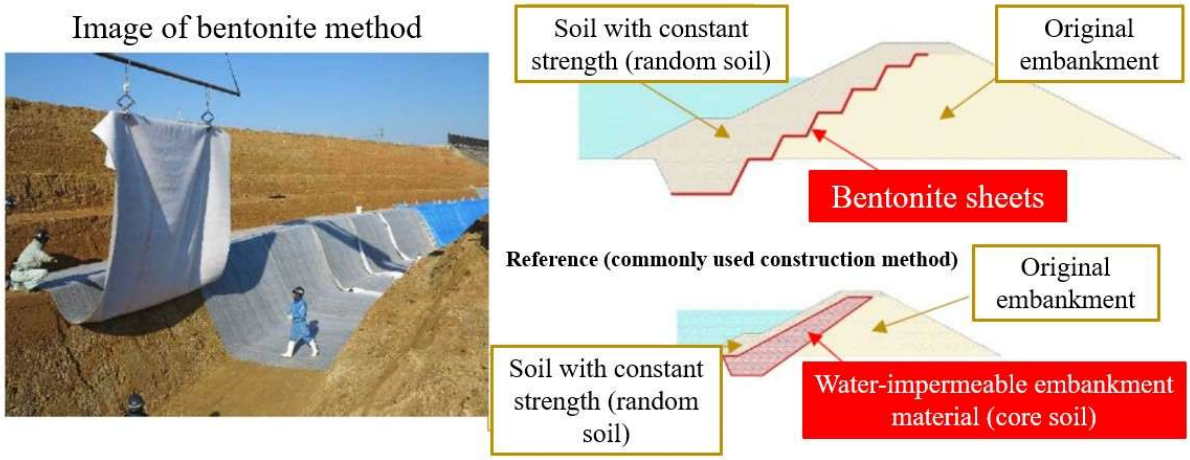
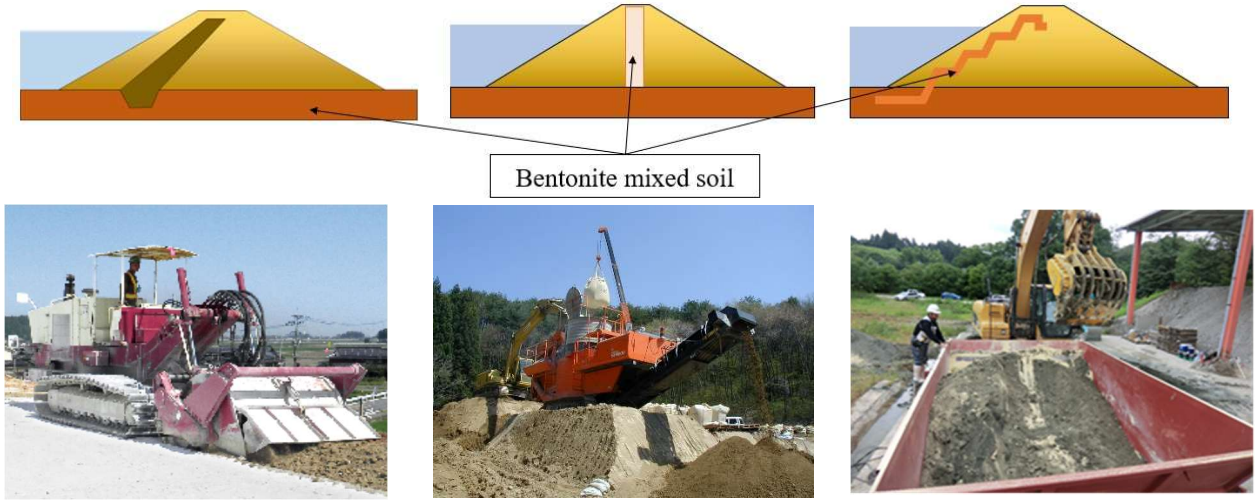


Figure C.4 Outline of the bentonite sheet method



Bentonite mixed soil production status

Figure C.5 Outline of bentonite mixed soil method

Sandbag stacking method

This is a repair method for embankments and earthen channels that can be carried out by WUAs. This method was developed by National Institute for Rural Engineering (NIRE), and uses special large sandbags to easily improve the durability of reservoir embankments, and its safety has been confirmed through large-scale vibration tests. This method consists of (i) large, flat sandbags with tails that provide high reinforcing effect, and (ii) an embankment structure in which these sandbags are piled on the slope so that the inside of the embankment is lower (Figure C.6). This method has been applied to pilot tests in Bangladesh on rural roads that are subject to severe wave action due to flooding, and has shown good results.

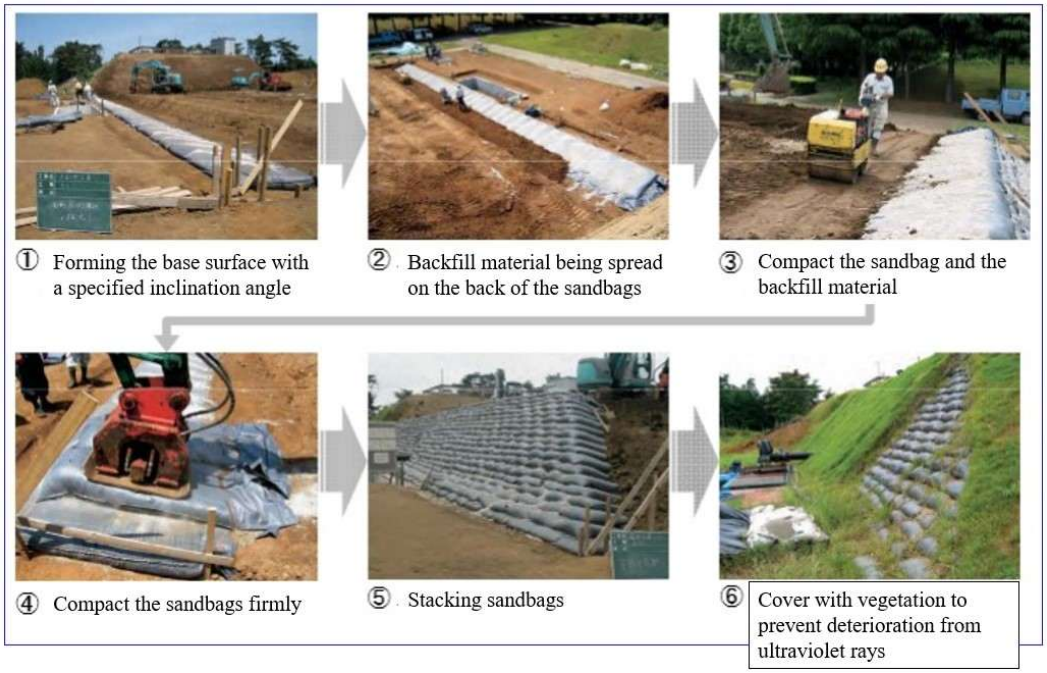


Figure C.6 Construction procedure for sandbag stacking method

In addition to the above, Table C.2 lists technologies related to the repair of earth dams.

Table C.2 Various technologies for repairing earth dams

CAT	Company name	Technology name	Representative photo	Summary of technology	Unit price
Pca method	Yamato Cres Co., Ltd.	Bottom gutter		A precast concrete bottom gutter that is flexible and conforms to the deformation of the ground, and uses a joint construction method that completely stops water.	-
Wire mesh basket	Kyowa Harmotec Co., Ltd.	Steel assembly mesh Guardon		A panel-type cage construction method (large bedding cage construction) that can be freely designed and constructed according to the shape of the site. Since the cage body is mainly composed of diamond-shaped wire mesh, it is highly flexible and can be constructed in places with poor ground such as landslide areas and uneven ground.	-
Water-proofing materials	Volclay Japan Co., Ltd.	Volclay mat (bentonite-based water-proofing mat)		Waterproofing civil engineering material made from the highly water-proof natural clay bentonite. It has a self-repairing function and does not require special technology for construction. It has a proven track record of use around the world as a replacement for natural clay layers in reservoirs, a water-proofing layer in final disposal sites, and an underground water-proofing material. http://www.nisshakyo.gr.jp/note/volc02.pdf	JPY 4,900/m2
Constr. method	Fujita Corp.	Crushing and compaction embankment method (renovation technology for fill dams and reservoir embankments)		Renovation (reinforcement and leakage prevention) of old fill dams and reservoir embankments is carried out by solidifying and improving the bottom mud in the reservoir and effectively using it for embankment soil, and it is a technology that combines embankment renovation and removal and disposal of the bottom mud. https://www.maff.go.jp/j/nousin/sekkei/kanmin/attach/pdf/kanryou-167.pdf	JPY 6,600/m3
Constr. method	Mori Environmental Technology Institute Co., Ltd.	Renovation technology for old reservoirs: Bon Terran method		A technology to renovate and reinforce the embankment by adding and mixing the fibrous mud improvement material "Bon Fiber" and solidification material to the bottom mud of the reservoir or the excavated soil of the embankment, and recycling it into a high-performance ground material. https://chuosangyo.web.fc2.com/sekoutankahikaku27total.pdf	JPY 2,799/m3

(2) Headworks countermeasures

The main countermeasure construction methods for concrete facilities of headworks are shown in Table C.3 (MAFF. 2016).

Table C.3 Main countermeasures for concrete facilities in headworks

CAT.	Method	Details	Main target facility	Required performance
Repair method	Surface treatment methods	Surface coating methods, impregnating material application methods	Weir pillar tops, management bridges, etc.	Improve roughness coefficient, block water leakage, block deterioration factors
	Crack repair methods	Surface treatment methods, filling methods, injection methods	Concrete structure	Block water leakage, block deterioration factors
	Cross-section repair methods	Plastering methods, spraying methods, mortar injection methods, deteriorated section repair methods	Concrete structure	Improve roughness coefficient, block water leakage, remove deterioration factors, improve load-bearing capacity and deformation performance
	Electrochemical methods	Electrical protection methods, desalination methods, re-alkalization methods	Reinforced concrete structure	Remove deterioration factors
	Joint repair methods		Concrete structure	Block water leakage
Reinforce-ment method	Adhesion methods (wrapping methods)	Steel plate adhesion methods, panel adhesion methods, continuous fiber sheet adhesion methods	Reinforced concrete structure	Improved load-bearing capacity and deformation performance, blocking deterioration factors, blocking water leakage, improved roughness coefficient
	Concrete thickening method (wrapping method)	RC wrapping method, PC wrapping method, precast panel wrapping method, spraying method, top surface thickening method, bottom surface thickening method	Reinforced concrete structure	Improved load-bearing capacity and deformation performance
	Replacement method	Partial replacement method, full replacement method	Concrete structure	Improved load-bearing capacity and deformation performance

The following provides an overview of the surface treatment method, crack repair method, cross-section repair method, wrapping method, and replacement method (MAFF. 2015).

Surface treatment method

Surface coating method

This is a method of coating the surface of a concrete structure with organic or inorganic coating materials in order to prevent or block the intrusion of deterioration factors from the surface or cross-section repair area of the concrete structure, improve durability, inhibit the progression of deterioration, and restore the beauty of the structure.

Impregnating material application method

This method involves applying an impregnating material to the surface of concrete to prevent the intrusion of deterioration factors or to impart new properties. Materials are broadly divided into silane-based materials, which form a water-absorption-resistant layer and inhibit the intrusion of moisture and deterioration factors, and silicate-based materials, which are primarily intended to impart alkalinity to concrete and strengthen or densify weak areas of the surface. Furthermore, silicate-based materials are divided into lithium-based and sodium-based. Lithium silicate-based materials form a solid, continuous coating on the surface of pores, solidifying the weak concrete surface and imparting alkalinity to the neutralized concrete surface, improving the corrosive environment for reinforcing bars. Meanwhile, sodium silicate-based materials function by forming insoluble crystals inside pores and inhibiting the intrusion of water and carbon dioxide gas from the outside.

Crack repair method

Crack covering method

This is a method of improving waterproofing and durability by forming a surface coating layer on fine cracks (generally 0.2 mm wide or less). There are methods that cover only the cracked parts and methods that apply the coating to the entire surface. This method has the advantage of being easy to apply and economical when the purpose is to waterproof the surface of cracks with small fluctuations. However, if it is not possible to treat the inside of the crack or if the crack is progressing or has large fluctuations, there is a high possibility that the fluctuations will not be followed and deformation will occur. The materials used vary depending on the purpose of the repair and the environment in which the structure is located, and generally include paint elastic waterproofing material, polymer cement paste, and cement filler. When applying, the method and materials are selected according to the crack width and the progression of the crack. In order to ensure workability, it is necessary to select materials that match the construction conditions because the hardening of the materials differs depending on the outside temperature.

Injection method

This is a method that injects resin-based or cement-based materials into cracks to seal the interior of the cracks and improves waterproofing and durability. Depending on the construction method, this is classified into low-pressure, low-speed injection methods and mechanical injection methods. Currently, the most common method is to use injection equipment to inject at low pressure and low speed with a pressure of 0.4 MPa or less. This method has the following features: (i) the injection accuracy is not affected by the skill level of the worker, (ii) the injection amount is easy to control, and (iii) injection can be performed reliably even when the crack width is as narrow as 0.05 mm at the deepest part of the crack. Materials used in injection methods include resin-based materials such as epoxy resin and acrylic resin, polymer cement-based materials, and cement-based materials. Resin-based injection materials have the following characteristics: (i) they have excellent adhesion to concrete, and can restore the integrity of the structure; (ii) injection materials with the appropriate viscosity and elongation can be selected according to the purpose; (iii) the durability of epoxy resin injection materials has been confirmed to be approximately 40 years in follow-up surveys of actual structures after repairs. Polymer cement-based injection materials also have the following characteristics: (i) they are cheaper than resin-based materials; (ii) their linear expansion coefficient is close to that of concrete; and (iii) they can also be used to prevent rust on reinforcing bars.

Filling method

The filling method is used to repair cracks that are 0.5 mm or wider and where there is no rebar corrosion. The concrete is cut into a U- or V-shape along the crack and the area is filled with repair materials. Materials used include sealants, flexible epoxy resins, polymer cement mortar, etc. If the rebar is corroded, the rust must be completely removed before filling.

Cross section repair method

Plastering method

This method is applied to repair relatively small cross sections, and a plasterer uses a plastering trowel to fill the cross section defect with polymer cement mortar or lightweight epoxy resin mortar. The finished product depends largely on the skill of the craftsman. It is applied to the top of a weir pillar that is not affected by running water.

Spraying method

This method is applied when the repair area is relatively large, and uses a special spraying machine to restore the cross section with a pre-mixed repair material. Generally, after spraying, a plastering trowel is used to finish the surface smooth. There are two types of spraying machines: the wet method, in which a pre-mixed repair material is sprayed, and the dry method, in which powder and water or hardening initiators, accelerators, and other admixtures are separately pumped and sprayed.

Mortar injection method

This method is applied to repair large cross sections, and forms are made to fit the shape of the section to be repaired, and polymer cement or cement mortar with excellent fluidity is pumped in and filled with the formwork. It is applied to vertical surfaces (sides) and undersides.

Repair method for deteriorated parts

This is a common method for areas that are subject to severe conditions of flowing water, such as spillways and fixed weirs. The minimum thickness differs depending on the method. The method must be selected taking into consideration the repair area and direction of construction, and care must be taken not to leave any voids inside. When removing damaged parts, it is necessary to select a method that does not damage healthy parts.

Winding method

Steel plate winding method

This method is expected to compensate for the lack of tensile rebar or prestress by bonding or wrapping a steel plate around the outside of the tensile edge of the concrete member, transferring the shear force between the two and integrating the existing concrete with the steel plate.

Reinforced concrete wrapping method

Reinforcement is achieved by placing reinforcing bars (high-strength column bars, spiral ties, intermediate bars, etc.) around the existing members, pouring more concrete, and increasing the cross-section. The basic condition is that the existing concrete and the new concrete behave as a single unit against external forces.

Textile wrapping method

It is adhered to or wrapped around concrete while being impregnated with an adhesive (room-temperature curing resin such as epoxy resin). Continuous fibers include carbon fiber, aramid fiber, glass fiber, etc. Characteristics of this material include its light weight, the ability to be installed by hand, and its excellent workability, allowing it to flexibly accommodate the complex shapes of structures.

Replacement method

This method is applied to members that have deteriorated significantly due to cracks caused by rebar corrosion and other factors, reducing their strength. After removing the existing members, new members with the required strength are constructed.

Other related technologies for repairing headworks are listed in Table C.4.

Table C.4 Various technologies for repairing headworks

CAT	Company name	Technology name	Representative photo	Summary of technology	Unit price
Blocks	Giken Kogyo Co., Ltd.	Beehive		Beehive is a highly stable block developed for multipurpose use as a single unit or structure.	-
Blocks	Nikken Kogyo Co., Ltd.	Footing block method		This method can be used in a variety of local conditions, including the "Stone Block," a flat type suitable for layered construction, the "Triple Block," a three-dimensional type with relatively large roughness that can be used for both layered and random stacking, and the "Lacuna IV."	-
Blocks	Landes Co., Ltd.	Square		Footing block with fish nest function that maintains the function of footing while also protecting the ecosystem of fish and other creatures.	-
Blocks	Landes Co., Ltd.	Energy-reducing bed protection block		A flow velocity reducing bed protection block suitable for the downstream side of a gently sloping drop work.	-

(3) Open canal countermeasures

Repair methods for reinforced concrete open canals are broadly divided into surface treatment methods, crack repair methods, cross-section repair methods, and joint repair methods. Surface treatment methods are further divided into surface coating methods and surface impregnation methods. Surface coating methods are further divided into inorganic coating methods, organic coating methods, panel methods, and sheet methods (Figure C.7) (MAFF. 2015).

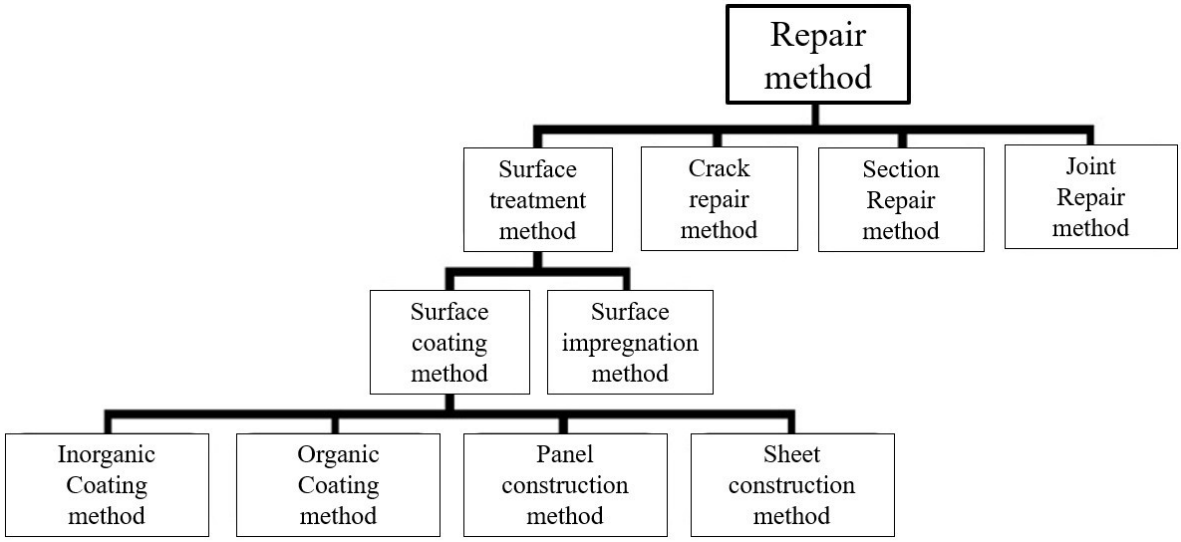


Figure C.7 Classification of repair methods (MAFF. 2015a)

Figures C.8 shows schematic cross-sectional diagrams of repair methods used alone.

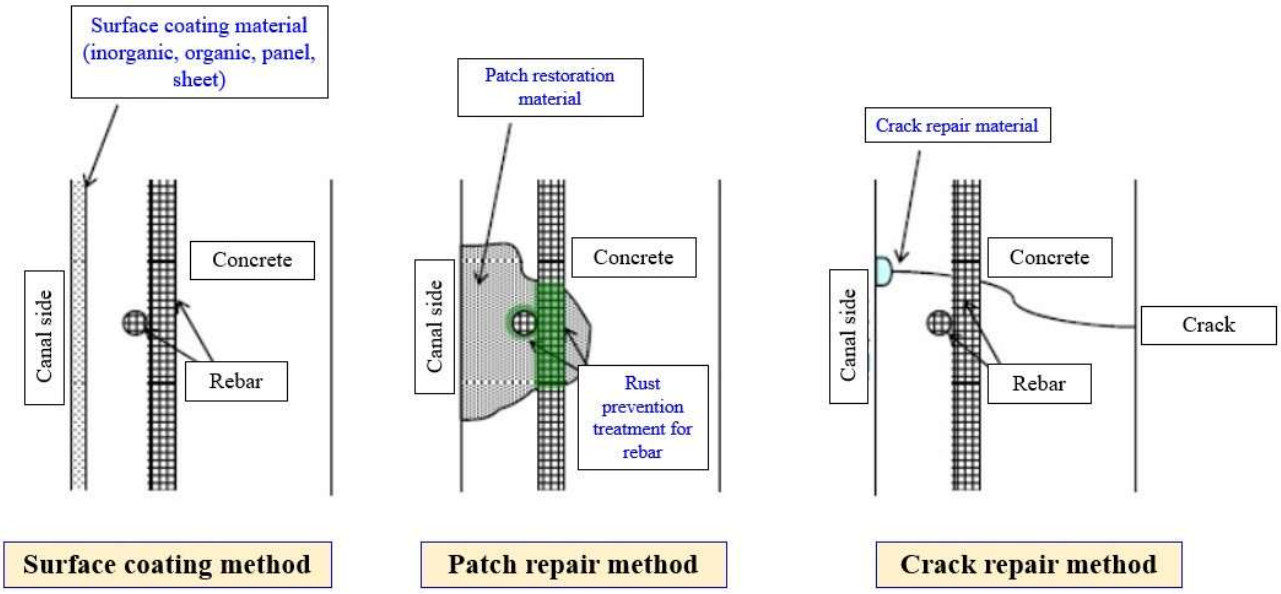


Figure C.8 Conceptual diagram of various repair methods (examples of individual construction methods)

The main construction methods are outlined below.

Surface treatment method

This is a method that prevents or inhibits the intrusion of deterioration factors into concrete. Surface coating methods, one type of surface treatment method, involve applying an organic or inorganic coating material (mainly adhesives) to the surface of concrete. The effectiveness and application vary greatly depending on the type of adhesive. Surface impregnation method involves gradually impregnating the surface of concrete with a material that has a deterioration inhibition effect, modifying the concrete's structure and giving it special functions, and can use both organic and inorganic materials. Compared to surface coating method, surface impregnation method lacks the immediate effect, but has the characteristic of allowing the structure to become more dense over a long period of time. Each method can be classified according to material as shown in Table C.5 (Japan Society of Civil Engineering, 2012).

Table C.5 Materials for surface treatment methods

CAT.	Details		Substance name
Surface coating	Organic	Thermoplastic	Acrylic resin (MMA), fluoro-resin, vinyl acetate resin (woodworking glue), polyvinyl alcohol (for interleaf paper, plywood), ethylene-vinyl acetate resin (EVA), polyamide (nylon), cellulose (representative: cemedine), polyvinyl chloride resin, water-based polymer-isocyanate (for wood), α-olefin resin (polyethylene, etc.)
		Thermosetting	Epoxy resin, urea resin (urea resin), melamine resin, vinyl ester resin, silicon resin, polyurethane resin, polyester resin, polyaromatic resin
		Thermoplastic elastomer	Silicone resin, acrylic rubber resin, polybutadiene rubber resin, chloroprene rubber resin, chloro-sulfonated polyethylene resin, SBR (styrene butadiene rubber) resin, polyurea resin, butyl rubber
		Natural polymer	Asphalt
	Mixed type		SBR polymer cement, epoxy polymer cement, acrylic polymer cement
	Inorganic		Cement, bentonite
Surface impregnation	Organic		Silicon (silane)-based, non-silicon-based
	Inorganic		Cement crystal growth material

Surface treatment methods are divided into a primer, intermediate coat, and top coat, with most intermediate coats being applied in 2-3 layers and top coats being applied in 1-2 layers. For old concrete, cross-section repair is carried out to a depth of about 5-20 cm, but for new concrete, a thin layer of putty may be applied. There are also surface treatment methods that do not require putty. The intermediate coat performs the main function, and the top coat is intended to ensure weather resistance and aesthetics. Surface impregnation materials are often applied only as an intermediate coat.

- Primer: A primer is a layer that is applied to improve adhesion. A material with high adhesive power and high permeability is used. There are two types: one that is applied by wetting the base and one that is applied after drying.
- Putty: Putty is a paste-like material used to fill depressions and gaps and ensure flatness.
- Undercoat: The undercoat is the part that performs the main function of preventing the intrusion of deterioration factors.

- Topcoat: The topcoat is a finishing layer that is intended to protect against UV rays, prevent dirt, and give a glossy finish. When applying multiple layers of materials that contain organic solvents, the time it takes for the organic solvent to evaporate must be strictly observed, otherwise adhesion problems will occur. It is also necessary to take into consideration that each material has a set pot life, workable temperature, and humidity. Pot life is the time that the material can be used after the base agent and hardener are mixed. Anything that has passed the pot life cannot be used, and the pot life differs between summer and winter, and even with the amount mixed at one time.

Surface impregnation method

This is one of the surface protection methods. It aims to restore or improve the durability of concrete by modifying the structure of the surface layer of concrete and imparting performance that exerts a specified effect. It is a method in which a surface impregnation material is impregnated from the surface of concrete.

- Materials: Surface impregnation methods vary depending on the repair purpose, and silane-based or other surface impregnation materials are used.
- Methods: Depending on the type of material used, there are three main types: those that use silane-based materials, those that use silicate-based materials, and those that use other materials. The method can be brush application, roller application, spraying, etc., depending on the type of material and the construction environment.

Panel method

This is a surface coating method that covers the surface of an open canal by installing panels as one of the components of the coating, with the aim of preventing the intrusion of deterioration factors such as carbon dioxide, chloride ions, moisture, and hydrogen sulfide, blocking water leakage, and improving water permeability.

- Materials: Panels include reinforced plastic composite panels, rigid polyvinyl chloride panels, resin concrete panels, and fiber-reinforced concrete panels.
- Construction method: This method can be used for a wide range of needs, from repairing open canals to minor reinforcement. Depending on the method of installation on the existing canal structure, it is classified into adhesive and anchor fixing methods.

Sheet method

This is a surface coating method that covers the surface of an open canal by installing a sheet as one of the components of the coating, with the aim of preventing the intrusion of deterioration factors such as carbon dioxide, chloride ions, moisture, and hydrogen sulfide, blocking water leakage, and improving water permeability. There are two types of sheet method: FRP sheet method and inorganic lining sheet method.

- Materials: Organic, FRP (fiber reinforced plastic) or EVA (ethylene vinyl acetate) resin.
- Construction method: The construction method involves applying an adhesive material to the surface of the open canal and adhering the sheet. The FRP sheet method has the ability to conform to cracks, but the inorganic lining sheet method has a protective layer made of inorganic materials on the surface of the sheet

to prevent external damage, so it has little ability to conform to cracks.

Crack repair method

This is used to repair cracks with the aim of preventing the intrusion of deterioration factors such as carbon dioxide, chloride ions, moisture, and hydrogen sulfide. When repairing cracks in open canals, it is necessary to select an appropriate method by taking into account the cause and condition of the cracks.

- Materials: The methods vary depending on the purpose of repair and the installation environment of the existing canal, but like surface treatment methods, inorganic (polymer cement-based materials, etc.) and organic (epoxy resin-based materials, etc.) materials are used. When selecting materials, the characteristics of each material must be fully considered.
- Methods: There are three types of construction methods: the crack covering method, the crack injection method, and the crack filling method. These are applied alone or in combination depending on the crack width and repair purpose, etc.

Cross section repair method

This is a method of filling the missing or removed parts with repair materials, with the aim of repairing concrete that has been damaged by corrosion expansion of internal rebar, cracks caused by alkali aggregate reaction, etc., repairing areas where concrete has been removed in blocking deterioration factors, and repairing areas where concrete containing deterioration factors such as chloride ions has been removed.

- Materials: Inorganic (polymer cement materials, etc.) and organic (polymer mortar, etc.) materials are used. When selecting materials, the characteristics of each cross-section repair material must be fully considered.
- Methods: There are three types of construction methods for cross-section repair: plastering, spraying, and filling.

Joint repair method

This is a method for repairing joints that have leaks due to deterioration or loss of joint material, by cutting the existing joint and filling (inserting) new joint material, or by covering the surface of the existing joint material with a covering material.

- Materials: Elastic sealants (silicon-based, modified silicone-based, and polyurethane-based), film-based materials (aluminum film, fluorofilm, etc.), organic materials (epoxy resin, polyurethane resin, etc.), and rubber-based materials (ethylene propylene rubber, etc.)
- Methods: The methods include the joint filling method, joint covering method, and joint molded rubber insertion method, of which joint covering methods include painting, sheet (tape) application, and sheet fixing.

Reinforcement method

The method must be designed and constructed taking into consideration the strength of the target components, construction constraints, and the construction environment.

Adhesive method

The steel plate/panel adhesive method is a method of attaching steel plates or panels to the surfaces of concrete members that are primarily subjected to tensile stress, thereby improving their bending strength and shear strength. The continuous fiber sheet adhesive method is a method of attaching continuous fibers in one or two directions to the surfaces of concrete members that are primarily subjected to tensile stress. The adhesive bonds and integrates the sheet-shaped reinforcement material with existing members, thereby improving their bending strength.

Replacement method

This is a construction method in which members with reduced strength are demolished and replaced with members that have the necessary strength. Since there is a risk that the safety of the structure will be reduced by removing the members, it is necessary to ensure safety by using temporary materials, etc., during the removal of the members.

Thickening method

This is a method of strengthening existing concrete by bonding and integrating mortar, concrete, or reinforced concrete onto the surface of the existing concrete, thereby increasing the cross section of the component and the amount of rebar. When reducing the internal cross section of a canal, it is necessary to thoroughly consider the hydraulics.

In addition, methods being tried out for extending the lifespan of concrete structures when building new structures or replacing existing ones (submersion curing method) are those to suppress alkali aggregate reaction (ASR), methods to prevent spalling using continuous fibers, and tough mesh methods. Among them, the tough mesh method is shown below.

Tough mesh method

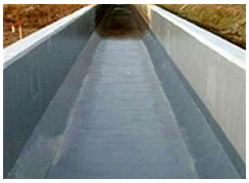
This is a spalling prevention method in which continuous fibers are molded into sheets using resin and attached with an adhesive. Continuous fibers that can withstand concrete spalling are thinly coated with weather-resistant acrylic resin, and the sheet is attached with an adhesive with excellent strength, so the anti-spashing effect can be maintained for long periods even outdoors. As it is in film form, it is thin and light, making it easy to work with. Applicable ranges are concrete surfaces where the base material does not break when the adhesion strength test is 1.5 N/mm^2 or less, temperatures are 5 to 40°C, humidity is 85% or less, concrete surface moisture content is 5.5% or less, and places that are not worn down (places not exposed to running water).

Other related technologies for the repair of open canals, including the rehabilitation of earth canals, are listed in Table C.6.

Table C.6 Various techniques for repairing open canals

CAT	Company name	Technology name	Representative photo	Summary of technology	Unit price
Blocks	Kyowa Concrete Kogyo Co., Ltd.	Simple base		Three types of solid blocks are integrated with steel wires and connected with metal fittings, making it highly flexible. The covering soil is continuous with the ground, ensuring moisture supply and promoting root establishment. https://chuosangyo.web.fc2.com/sekoutankahikaku27total.pdf	300 type: JPY 8,430/m2 350 type: JPY 9,510/m2
Blocks	Maruei Concrete Kogyo Co., Ltd.	Prefab fish nest block for canals		Prefab fish nest block for canals that takes into account the aquatic biological environment of fish, aquatic organisms, insects, etc.	-
Embedded formwork	Aso Shoji Co., Ltd.	AS form method		A method of repairing, renovating, and preventing corrosion of concrete using highly durable buried formwork material made of resin concrete.	-
Pca method	Landes Co., Ltd.	FT flume		Large precast three-sided canal. Can be constructed on only one side using the L-shaped type. Can be combined with the eco-waterway method to create an ecosystem conservation area. http://www.shucon.co.jp/ft-1.htm	JPY 63,800/m
Pca method	Maruei Concrete Kogyo Co., Ltd.	TS flume		Three-sided canal with excellent earthquake resistance, water-stopping properties, and flexibility.	-
Pca method	Fukui Prefecture Land Improvement Association	Fish Station		A fish nest manhole for the purpose of preserving the ecosystem, providing a space for aquatic animals, mainly fish, to live in a three-sided concrete canal. As it is a precast product, it is not only environmentally friendly, but also shortens the construction period and saves labor.	-
Pca method	Kyowa Concrete Industry Co., Ltd.	Angled gate culvert		A "gate culvert" that crosses rivers and drainage canals without demolishing them as an alternative construction method to small-span bridges. The "side wall adjustable precast gate culvert" allows the angle of the side wall to be freely changed to suit the site. https://www.pref.saitama.lg.jp/documents/186003/h22-3.pdf	JPY 2,067,450/unit
Pca method	Landes Co., Ltd.	BFS concrete slab		This is a precast deck for constructing a simple deck bridge on a farm road. By using "BFS concrete", an ultra-durable concrete made from blast furnace slag, the resistance to frost and salt damage is significantly improved compared to ordinary concrete, and the life of the structure is extended.	JPY 2,049,000/piece

CAT	Company name	Technology name	Representative photo	Summary of technology	Unit price
				https://www.jst.go.jp/sip/dl/k07/shiryo_20170907-03.pdf	
Wire mesh cage	Kyowa Harmotec Co., Ltd.	Large plated cage frame: Large EG box		Large cage frame with outstanding durability and rigidity. Zinc plating treatment achieves superior durability compared to conventional technology. Furthermore, by providing sufficient reinforcement, it is possible to make each step 1m high, greatly improving workability.	-
Wire mesh cage	Kyowa Harmotec Co., Ltd.	"Labor-saving Cage" Hyperma t SG Type		A technology in which zinc-aluminum alloy pre-plated welded wire mesh, mainly made of φ6mm wire, is assembled into a box shape using coil and bolt connections to form an integrated cage body. It allows the use of soil and sand as the filling material, making it more economical than conventional cage frames.	-
Construction method	Metry Technical Research Institute Co., Ltd.	D-Box Method (Surface Improvement method)		A construction method in which a box-shaped bag filled with crushed stone, etc. is laid under the foundation, and the internal restraint device installed inside the bag maintains the lifting shape at one point, making it possible to increase the bearing capacity of soft ground with an N value of about 1 to more than three times the original ground strength without using cement-based solidification materials.	-
Surface coating	Sekisui Chemical Co., Ltd.	PPS lining method		An organic lining method that applies a UV-curable FRP sheet that hardens in a short time under sunlight or UV lamps to prevent corrosion of water structures such as irrigation canals and overturning weirs, and to prevent wear caused by running water and to follow joints and cracks to extend their life. https://www.pref.ibaraki.jp/doboku/kensa/kanri/07nechis/akoho/documents/a22064.pdf	Sheet: JPY 90,000 /1.5m2
Surface coating	Fronte Engineer Co., Ltd.	FE method (non-destructive repair method)		A non-destructive repair technique that covers the deteriorated surface of a canal with FE-GRC (glass fiber polymer cement mortar) material with the aim of extending the life (effective use) and restoring the function of aging irrigation and drainage canals.	-
Surface coating	Tanaka Civil Tech Co., Ltd.	Tough mortar lining method		A repair and reinforcement technique that covers the deteriorated surface of concrete canal with a highly durable, highly tough fiber-reinforced cement composite.	-
Surface coating	D&D Co., Ltd.	Inorganic sealant Permeate		By sealing the micropores in the concrete and forming a coating on the surface, it prevents the intrusion of water, CO2 gas, etc., and prevents deterioration of the concrete. In addition, since it is a water-repellent inorganic resin, it does not deteriorate due to UV rays, has good water fluidity, and can last for an extremely long time.	-

CAT	Company name	Technology name	Representative photo	Summary of technology	Unit price
Surface coating	SQS Method Association	SQS Method		A method that forms a seamless, strong waterproof coating using ultra-fast curing polyurethane polyurea. https://www.kensetsu.metro.tokyo.lg.jp/jigyo/tech/shingijutsu/pdf/old/0701021.pdf	CVS: JPY 11,350/m2 RT-1: JPY 10,800/m2 WG: JPY 17,885/m2
Surface coating	ADTEC Co., Ltd.	Advantage method		High-performance material "Advantage Red" allows for a thin coating of 2 mm. Although it is a thin coating, it has high compression and adhesion strength and also has elasticity, improving the durability of concrete structures. As a base material, there is Advantage Blue, which can be applied thinly to thickly.	-
Surface coating	Fronte Engineer Co., Ltd.	FE method (non-destructive repair method)		A non-destructive repair technique that covers the deteriorated surface of a canal with FE-GRC (glass fiber polymer cement mortar) material with the aim of extending the life (effective use) and restoring the function of aging canals.	-
Surface coating	Sunrec Co., Ltd.	Resin concrete panel canal restoration method		A 10mm thick resin concrete panel is installed on the inside of an existing canal, and an adhesive is injected into the back of the panel to fix it in place, minimizing the loss of the canal cross-sectional area while restoring the water flow function of the existing canal through the smoothness of the panel surface. https://sagashiba.jp/products/11	Lower limit: JPY 15,000/m2 Upper limit: JPY 16,500/m2
Surface coating	Daitai Kako Co., Ltd.	Airtight ND method (FRP lining method)		A method of covering with soft FRP lining. The highly durable material has been confirmed to last for over 27 years. It improves adhesion and conformity to the base, peel resistance, and strength retention, and improves workability and hardening, allowing for cheap construction in a short period of time. https://daitai.co.jp/products/airtight/docs/airtight-price.pdf	Wall section: JPY 14,600/m2 Ceiling section: JPY 17,400/m2 Bottom plate section: JPY 14,000/m2 Other: JPY 21,600/m2
Surface coating	New Tech Co., Ltd.	Naoshitar method		A wet spraying method using high-quality mortar. The mortar has high thixotropy, so there is no dripping during construction and it has excellent thickness application. It also has excellent resistance to abrasion and frost damage, and is used for surface coating of open canals. https://www.midori-kosan.jp/shop/products/detail.php?product_id=45	JPY 8,250/25kg bag

CAT	Company name	Technology name	Representative photo	Summary of technology	Unit price
Surface coating	F-Mol Kogyo Co., Ltd. (Minami gumi)	F-Mol polymer cement mortar		A polymer cement mortar with blast furnace slag and fiber that has excellent resistance to salt damage, chemical resistance, and abrasion. https://www.maintenance.jp/?pid=167219386	JPY 3,575/12.5 kg bag
Surface coating	Sanyu Rec Co., Ltd.	Neptun Lining Canal Method		A surface repair method for all water facilities such as agricultural canals. By spraying fast-curing polyurethane resin, it gives concrete structures properties such as abrasion resistance, freeze-thaw resistance, and crack tracking that inorganic materials do not have, and aims to extend the life of the concrete structure. https://nn-techinfo.jp/technology/200	JPY 11,570/m2
Surface coating	Maeda Kosen Co., Ltd.	PW method		An inorganic surface coating method that uses polymer cement mortar (PW mortar), which has high adhesion and abrasion resistance, to repair deteriorated canals. https://www.jagree.or.jp/publication/pdf/1.pdf	5mm: JPY 9,000/m2 10mm: JPY 11,000/m2

(4) Bank protection method

Revetments are constructed to safely protect levees and riverbanks from erosion caused by flowing water, and their structure consists of slope protection works, foundation works, foot protection works, etc. The outline of each type of work is as follows (Figure C.9).

- Slope covering work: A structure to protect levees and riverbank slopes to make them safe against flowing water and driftwood.
- Foundation work: A structure installed at the toe of the slope covering work to support the slope covering work.
- Foot protection work: A structure installed in front of the foundation work of low-water revetments and embankment revetments to mitigate rapid riverbed scouring caused by flowing water and prevent the foundation work from sinking and soil being sucked out from the slope.
- Crest work: A structure to protect the top of the slope by covering with something equivalent to the slope.
- Crest protection work: A structure to improve the fit between the upper end of the low-water revetment and the land behind it, and to protect the low-water revetment from being destroyed from behind by flowing water.
- Edge retention work: A structure installed at the upstream and downstream ends of the slope covering work to protect the revetment.
- Grinding work: A revetment installed at the upstream and downstream ends of the revetment to improve the fit with the riverbank or other facilities.
- Drain pipe: A drainage pipe installed on a revetment to prevent residual water pressure from acting on the concrete slope covering in areas with high groundwater levels.

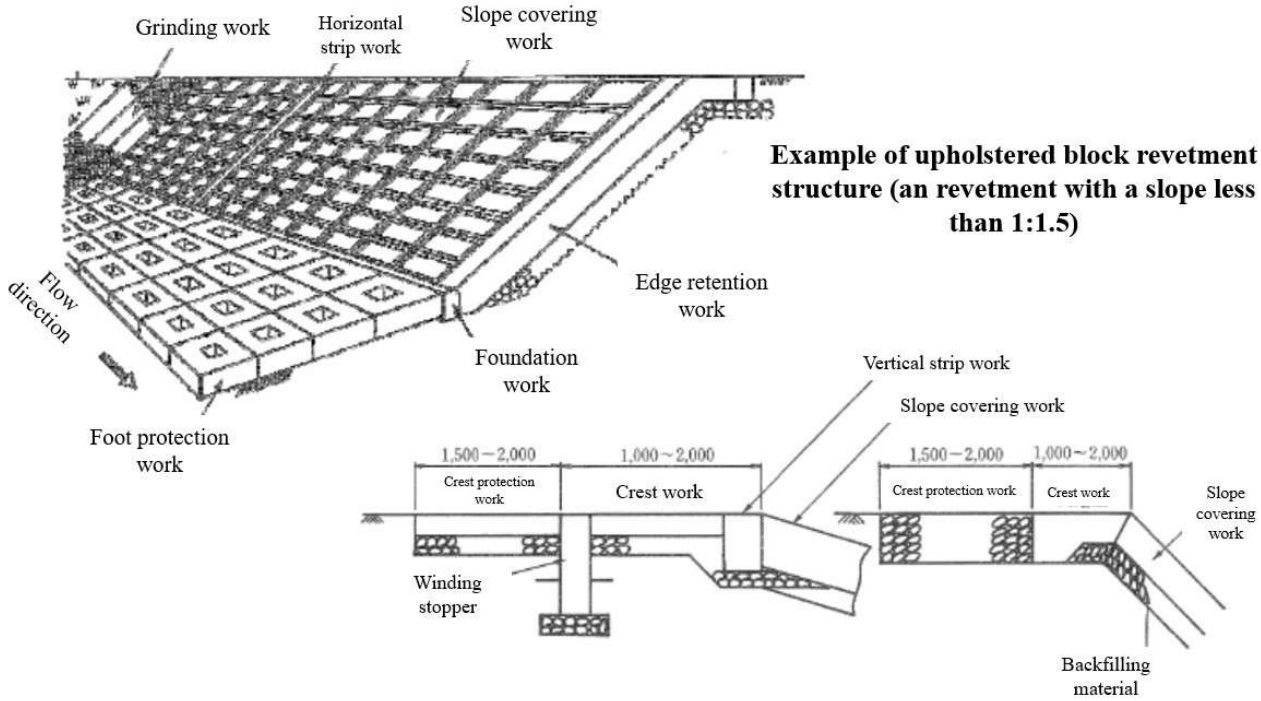


Figure C.9　Example of revetment work (MLIT. 2018)

Table C.7 lists related technologies for repair of revetment of earth dams, headworks and river banks.

Table C.7　Technologies for repair of revetment of earth dams, headworks and river banks

CAT	Company name	Technology name	Representative photo	Summary of technology	Unit price
Geocell Constr.	Asahi Kasei Advance Co., Ltd.	3D Geocell Construction: Geoweb		A geocell product made by compressing durable high-density polyethylene sheets into a continuous honeycomb shape using high frequency waves, and filling the cell structure with filler to create a strong structure. It has been used for slope protection, retaining wall construction, and bank protection construction (reservoirs, waterways, rivers).	-
Block	Landes Co., Ltd.	Basket Box Multi-Stack Type		A multi-natural cage-type bank protection block with excellent permeability for everything from slope protection to bank protection.	-
Block	Maeda Kosen Co., Ltd.	Civic Mat		A block mat made by integrating multiple concrete blocks onto a sheet. A technology that uses heavy construction machinery to lay on river slopes and other areas while significantly improving construction efficiency, preventing soil surface erosion. https://www.mlit.go.jp/report/press/content/001476796.pdf	Material: JPY 5,890/m2 Including auxiliary materials: JPY 6,786/m2 Construction cost: JPY 1,452/m2

CAT	Company name	Technology name	Representative photo	Summary of technology	Unit price
Block	Asahi Kasei Advance Co., Ltd.	Solcomat		A block mat for slope protection and erosion prevention. It is made by gluing and fixing a uniquely shaped concrete block onto a filter cloth made of high-strength synthetic fibers. It can be lifted and laid using heavy machinery, which saves labor and shortens the construction period. https://www.mlit.go.jp/report/press/content/001476796.pdf	Product: JPY 5,890/m2 Including auxiliary materials: JPY 6,605/m2 Construction cost: JPY 775/m2
Block	ENV Engineering Co., Ltd.	Block net		The block net method is a large soil covering block or tension block that has a large installation area of 4m2 per block compared to conventional blocks and is easy to construct. Small blocks are fixed to a wire mesh to create gaps, and the random arrangement of the blocks makes it difficult for the interfilled soil to flow out.	-
Chemical fiber basket	Taiga Sangyo Co., Ltd.	Super fiber basket		A product made of polyester wire reinforced with resin and used for basket-shaped or flat construction, mainly used for bank protection and bed protection works for irrigation canals, drainage canals, and reservoirs, and slope work for farm roads. Lightweight and resistant to acid and salt, it can be installed more cheaply than coated iron wire basket mats.	-
Wire mesh basket	Kankyo Kogaku Co., Ltd.	Stone net method		A product made by integrating natural stone and wire mesh using a special manufacturing method, which is laid on the slopes and riverbeds of rivers and ponds to cover them with soil. A natural stone-attached wire mesh method that ensures the safety of flood control and also takes into consideration the ecosystem around the water.	-
Wire mesh basket	Kyowa Harmotech Co., Ltd.	Labor-saving flat-lay cage work: Hyper Mat flat-lay type		This technology uses welded wire mesh for the main body except for the cover net, improving the self-supporting property during assembly and the out-of-plane rigidity of the net when filling it with stones, and is a flat-lay iron wire cage-type revetment that achieves labor-saving construction while maintaining the same durability, strength, and flexibility as the conventional cage mat construction.	-
Wire mesh basket	Kyowa Harmotech Co., Ltd.	Labor-saving river cage work: Hyper Mat KM type		A stepped river cage construction method that improves the workability of "basket mats." The issues of the low workability and finished form accuracy of cage mats are resolved by using the Hyper Mat KM type, which has a U-shaped self-supporting main body.	-

CAT	Company name	Technology name	Representative photo	Summary of technology	Unit price
Wire mesh basket	Kankyo Kogaku Co., Ltd.	Stone mat method		A product that integrates a special cage mat and stone net. It is a revetment, bed protection, and foot protection construction method that takes ecosystems into consideration. It can be used for rivers with large sweeping force. It is also possible to use locally generated materials and concrete waste for the filling material.	-

D ICT water management technology

1. Use of ICT technology in water management

To address basic issues in water management like mismatched water demand, it is important to restructure each component of the irrigation system (canal system, organization, order, etc.) in a well-balanced manner according to the local situation.

In carrying out this restructuring, it will become more important to utilize ICT technology for efficient water management. For example, to address current issues, by utilizing ICT technology in addition to improving the function of facilities, it is expected that the burden on water management organizations will be reduced and water use order will be improved while responding to changes in water demand.

When utilizing ICT technology, it is important to consider with stakeholders the future vision of regional agriculture and the state of the canal system and water management system (organization, order, etc.) that supports it, taking into account costs, effectiveness, and efficiency.

If ICT is introduced all at once from the upstream main canal to the fields, it may cause confusion in the organization and order of the current water management system, so it is desirable to introduce it in stages.

ICT water management technology is divided into (1) main water management system (Main-WMS), (2) water distribution management system (Distribution-WMS), and (3) field water management system (Field-WMS).

The followings are examples of the use of ICT technology in water management:

- Remote monitoring of canal systems at the main, branch and terminal levels
- Introduction of remote operation and automatic control systems
- Installation of multi-function automatic water taps and valves in fields
- Interoperability between these systems
- Sharing of water supply and demand information between facility managers and farmers

When introducing ICT systems, the impact and effect of the ICT technologies on the overall water management will vary depending on the level of the target canal system (main canal, branch canal, terminal canal, fields), its scope, and whether or not data is shared between each level. It is desirable to introduce ICT appropriately according to the current state of water management in the region, and it is necessary for stakeholders to thoroughly discuss whether the ICT can be a solution to the issues.

The most ICT-based water management is one in which ICT is used to support (1) the Main-WMS (TM/TC), (2) the Distribution-WMS, and (3) the Field-WMS, together with information/communication and control technology.

The terminal field water management system uses ICT to enable remote monitoring of the water depth at the fields, and remote operation of water supply and drainage valves. The water distribution system realizes efficient water distribution by introducing remote monitoring and control of distribution facilities such as pumping stations managed by WUAs, automating water distribution, and simulating optimal water distribution. A new water management system will be established by utilizing ICT to share information between the water taps and water distribution facilities in paddy fields managed by farmers. At the top of the systems is the Main-WMS that manages regional water using main irrigation facilities. By sharing information aggregated at the branch canal level, it will be possible to link the Main-WMS to water management for the entire river basin (Figure D.1).

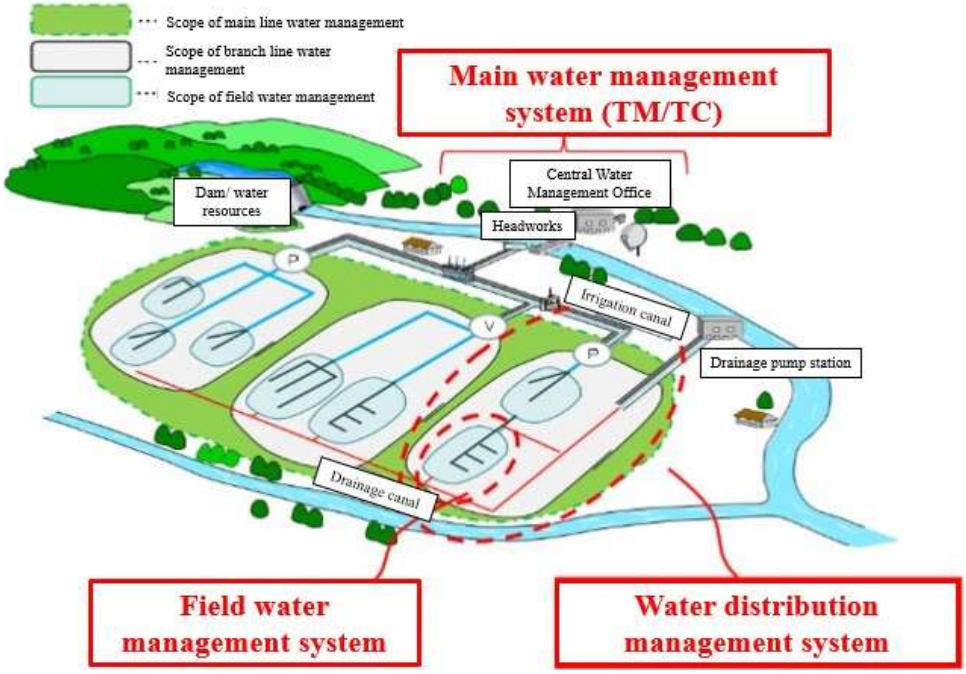


Figure D.1　Conceptual diagram of water management system (NIRE. 2019)

The outline of the water management system for the facility is shown below. Figure D.2 shows the conceptual diagram of the layout of ICT equipment in the most advanced water management system.

(1)　Main-WMS (basic water management system: managed by government agencies or WUAs, etc.)

The Main-WMS is a water utilization system established by a national or local government agency and managed by the government agency or WUA. It consists of water source facilities such as dams, headworks, and pumping stations, and water distribution facilities such as main and branch canals and large-scale diversion works. Water management systems that monitor and operate these facilities vary from standalone systems to complex systems, but basically, the supply side (WUA, etc.) adjusts the amount of water based on a water use plan.

(2)　Distribution-WMS at the branch level (managed by WUAs, etc.)

The Distribution-WMS is a system that takes over from the Main-WMS and delivers water to farm fields, and is managed by WUAs and water user groups (WUGs). Here, this is assumed that the water to the system is supplied from the Main-WMS, and that the water distribution by the water distribution facilities is managed by local WUAs and WUGs. As TM/TC is not installed, it is operated manually according to the water demand of farmers.

By introducing TM/TC, automation of water distribution, and optimal water distribution simulation, it is expected that the patrol and operation labor of WUAs and others who manage the canal system will be reduced, and enabling efficient water distribution management by reducing ineffective discharge.

(3) Field-WMS (managed by farmers)

Water is supplied from the Distribution-WMS at the branch canal level, and farmers manage the water at the field level. Although direct working hours for rice cultivation have decreased due to progress in land consolidation and the use of larger agricultural machinery, there has been no progress in reducing water management working hours. It is expected that the introduction of remote water level monitoring devices and multi-function automatic water taps will reduce the labor required for farmers to patrol and manage water.

It is expected that system linkages, such as enabling automatic operation of pumps depending on the operating status of the multi-function automatic water taps in the field, will reduce ineffective discharges and reduce electricity costs. It is also expected that a semi-demand-driven system will be created by farmers and WUAs sharing information in real time and making water management two-way, allowing WUAs to supply water according to demand of farmers to carry out planned farming.

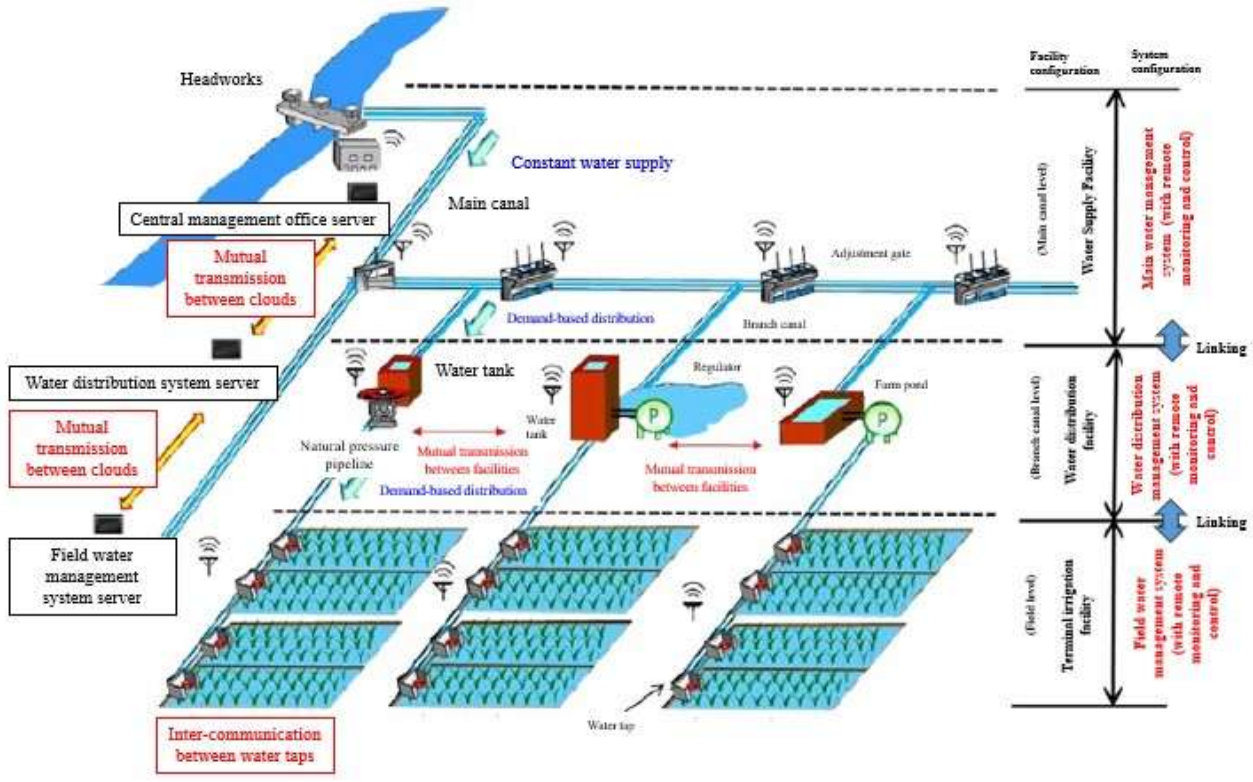


Figure D.2 Schematic diagram of the layout of ICT equipment in the latest water management system (NIRE. 2019)

2. Examples of introducing ICT water management equipment

With support from the Ministry of Agriculture, Forestry and Fisheries, ADCA has introduced ICT water management equipment in Indonesia, Thailand, Vietnam and Myanmar to improve the efficiency of water use. Below, introduce the implementation examples for the main, distribution, and field water management systems.

(1) Main-WMS

Indonesia

In consultation with the Indonesian Ministry of Public Works (PU), the study area was selected as the Way Sekampung irrigation area under the jurisdiction of the PU Musri Sekampung River Basin Management Office (BBWS-MS) in Lampung Province in southern Sumatra.

The Way Sekampung area was developed through a Japanese ODA loan project, and its main facilities include the Batutegi Dam (122 m high, 665 million m^3 effective storage), the Argoguruh Headworks, 328 km of main canals, and 821 km of branch canals, with an irrigable area of 76,000 ha (55,000 ha of actual irrigation area). This study targeted the No. 1 main canal (FC1) that takes water from the Argoguruh Headworks, and the Batang Hari main canal (beneficiary area approximately 10,000 ha) that is diverted from FC1 by the KH2 diversion work. The layout of the TM equipment in the study area is shown in Figure D.3 and Photo D.1.

TM water level gauges, rain gauges and data transmission systems were installed at seven locations: immediately upstream of Argoguruh Headworks, the most upstream of FC1, KH2 Diversion Work (one immediately upstream of the diversion work, one each in Bunut Canal and Batang Hari Canal after diversion), one each in the middle (downstream of KBH8 Diversion Work) and downstream (downstream of KBH12 Diversion Work) of Batang Hari Canal. At the FC1 point, cross-sectional surveys of the canal and flow observations were carried out, and the water level and flow equation (HQ formula) was developed.

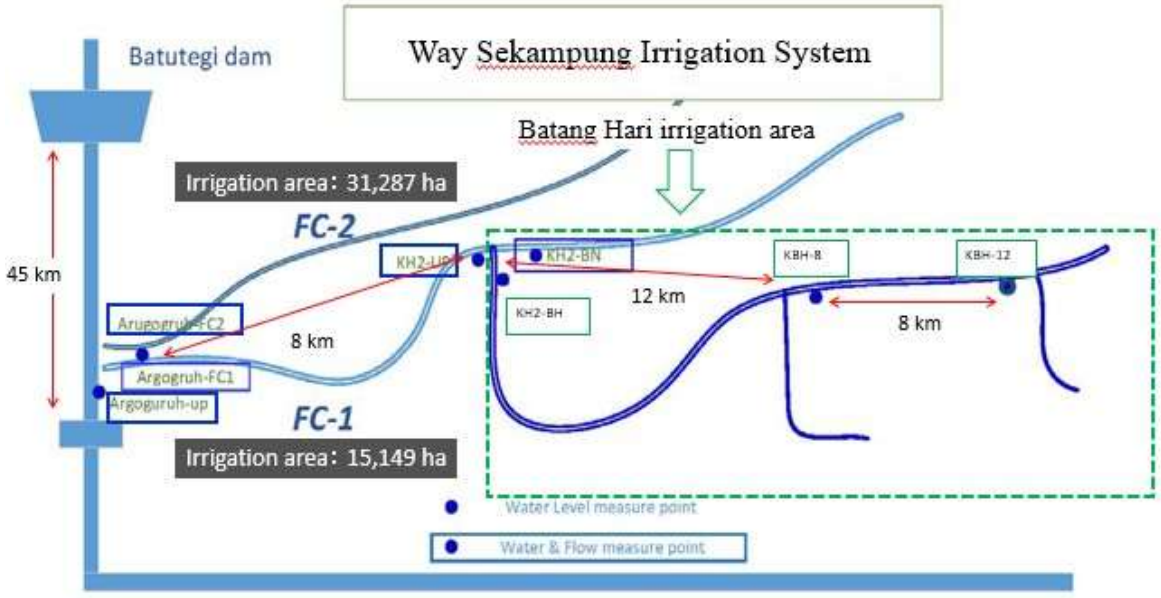


Figure D.3 Schematic diagram of TM equipment installation in Way Sekampung Irrigation System

Photo D.1 TM equipment installed in the Way Sakampung Irrigation System

*) To prevent theft, a communication device, rain gauge, and solar panel are installed on a 5m-high PVC pipe with a diameter of 250 mm. A cage reinforcing bar is inserted into the PVC pipe and reinforced with concrete.

Viet Nam

In Vietnam, in consultation with the Vietnam Academy for Water Resources (VAWR), the survey area was first set to the jurisdiction of the South Nghe An Irrigation Management Company (IMC) in Nghe An Province, followed by the An Hai Irrigation Management Company (IMC) in Hai Phong City. Within the jurisdiction of South Nghe An IMC, TM equipment (SESAME) was installed upstream and downstream of three gates and 14 pumping stations, which are key facilities under the jurisdiction of IMC, as well as three rivers and main canals, including TM equipment provided by the Japan-ASEAN Integration Fund Project (JAIF1) (Figure D.4, Photo D.2).

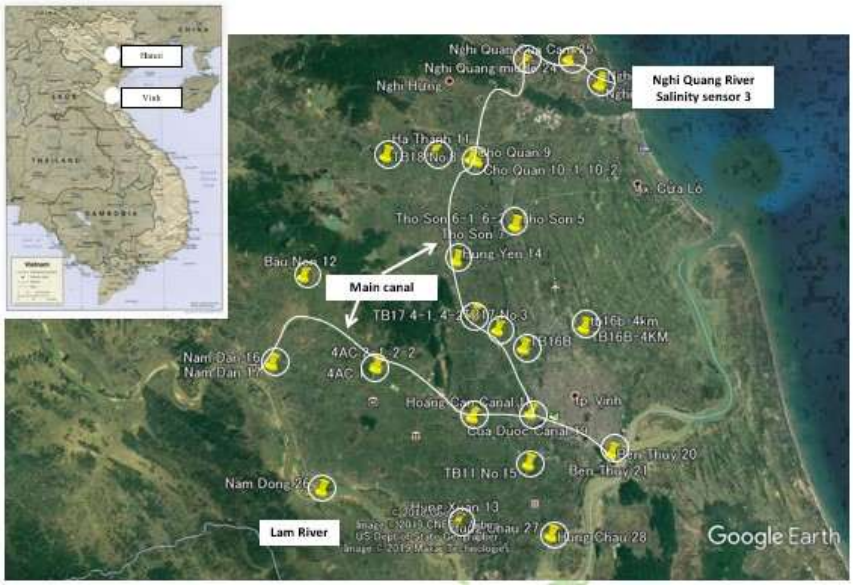


Figure D.4 Location of TM equipment installed in the South Nghe An IMC

Photo D.2 Example of TM equipment installed in the South Nghe An IMC

At An Hai IMC in Hai Phong, TM equipment (SESAME and FARMO) was installed at 15 water intake gates, one river, and one pumping station, including the TM equipment provided by the Japan-ASEAN Integration Fund Project (JAIF2) project (Figure D.5, Photo D.3). The JAIF2 project also covers Hai Duong Province, and TM equipment (SESAME) was installed upstream and downstream of five water intake gates under the jurisdiction of Hai Duong IMC.

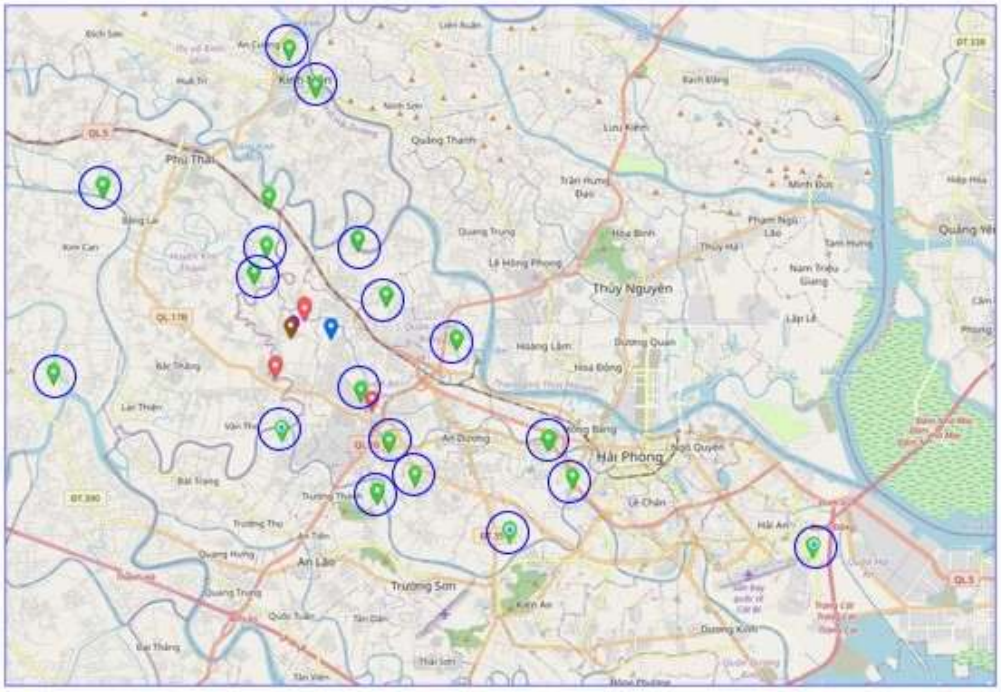


Figure D.5 Location of TM equipment installed in An Hai IMC and Hai Duong IMC

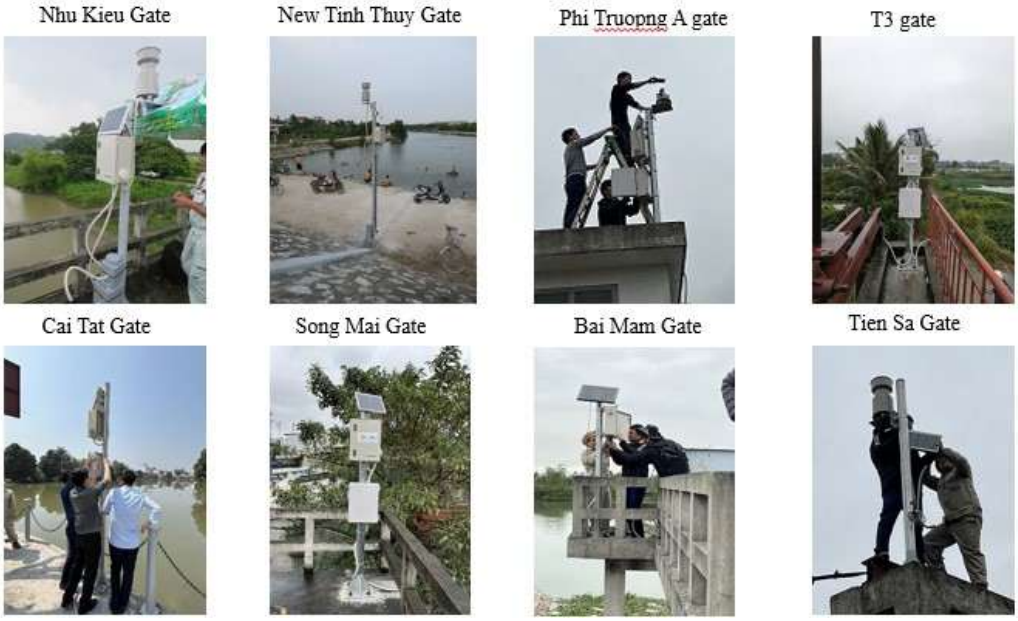


Photo D.3 Examples of TM equipment installed in the An Hai IMC and Hai Duong IMC

Thailand

In Thailand, after consultation with the Royal Irrigation Department (RID), TM equipment (SESAME) was installed at four dams, six rivers, and three main canals in the Bangpra Lake (earth dam, effective storage capacity of 117 million m^3), Prasae Lake (earth dam, effective storage capacity of 248 million m^3), Nong Plalai Lake (earth dam, effective storage capacity of 164 million m^3), and related river basins under the jurisdiction of the 9th Regional Irrigation Office in eastern Thailand, where TM equipment was not functioning (Figure D.6, Photo D.4).

Red circle : water level + rain sensor, White circle: water level sensor

Figure D.6 Location of TM equipment installed in the Bangpra Lake Basin

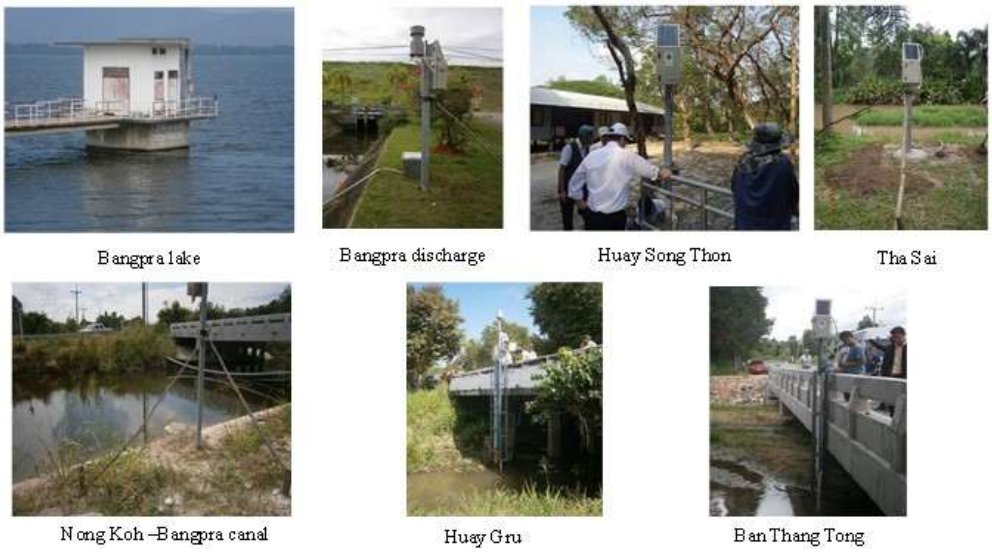


Photo D.4 TM equipment installed in the Bangpra Lake Basin

Myanmar

In Myanmar, after consultation with the Ministry of Agriculture, Livestock and Irrigation, there was a plan to install TM equipment at 23 irrigation dams in the Sittaung River basin with assistance from the MAFF of Japan, as well as through the JAIF2 project in collaboration with Vietnam, but this was suspended due to the military coup in 2021. However, TM equipment (SESAME) was installed at Sinthe Dam (earth dam, effective storage capacity of 176 million m^3) before the coup, so data was obtained (Photo D.5).

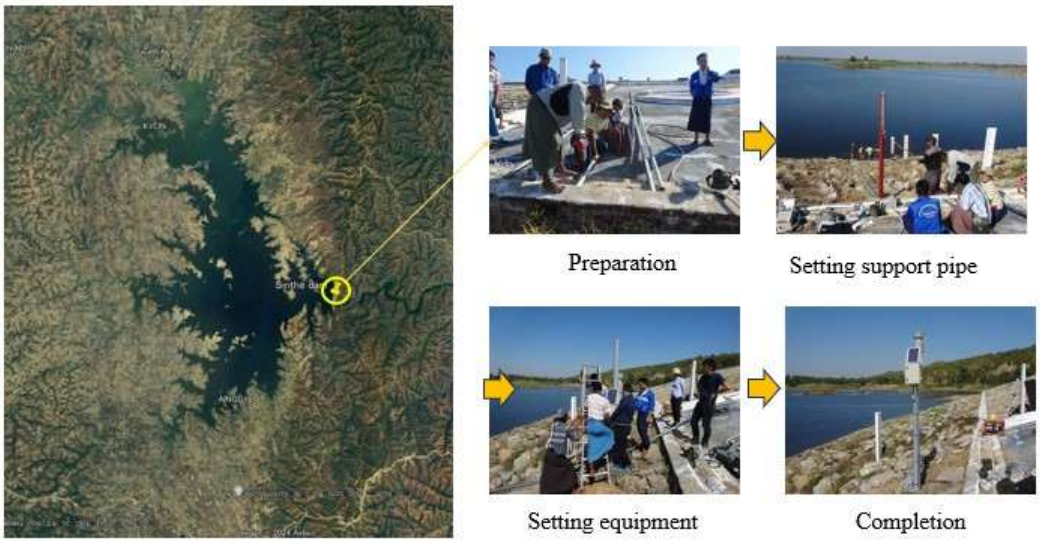


Photo D.5 Location of TM and TM equipment installed at Shinthe Dam

(2) Distribution-WMS

As an example of the introduction of ICT equipment to a water distribution management system, here shows its introduction at the 5th Irrigation Water Management Experimental Station (IWMES-5) under the jurisdiction of

Thailand's RID. At IWMES-5, water is pumped up from the branch canal to a regulating tank. From the regulating tank, water is supplied to the terminal canal within the facility by gravity using gate operation. As ICT equipment, water level sensors are installed at the branch canal and the distribution box of the terminal canal (Photo D.6). Data from these water level sensors is transmitted to a server using the LPWA system via communication devices installed near the IWMES-5 management office.

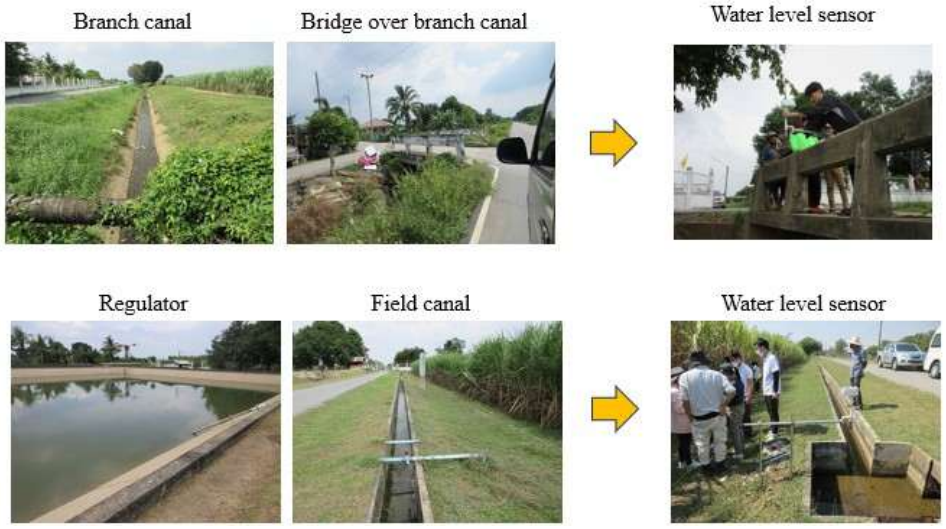


Photo D.6 TM equipment installed at the crossing bridge of the branch canal and at the distribution box from the regulating tank at IWMES-5

(3) Field-WMS

As an example of a field water management system, here shows a paddy field water level sensor and a monitoring camera installed in a farmer's field supplied with water by An Hai IMC in Vietnam (Photo D.7).

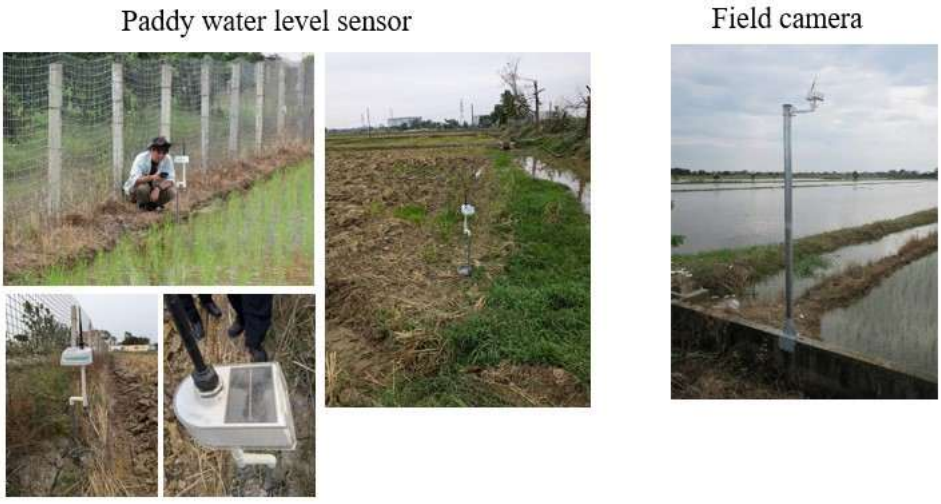


Photo D.7 Sensor and camera for field water management installed in Vietnam

Photo D.8 shows an example of an open-field sensor installed in the test field of Thailand's IWMES-5. The open-field sensor can measure air temperature, soil temperature, illuminance, soil moisture, and salinity (EC).

In both Vietnam and Thailand, data is transmitted using the LPWA system, and a single communication device can transmit data from all sensors installed within a radius of 1.7 to 3.0 km to a server.

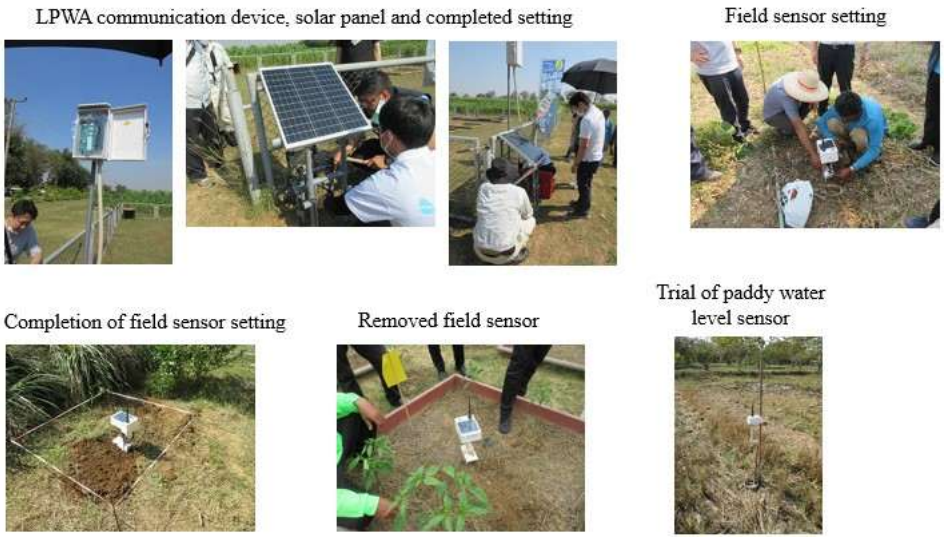


Photo D.8 Sensor for fields installed at IWMES-5 in Thailand

E Cost evaluation by LCC

1. Project evaluation method

In the case of loan aid, it is judged whether the project's effects are commensurate with the costs. This is called the economic evaluation of the project, and there are two types: financial analysis, which is done from the investor's perspective, and economic analysis, which is done from the perspective of national resource allocation. Financial analysis evaluates how much benefit the profit-making business entity will derive from the funds they have invested in the project, while economic analysis evaluates how much benefit the public will derive from the national resources (funds) invested in the project from a national perspective.

For example, in the case of a highway project, a financial analysis would be done from the perspective of the income and expenditure (toll revenues, etc.) of the company that manages the highway, while an economic analysis would be done from the perspective of the convenience the highway provides to the public (reduced travel time, reduced travel expenses, etc.). In either case, the cost-benefit relationship is sought.

[Reference] "External economies" and "external diseconomies"

- In economics, there are two types of externalities: "external economies" and "external diseconomies." "External economies" refer to the positive impact of an economic activity on a third party that does not go through the market, and are also called "positive externalities." Conversely, "external diseconomies" refer to cases where an economic activity has a negative impact on a third party, and are also called "negative externalities."
- For example, in urban development, if transportation infrastructure is improved, shopping malls are opened, and scenery is improved, local residents may benefit from improved convenience of life, higher land prices, and increased employment. This falls under the category of external economies where urban development has a positive impact on third parties.
- The major negative impacts (external diseconomies) that ODA has on third parties are environmental and social issues. For example, dam construction creates a variety of external diseconomies, such as destruction of nature including ecosystems, submergence and compensation of residential areas, relocation issues for residents (in some cases ethnic issues), sedimentation, landslides around reservoirs, and deterioration of water quality. JICA has established "Guidelines for Environmental and Social Considerations" and is working to implement projects that take environmental and social aspects into consideration.

The costs and benefits that occur during the project life (the period from the start of the project to the end of the project's service life) are not simply accumulated, but are discounted at a certain discount rate and compared to their current value (present value). This is because the flow of project costs and benefits spans a long period of time, such as 10 or 20 years, and the decision on whether to invest or not must be made at the present time by comparing them.

For example, the value of 1 million JPY with an interest rate of 6% one year from now is 1.06 million JPY, 2 years from now is 1.12 million JPY, and 10 years from now is 1.79 million JPY. If these are compared in present value, 1 million JPY one year from now is equivalent to 943,000 JPY (1 million JPY x 1/1.06), 2 years from now is 890,000 JPY (1 million JPY x 1/1.062), and 10 years from now is 558,000 JPY (1 million JPY x 1/1.0610).

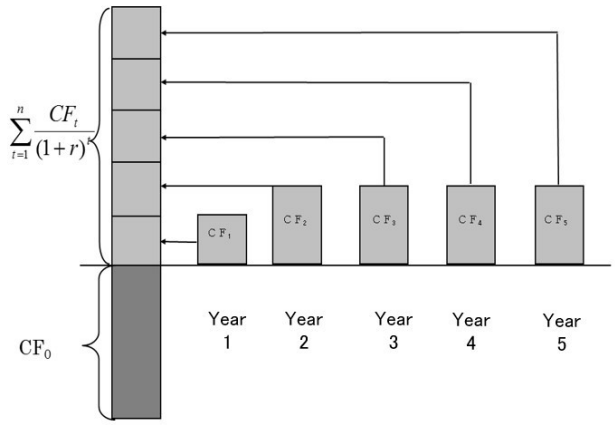
In this way, when the effects of the investment will continue into the future, a characteristic of project evaluation is that it is not evaluated simply based on whether the price is high or low. Investment is the act of giving up a portion of current consumption in order to invest in productivity that will increase future consumption. The future

consumption that investment in a project creates will be enjoyed not only by those who have invested in the project, but also by future generations. It is impossible to evaluate the appropriateness of an investment without incorporating the concept of discount rates (concept of time).

In project evaluation, the present value of benefits and costs are compared, and there are three methods for doing so:

Internal rate of return (IRR)

IRR is the discount rate when the sum of the present value of benefits and costs is equal. The calculation method of the IRR is as shown in Figure E.1 (Excel has an "IRR" function). Below is an example of calculating the IRR.



[Formula]

$$CF_0 = \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t}$$

CF_t : Cash flow in year t
After-tax profit/loss + depreciation + interest paid
CF_0: Initial investment
r : IRR

Year	Cost	Benefit	Balance
1	120		-120
2	12	30	18
3	12	30	18
4	12	30	18
5	12	30	18
6	12	30	18
7	12	30	18
8	12	30	18
9	12	30	18
10	12	30	18
11	12	30	18
計	240	300	IRR 8.1%

Year(y)	Cost	Benefit	Balance	1/(1+r)^y
1	110.96	0.00	-110.96	**0.924692**
2	10.26	25.65	15.39	**0.855055**
3	9.49	23.72	14.23	**0.790662**
4	8.77	21.93	13.16	**0.731118**
5	8.11	20.28	12.17	**0.676059**
6	7.50	18.75	11.25	**0.625146**
7	6.94	17.34	10.40	**0.578067**
8	6.41	16.04	9.63	**0.534534**
9	5.93	14.83	8.90	**0.494279**
10	5.48	13.71	8.23	**0.457056**
11	5.07	12.67	7.60	**0.422635**
	184.92	184.92	0.00	**r= 8.1% (IRR)**

EXCEL function " IRR(value) "

Investment: 120 ('000 USD)
Service life: 10 Year
O&M cost: (Investment) × 0.1
Benefit: 30 ('000 USD)/Year

Figure E.1 Example of IRR calculation

(Example)

A project is viable if its present value (NPV) is > 0. If invest 100 now (year 0) at a discount rate (r) of 8% and receive a benefit of 130 at the end of the first year, the NPV is:

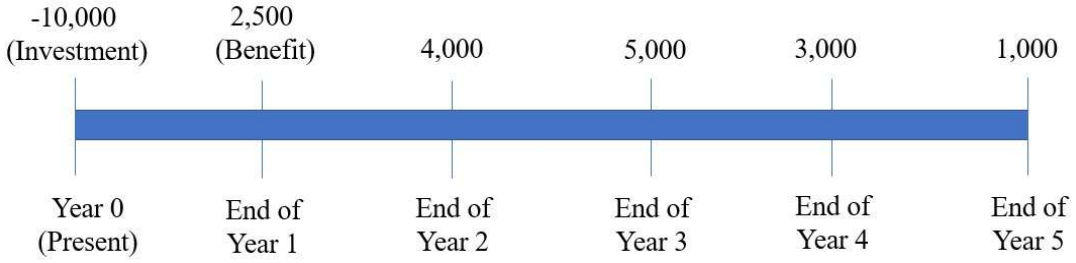
NPV= -100 + 130 / (1 + 0.08) = 20.37 (> 0)

In other words, this investment is feasible. The internal rate of return (R) is as follows:

NPV = 0 = -100 + 130 / (1 + R)
R = 0.30
0 = -100 + 130/1.30＝0

In this case, if R (internal rate of return = 30%) is greater than r (discount rate = 8%), the project is viable.

Question: If the discount rate is 6%, is the following project feasible and what is the internal rate of return?



Answer

Discount rate " r " = 6 %

Net Present Value (NPV) = - 10,000 + 2,500 / $(1.06)^1$ + 4,000 / $(1.06)^2$ + 5,000 $(1.06)^3$ + 3,000 / $(1.06)^4$ + 1,000 / $(1.06)^5$
= - 10,000 + 13,240
= 3,240 > 0 Feasible

NPV = C / $(1 + r)^t$
C : Cost
r : Discount rate
t : Year

NPV (r = 6 %)

Year	Cost	Benefit	Balance	Discount
0	10,000		-10,000	-10,000
1		2,500	2,500	2,358
2		4,000	4,000	3,560
3		5,000	5,000	4,198
4		3,000	3,000	2,376
5		1,000	1,000	747
Total	NPV		6.00%	**3,240**

NPV = 3,240 > 0 : Feasible

IRR = 18.09 %

Year	Cost	Benefit	Balance	Discount
0	10,000		-10,000	-10,000
1		2,500	2,500	2,117
2		4,000	4,000	2,868
3		5,000	5,000	3,036
4		3,000	3,000	1,543
5		1,000	1,000	435
Total	IRR		18.09%	0

IRR = 18.09 % > 6 % : Feasible

Net present value (NPV)

The benefits and costs that will occur during the project life are discounted at a certain discount rate, converted to present value, and then compared to see whether the benefits are greater than the costs. There is an issue of what discount rate to use, but usually a discount rate of 12% is used as the opportunity cost of capital in developing countries (for example, the yield on government bonds). (Excel has a function called "NPV".)

Benefit cost ratio (B/C ratio)

The present value of benefits divided by the present value of costs. If B/C is 1 or more, benefits exceed costs. The discount rate is also an issue in this case.

2. Concept of LCC

The cost of maintaining the function of irrigation facilities is calculated for the scenarios created by examining the countermeasure construction methods, and an economic comparison is performed. Specifically, the process is as follows.

(1) Organize the expenses required for each countermeasure method for each scenario.
(2) Organize the maintenance expenses that are normally required (labor costs for operations, minor repair expenses within the scope of management, electricity charges, oil charges, etc.). Note that if there is no significant difference in maintenance expenses among all scenarios, this can be omitted.
(3) Calculate the residual value of existing facilities in the final year of the period under consideration (which should be 40 years or "construction period + 40 years" in principle) using the concept of depreciation, and organize it as the amount to be deducted from the above expenses.
(4) Convert the above totals for each year of the period under consideration into present value basically using the social discount rate (4% per year), and add them up to determine the function conservation cost.

Regarding the cost estimation of countermeasures, if the construction unit price is determined for each construction method, it is convenient to grasp the approximate cost amount. Table E.1 shows an example of standardization of construction unit price (Myanmar).

Table E.1 Simplified example of construction cost for countermeasure methods

Cost classification	Capital cost (Kyat/feet)			Standard height
	N-lined	Brick	Concrete	
C1	2,240	61,000	91,000	5 feet
C2	2,400	65,000	95,000	
C3	2,600	70,000	100,000	

Note) 1USD=1,506 MMK (Kyat) (December, 2019)

Function conservation costs are calculated as life cycle costs.

For irrigation facilities, the entire process from survey and planning to design, construction, operation, maintenance, renewal and disposal is called the life cycle, and all the costs required during this period are called the life cycle cost (LCC). Generally, LCC is expressed by the following formula:

LCC = Initial construction cost + Maintenance cost + Renewal and disposal cost - Residual value

Until now, irrigation facilities have often been planned mainly by comparing only initial construction costs. However, by introducing LCC evaluation, it becomes possible to make the most advantageous and efficient investment over the life cycle. When calculating LCC, start by considering various cases for the life cycle of an irrigation facility. An important item in calculating LCC is the service life, which is one of the required performances. Service life can be classified into physical service life, economic service life, function service life, and social service life. When calculating LCC, the economic service life is often set as the service life, but in reality, it is determined based on past cases and deterioration prediction data.

As an example, the service life for each type of canal is shown in Table E.2.

Table E.2 Service life and replacement scenarios by canal type

Canal type	Standard service life[*1]	Renovation scenario		
		Description	Frequency	Cost
Concrete canal	40 years	Partial renovation	Once in 20 years	10% of the construction cost[*2]
Masonry canal	30 years	Complete renovation	Once in 30 years	100% of construction cost[*2]
Brick canal	20 years	Complete renovation	Once in 20 years	100% of construction cost[*2]
Earth canal	10 to 20 years	Complete renovation	Once in 15 years	100% of construction cost[*2]

*1 From “Various parameters required for cost-effectiveness analysis of land improvement project - March 2017, Land Improvement Planning Department, Rural Promotion Bureau, MAFF”

*2 Construction cost excludes land acquisition cost.

Source) JIID. 2018

To calculate LCC, it is necessary to calculate the construction, maintenance, and decommissioning costs at current unit prices, allocate the expenses by year, discount them by the social discount rate, and convert them to present value.

The Social Discount Rate (SDR) is the discount rate used in calculating the value of funds spent on social projects. Determining this rate is not always easy and can be subject to discrepancies in the true net benefits for certain projects, plans, and policies. The discount rate is considered an important element of cost-benefit analysis when the distribution of costs and benefits varies over time. This usually occurs when the project under study occurs over a long period of time.

The formula for calculating LCC is shown in Figure E.2.

$$LCC = CI + \sum_{t} \left(CM \times F_{pw} + CR \times F_{pw} - RV \times F_{pw} \right)$$

$$F_{pw}(t) = 1/(1+i)^t$$

Here,

LCC: Life cycle cost

CI: Initial cost (labor cost + material cost + machine operation cost + land acquisition cost)

CM: Operation and maintenance cost

CR: Renovation cost

RV: Residual value

Fpw (t): Present value coefficient (*t* annual discount coefficient) = $1/(1+i)^t$

i: Social discount rate

t: Year

* If (1 - elapsed year/useful life) < 0, then (1 - elapsed year/useful life) = 0 is used.

* Excel has a following function to calculate net present value: NPV(discount rate, value 1:value n)

*See 'Referencer' (1) JIID. 2018. 'Guidelines of canal selection method considering life cycle cost.' The Japanese Institute of Irrigation and Drainage.

Figure E.2 LCC calculation formula

The appropriate discount rate should represent the opportunity cost of other things a project could achieve with the same funds. For example, if a fund is invested in the private sector, which offers a 5% return and is the next best option for using the funds, then 5% would be the social discount rate.

The US government uses a variety of discount rates, but the Office of Investment Management recommends a pre-tax rate of return on private investment of about 7%. In the UK, the Treasury has fixed the social discount rate for the public sector at 3.5%.

The Asian SDR example is shown in Table E.3.

Table E.3 SDR in Japan and Southeast Asia (JIID. 2018)

Social Discount Rate (SDR)		Application
Japan	4%	Current value used in irrigation project
	0%	Japanese government bond yield (2016 - 2017)
Southeast Asia	9%	Value used by Asian Development Bank
	2.6%	Yield of government bonds in Thailand

As an example of LCC calculation, a comparison is made between the case of renovating an existing unlined canal into a block canal and a concrete canal. In this case, the canal cross section is the same for each type, and the construction cost is based on Table E.1. The evaluation period is 40 years, and the SDR is 4%. The service life is 10 years for unlined canals, 20 years for block canals, and 40 years for concrete canals, and they will be replaced when their service life is reached. The annual maintenance cost is 30% of the construction cost for unlined canals, 10% for block canals, and zero for concrete canals.

The calculation results are shown in Figure E.3. In the figure, the unlined canal has a short service life and high maintenance cost, but the LCC is the smallest because the construction cost is low. In comparing block canals and concrete canals, the construction cost is low for block canals, but the maintenance cost is high, so the LCC is lower for concrete canals. In other words, when comparing LCC, concrete canals are more advantageous than block canals.

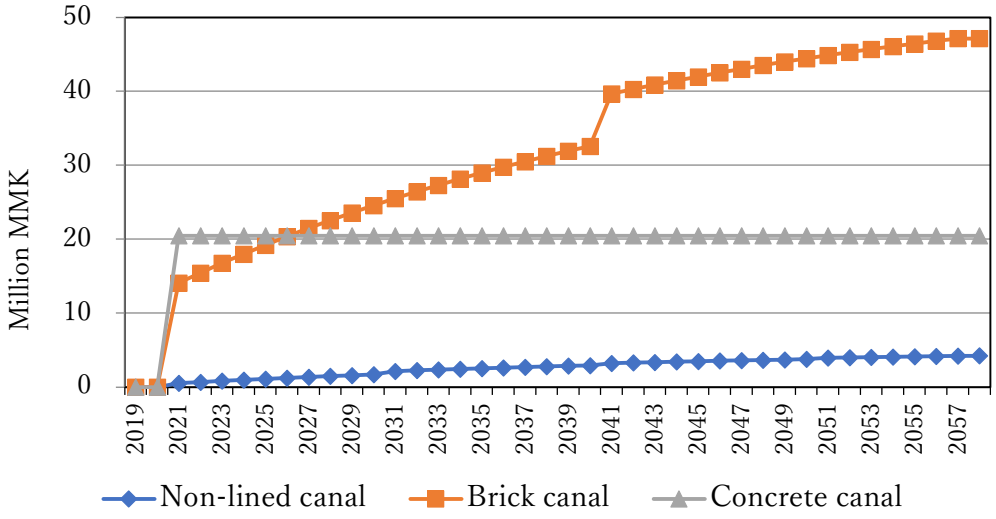


Figure E.3 Comparison of LCC for unlined canals, block canals, and concrete canals

Figure E.4 shows an example of an economic comparison of general function conservation costs. In this figure, Scenario I is the most advantageous. The reason that costs fall in the final year in all scenarios is because the residual value of the facility is deducted as a benefit. The longer the remaining lifespan, the greater the residual value, so Scenario II, which has a longer remaining lifespan, is more advantageous than Scenario III.

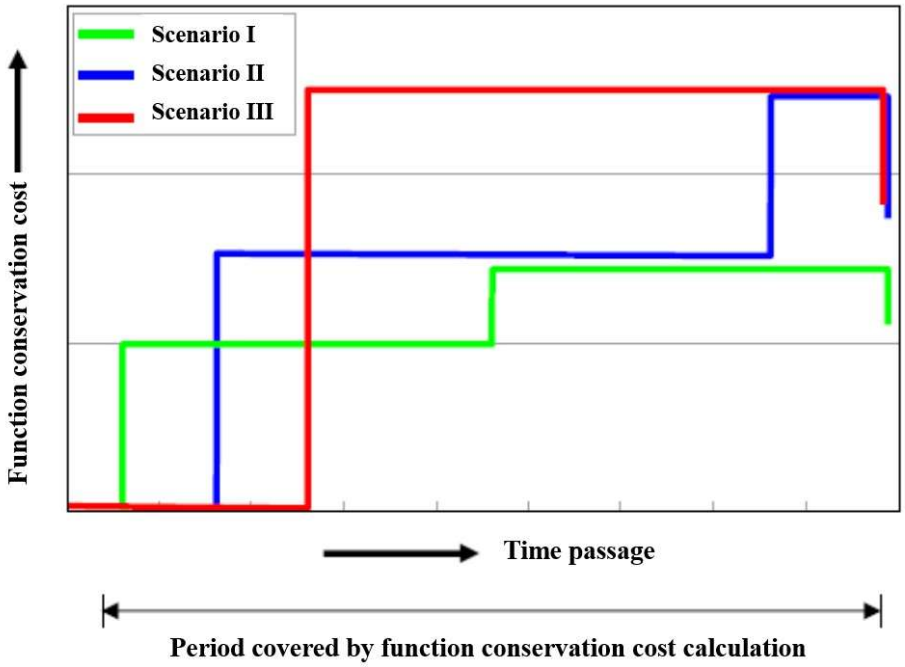


Figure E.4 Comparison of function conservation costs

The following is an example of scenario setting and function conservation cost comparison for a headworks.

- Regarding the headworks, where the deterioration is progressing, a deterioration prediction was carried out based on a function diagnosis, and the following results were obtained:

  α (time until repair is required (S-3 is reached)) = 0 years (currently S-3)
  β (time until reinforcement is required (S-2 is reached)) = 10 years
  γ (time until replacement is required (S-1 is reached)) = 16 years

- Consideration of countermeasures and scenario setting

  From a technical perspective, the following three scenarios are considered as countermeasures that can be applied to the facility:

- Scenario I

  A scenario in which repair work (surface covering method) is carried out at the S-3 stage, and then repeated at 10-year intervals. Repair work is carried out in 2017, 2027, 2037, and 2047 (service life 10 years).
  *Measures will be implemented two years after the plan is formulated.
- Scenario II

  Scenario in which reinforcement work (continuous fiber sheet adhesive method) is carried out in the S-2 stage. Reinforcement work is carried out in 2025 (service life 30 years).
- Scenario III

  A scenario in which facilities are replaced in the S-1 phase. Renovation work is carried out in 2031 (service life 40 years).
  *If the service life is unknown, set it based on interviews with the manufacturer or examples from nearby areas.

The progress of soundness for each scenario is shown in Figure E.5.

- Creating a comparison chart

Organize the above considerations into a comparison chart.

(1) For each scenario, convert the costs required for each countermeasure for each expenditure year into present value using the social discount rate (4%).
(2) Calculate the residual value of the facility in the final year of the calculation period using depreciation methods.
(3) Subtract (2) from (1) above to obtain the function conservation cost for the calculation period.
(4) The results of this comparison of function conservation costs for each scenario are shown in Table E.4 and Figure E.6.

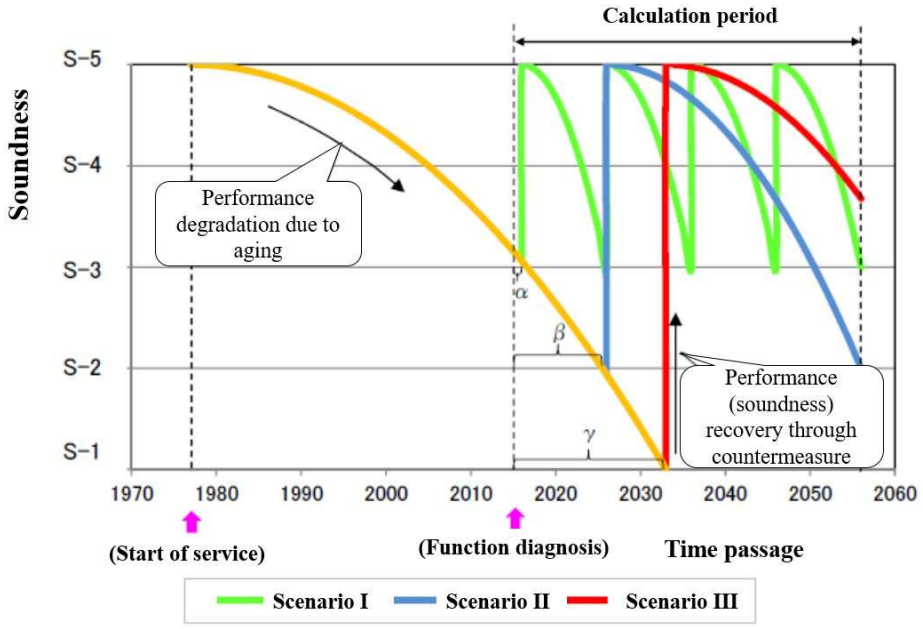


Figure E.5 Progress of soundness by scenario

Table E.4 Comparison of function conservation costs for each scenario (unit: thousand JPY)

Scenario	Countermeasure timing		Group number or part	Quantity	Counter-measure method	Cost	Present value	Residual value at the end of the period	Function conservation cost	Evaluation	Overview
	Years in service	Year									
1	38	2017	Fixed weir, spillway, retaining wall	set	A	10,000	9,246	0	9,246	2	Surface coating method is carried out at the S-3 stage, and the same repair methods are repeated at 10-year intervals.
	48	2027	Fixed weir, spillway, retaining wall	set	A	10,000	6,246	0	6,246		
	58	2037	Fixed weir, spillway, retaining wall	set	A	10,000	4,220	0	4,220		
	68	2047	Fixed weir, spillway, retaining wall	set	A	10,000	2,851	417	2,434		
	Sub-total					40,000	22,563	417	**22,146**		
2	46	2025	Fixed weir, spillway, retaining wall	set	B	23,000	15,539	0	**15,539**	1	Continuous fiber sheet adhesive method is applied at the S-2 stage
3	52	2031	Fixed weir, spillway, retaining wall	set	C	50,000	26,695	4,166	**22,529**	3	Replacing facilities in the S-2 phase

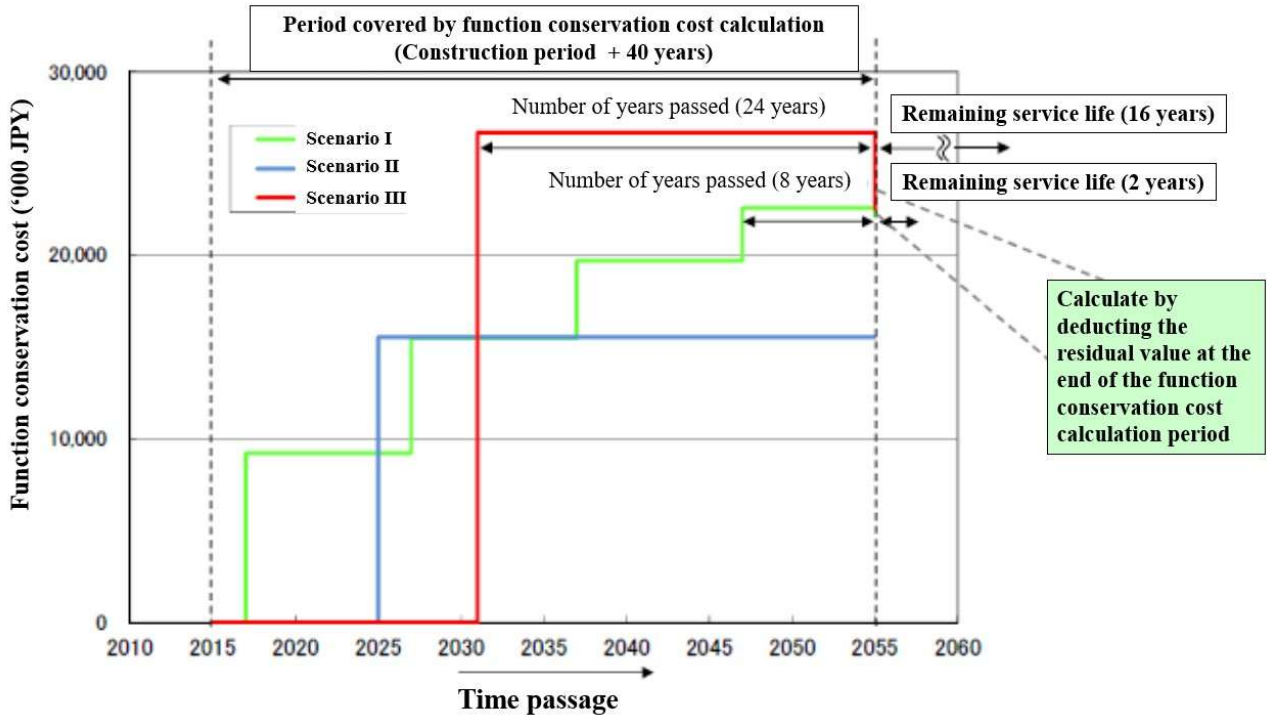


Figure E.6　Comparison of function conservation costs for each scenario (unit: thousand JPY)）

F Reducing methane emissions from rice paddies through intermittent irrigation

The main greenhouse gas (GHG) emitted from paddy fields is CH_4. Since CH_4 is produced by the action of microorganisms under anaerobic conditions, paddy fields have favorable conditions for CH_4 production. In Japan, all paddy fields are irrigated and are divided into intermittently irrigated paddy fields (paddy fields that are drained during the summer) and continuously flooded paddy fields, which are the subject of GHG emission calculations. In Japan, rice is mainly cultivated in intermittently irrigated paddy fields. GHG emissions from this category in FY2020 were 12,004 kt-CO_2 equivalent, accounting for 1.0% of Japan's total GHG emissions excluding LULUCF[12].

Intermittently irrigated (drained) paddy fields used by typical Japanese paddy farmers have different characteristics from intermittently irrigated paddy fields (multiple drainage) in the 2006 IPCC Guidelines[13], as shown in Figure F.1.

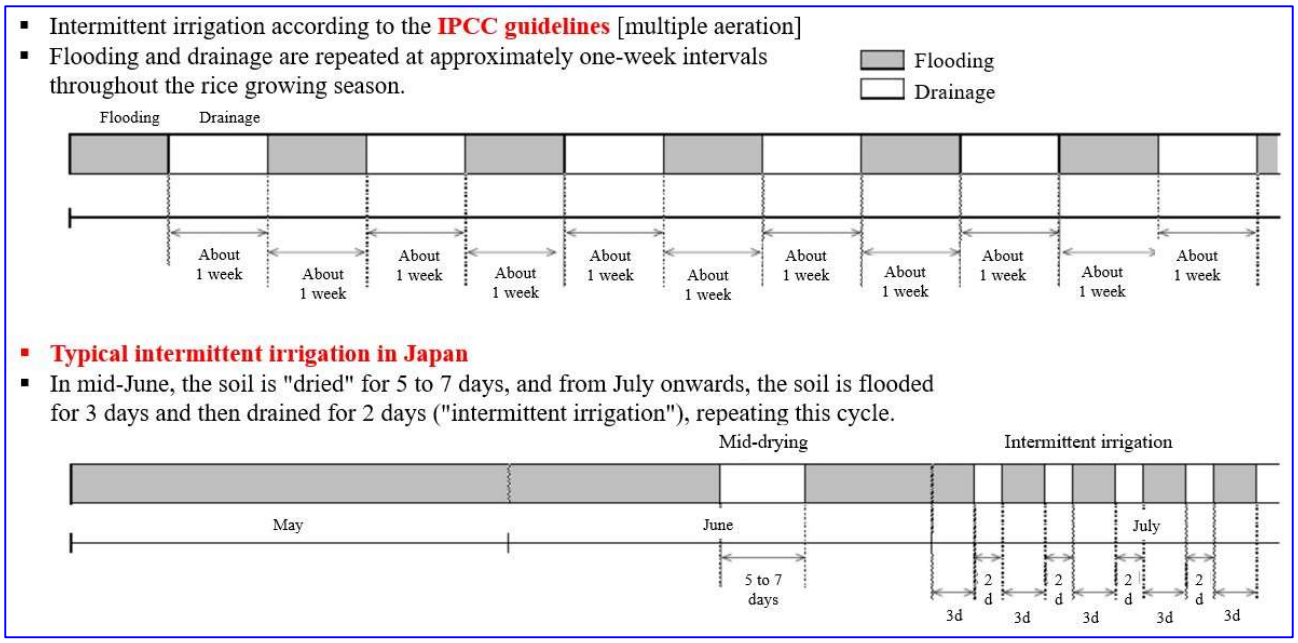


Figure F.1 Intermittent irrigation (multiple drainage) paddy fields in the 2006 IPCC Guidelines and typical intermittent irrigation (mid-drainage) paddy fields in Japan (GIO. 2022)

In Japan, GHG emissions are calculated using an estimation method based on the DeNitrification-DeComposition-Rice model (DNDC-Rice model), a mathematical model that estimates changes in methane emissions due to organic matter application methods and water management in paddy fields, based on the estimation methods of the 2006 IPCC Guidelines, and an emission factor calculated from the regression equation of CH_4 emission flux estimated from the model. The DNDC-Rice is a model that has been improved in Japan to enable estimation of CH_4 emissions from paddy fields. Figure F.2 is a conceptual diagram of the DNDC-Rice model.

[12] LULUCF (Land-Use, Land-Use Change and Forestry) is one of the calculation areas in greenhouse gas inventories. It mainly deals with the carbon balance of forests and land use such as agricultural land and developed land, and the carbon balance in land use changes such as conversion of forests to agricultural land.

[13] The IPCC Guidelines are guidelines established by the Intergovernmental Panel on Climate Change (IPCC) for each country to calculate greenhouse gas emissions and removals. They are based on the United Nations Framework Convention on Climate Change (UNFCCC) and are used by signatory countries when creating greenhouse gas inventories.

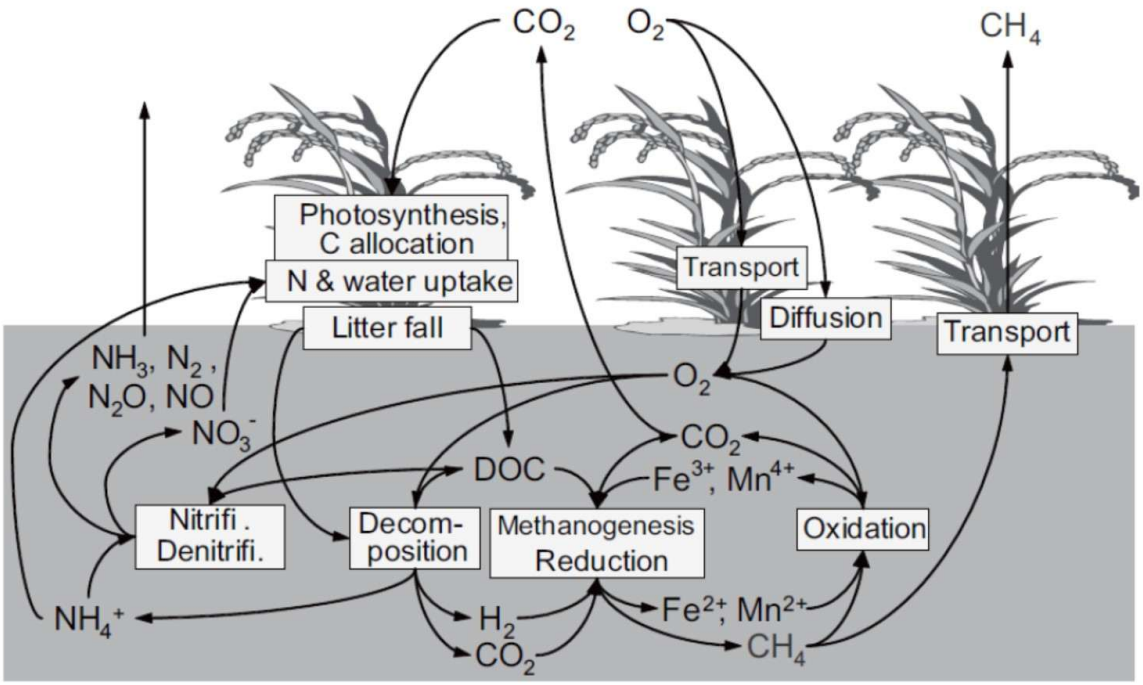


Figure F.2 Conceptual diagram of the DNDC-Rice model (GIO. 2022)

The formula for calculating methane emissions from rice paddies is as follows:

$$E = \sum_{i,j,k,l} \{(A_i \times f_{Di,j} \times f_{wi,k} \times f_{Ol}) \times EF_{i,j,k,l}\} \times 16/12$$

$$EF = aX + b$$

E: CH_4 emissions from paddy fields [kg-CH_4/year]
i: Region (7 regions nationwide)
j: Drainage (poor drainage, daily removal, 4-hour removal)
k: Water management (intermittent irrigation, continuous flooding)
l: Organic matter applied (rice straw, compost, no application)
A: Rice planted area by region [ha]
f_D: Drainage ratio
f_w: Water management ratio
f_O: Organic matter applied ratio
EF: Emission coefficient by region, drainage type, water management, and organic matter applied [kg-CH_4-C/ha/year]
X: Amount of organic matter applied [t-C/ha/year]
a: Slope (from the regression equation between the amount of organic matter applied and CH_4 emissions calculated by the DNDC-Rice model)
b: Intercept (from the regression equation between the amount of organic matter applied and CH_4 emissions calculated by the DNDC-Rice model)

The most important of these is the emission factor (EF), which is calculated based on information from paddy fields at 986 locations nationwide. Input data includes soil (soil organic carbon content, pH, clay content, dry density,

etc.), field drainage (maximum drainage rate), meteorological data (temperature, precipitation), and field management information (transplanting date, harvest date, tillage date, tillage method, fertilization date, fertilizer amount, organic matter application date, organic matter application amount, organic matter C/N ratio, flooding date, drainage date).

In order to reduce methane emissions from rice paddies, it is effective to shorten the flooding period as much as possible, and intermittent irrigation (AWD[14]) is recommended worldwide. It is said that the introduction of AWD can reduce GHG emissions from rice paddies by about 30% (NARO 2018). Compared to constantly flooded rice paddies, AWD is said to not only save water but also maintain and improve rice yields, and it is being promoted in irrigated rice paddies in Asia, which accounts for about 90% of the world's rice production. However, to ensure the implementation of AWD, it is necessary to develop irrigation and drainage canals in gravity irrigation areas, and pump operation according to the set rice paddy water level is necessary in pump irrigation areas.

To check the implementation of AWD, a PVC pipe is usually installed in the field, a scale is made on the inside of the pipe, and the water depth is recorded by reading it daily (Photo F.1).

Photo F.1 Simple water depth measurement using PVC pipe

Meanwhile, in Japan, the use of ICT equipment to measure water depth in rice paddies is becoming more widespread. FARMO, shown as an example of a field water management system in Appendix D, is one example, but other companies such as Kubota, Hokuetsu, Nishimu Electronics Industries Co., Ltd., and AmaterZ Co., Ltd. are also developing paddy field water level sensors and automatic water supply systems (Photo F.2).

If the area where AWD is implemented is known, it will be possible to grasp the approximate amount of GHG emission reduction from the IPCC default values, so it can be positioned as a domestic measure to achieve the reduction target (Nationally Determined Contribution (NDC)) set by each country in the Paris Agreement[15]. Therefore, in order to make AWD possible, it is necessary to promote the development of irrigation and drainage

[14] AWD (Alternate Wetting and Drying) is a water management technique in which rice is flooded and then drained and dried every few days during the growth of rice in a paddy field.

[15] The Paris Agreement is the successor to the Kyoto Protocol and is an international framework for climate change issues after 2020. In the Paris Agreement, countries around the world have submitted their commitments for the new framework to the Secretariat of the United Nations Framework Convention on Climate Change, and it is expected that efforts for emission reductions will progress in all countries, not just developed countries.

canals in irrigation districts, change farmers' awareness of rice paddy water management, grasp the area where AWD is implemented using satellite images, and popularize simple rice paddy water level measurements.

Photo F.2 Example of a manufacturer of paddy field water level sensors and automatic water distributers

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