CHAPTER 5

Structures for Water Acquisition

Much of the water used for irrigation in mountain irrigation systems is diverted from streams and rivers. Although it is seldom pumped from aquifers, groundwater flowing from springs is often channeled directly to fields. In addition to springs, rainfall, melting snow and ice feed the streams and rivers in many countries. In some hilly areas, pumping water from streams and rivers is the best source of irrigation supply. Wide riverbeds with deep alluvial deposits may have considerable flow through the bed material that can also be extracted with a suitable structure and pump.

Structures are designed and built to capture water from its natural source, remove undesirable material, and direct the water in a controlled manner into a conveyance system for delivery to fields. Although designing structures to accomplish these three tasks can be considered separately, the three tasks are often integrated in one structure. Even when separate structures are designed and constructed to accomplish water capture, sediment removal and water control functions, they are generally considered together as a part of the water acquisition activity and collectively called the "headworks." This chapter presents a series of examples describing structures for water acquisition.

LOCALLY BUILT GRAVITY DIVERSION

Farmers around the world have exhibited skill at diverting water from surface streams into canals that deliver water to their fields. In hilly or mountainous areas, the most common building materials are stones and boulders found in the riverbed, earth from the hillside, and forest products from the surrounding area, i.e., brush, branches, leaves, and timber. These materials are placed to divert all or part of the discharge to one side of the stream where a channel leads the water out of the riverbed.

With notable exceptions, such as in the low gradient Chiang Mai Valley in Northern Thailand, irrigators building their own diversions seldom attempt to use the structures to raise the water level. Most streams have sufficient gradient to intercept the stream at the desired elevation without significantly increasing the length of the canal. Increasing the height of the diversion dramatically increases the effort required to decrease leakage. Since locally built diversions are frequently swept away, rebuilding effort also has to be increased when the diversion must raise the water level.

Many locally built gravity diversions are intended primarily for supplemental irrigation during the rainy season. With abundant discharge in the source, leakage through the diversion is not a problem. During periods of drought and if irrigation is practiced in the dry season when the discharge is low, loss of water is minimized by plugging leaks with vegetative material such as grass and leafy branches. In some cases, woven bamboo mats are placed on the upstream side of a stone/brush diversion as a blanket against which sand and earth are placed to seal the leaks. Mud mortar and stones are sometimes used to capture all the water during low flows. Examples 5.1 and 5.2 illustrate locally built structures of the type found in many countries.

Most locally built diversion structures are subject to frequent damage by floods and must be continually maintained or even totally reconstructed. Farmers responsible for the construction find it annoying and costly to make these continual repairs. Decreased availability of forest products and, in some cases, labor to continually carry out the repairs is a concern in some communities. More durable structures are generally welcomed by

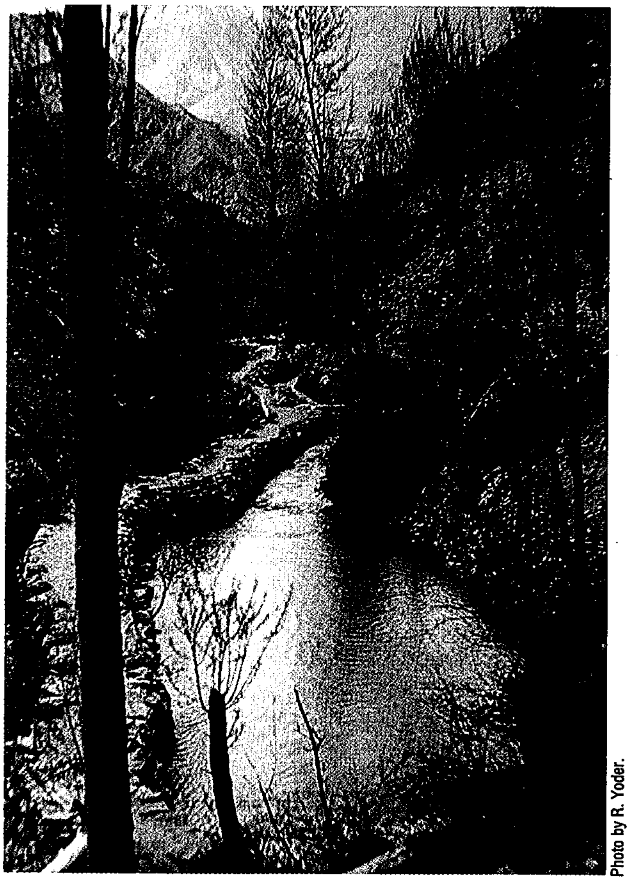

Figure 5.0.1. Settling basin built by farmers to trap silt in Hunza, Northern Pakistan.

Photo by R. Yoder.

irrigators who have only had access to locally available materials in the past. However, there are several features of locally built structures that need to be understood in designing "improved" structures.

Keeping excess water out of a canal during the time a stream is in flood stage is important for reducing erosion due to breaches in the canal. A stream in flood stage carries sediment and moves a great deal of bed load which will clog the conveyance system or even be carried into the fields, destroying valuable farmland, if the floodwater enters the canal. A locally built diversion that breaches or is swept away automatically reduces the danger of this happening. Improved diversion structures frequently depend upon the operation of gates to control excess water and silt. However, they are seldom accessible during storms when floods occur.

Locally built diversion structures seldom have adequate provision for bed load and sediment control. An exception, shown in Figure 5.0.1, is a settling basin built near the diversion of their canal by farmers in Hunza, Northern Pakistan. The width of the basin is slightly more than twice that of the canal and the length is about 10 m. A board blocking an opening near the end of the basin is removed periodically to clean the basin.

Although locally built canals frequently do not have an orifice to control the maximum flow into the canal, many utilize boulders and rock outcroppings to an advantage. Figures 5.0.2 and 5.0.3 show such examples. Water entering the canal (Figure 5.0.2) immediately enters a short tunnel cut through the rock outcrop (the opening is under the water surface). The tunnel acts as an orifice limiting the flow entering the canal. The diversion shown in Figure 5.0.3 was repaired at the beginning of the dry season using clay mortar to seal leaks. The strategically located boulder is used to limit the flow entering the canal during the rainy season.

Figure 5.0.2. Stone-brush diversion with water control orifice made by tunneling through the rock in Gulmi District, Nepal.

Photo by R. Yoder.

Figure 5.0.3. Mud-mortar masonry diversion used in the dry season to capture all the water in the stream. Water is diverted through a small opening behind the stone to block floods from entering the canal.

Photo by R. Yoder.

When floods damage their diversion, farmers shift the location to take advantage of changes in local features. This includes bends, rock outcrops and boulders. When improvements are proposed, it is important to tap this experience and benefit from the observations that have been made.

IMPROVED GRAVITY DIVERSION

Dwindling supplies of forest products and increasing restrictions on exploitation of forests that remain are creating difficulties for irrigators who must maintain diversion structures that are frequently damaged. In many countries, young people are seeking alternative employment, thus reducing the available work force. Farmers claim increasing frequency and intensity of flood damage to temporary diversions though such claims are usually unproven. These factors place stress on the centuries-old technology for building and maintaining locally built diversion structures.

The remainder of this chapter deals with diversion structures built with techniques or materials that are not always locally available. It is misleading to call all such structures "permanent." When forest products are no longer available and wire (to weave baskets to be used as gabions), cement, steel or other new materials are introduced, the new structure may last longer than the structure replaced. However, permanence is relative to the standard against which it is measured. All too often, a diversion that was considered "permanent" when constructed is swept away or damaged (see Example 5.3). Even when the frequency of failure is an order of magnitude less than for a locally built structure, this may not be acceptable where the irrigators are responsible for maintenance but do not have access to the materials or skills necessary to repair the damage. In such cases, the entire system may fail.

Many types of diversion structures have been constructed to replace and improve locally built ones. Most are costly, others are difficult for farmers to operate and repair. Frequently, irrigation agencies assume that they could post technical staff to operate and maintain the improved diversion only to discover that staff with technical competence are unwilling to live at the site because of the lack of funds to provide the necessary incentives. In some cases, management defaults to the irrigators who do not have the mandate, skills, equipment, materials or budget to achieve effective operation and maintenance. Determining who will manage operation, maintenance and designing of the structure to best utilize the available resources is an important goal.

Selecting the correct type of structure for diverting mountain streams is an engineering challenge and requires consideration of many factors. An estimate of the frequency of likely damage to the structure and the implications of failure must be made. Access to the site with necessary manpower, equipment and material not only to construct a structure but also to repair a damaged structure in time to avert crop failure is another factor. Much depends upon who will be responsible for the construction and management and for operation and maintenance.

For small systems in mountainous areas, heavy, durable diversion structures are usually too costly for consideration. As discussed in Example 5.3, traditional locally built structures may be the most cost-effective solution. However, where availability of forest products is declining, alternatives must be sought.

The use of gabion structures is referred to in many of the examples of this chapter. As an alternative to local materials, woven wire crates filled with stones are less costly than reinforced concrete or stone masonry but, typically, gabions structures are relegated to a secondary role. In Example 5.4, Williamson illustrates the use of gabions to prevent downstream erosion of a masonry diversion weir. In Example 5.3, Bellekens indicates that gabions were used to stabilize the riverbed after a masonry structure had failed. In Example 5.8, Smout, Bentum and Dorji also suggest the use of gabions in three locations at headworks: 1) for riverbed control, 2) to make an orifice controlling the amount of water diverted into the intake, and 3) as protection for the inlet structure from erosion by flow over the spillway and from the scouring gate.

Several reasons emerge for not using gabions as primary diversion structures. When water is scarce they do not provide an impermeable barrier. This makes them unacceptable in some locations. In Example 5.10, this is given as the reason for not selecting a gabion structure. However, the major reason that has emerged for not using gabions is that they are not "permanent." They often overturn within a few years which suggests they have failed. However, if more costly, rigid structures in the same location fail with the same frequency and local materials are no longer available, gabions may still be a cost-effective alternative.

Attempts have been made to establish diversions made entirely of gabions in mountainous areas. Smout, Bentum and Dorji suggest one of the reasons for the general failure of this approach; when stones are rolled along the bottom there is danger of damage to the wire destroying the crate. However, it has been observed that the gabion-diversion failure is almost always due to crates overturning rather than opening. The cause for overturn is the same as the mechanism that moves boulders of 10 m^3 to 20 m^3 in size during floods. Extremely high turbulence causes movement in bed material to a depth of several meters. The downstream support is temporarily eroded enabling the force of the flowing water to roll even the largest boulders.

Two questions need to be addressed with respect to gabion structures. What are appropriate applications for their use and are the best techniques being used in construction? Locally built diversions tend to divert the water to the side of the stream and lead it out of the stream bed. Frequently, engineered structures change the shape of the riverbed and raise the water level to make diversion into a canal easier (Example 5.4). Emphasis on bed stabilization rather than dam construction using gabions would possibly bring better results. This could be done by following the practice found with locally built diversions, in which, instead of damming the stream to raise the water level, a location is chosen far enough upstream so that water can simply be diverted to the side of the stream without disturbing the bed level.

The quality and gauge of wire, size of stones, and tightness of packing have been found to have a great deal of influence on the durability of gabions. Lack of training and quality control in the construction of gabions contributes to failure. Lack of suitable downstream foundation and toe protection is often the reason why gabions overturn.

In Example 5.4, Williamson advocates encouraging farmers to make design decisions when improving structures whose operation and maintenance were their responsibility. While this relates directly to the process of design, it also has major consequences for the outcome of the design. It is one way to ensure that the structure will be manageable by the irrigators. Possibly the most important point is that allowing farmers to make decisions gives them ownership and the willingness to take responsibility for maintenance. Instead of spending time trying to get the agency to return and make repairs when damage occurs, they will first try to use their own resources.

Example 5.5 illustrates the complexity of determining which locally built diversion structures need to be upgraded. While the objective for replacing the "leaky" locally built diversion was to increase the command area and reduce the labor required to maintain the diversion, there was failure in understanding how the situation in a particular valley was substantially different from others. Most fields were already irrigated and opportunity for expanding the irrigated area was minimal. Inter-system water rights, i.e., one of several important but invisible institutions, were well established but not officially recognized and, therefore, overlooked in the decision-making process.

The solution to this situation resulted in modifications in the operational procedures of the diversion gates to accommodate existing water rights. The example suggests that the irrigators consider the quantity of labor required to maintain the locally built diversion as the most important determinant of the acceptability of its replacement by a more durable structure. Using the procedure of enabling farmers to make such a decision, as suggested by Williamson in Example 5.4, would be one way to alleviate this problem.

Example 5.5 alludes to another potential problem that is not well understood. When an agency replaces a locally built structure with a more durable one with little, if any, input from the persons who had built or managed the earlier structure, there is danger that the organizational fabric essential for effective operation and maintenance will be damaged. Research in farmer-managed irrigation systems has shown that one of the major reasons for strong organization and equitable water distribution is the need for full user participation in the maintenance of the diversion and conveyance systems.

Elimination of all maintenance tasks increases conflicts over water distribution. In farmer-managed irrigation systems, overuse of water by those with easy access to the system is often constrained by the need to encourage those in the far reaches of the system to participate in maintenance activities when maintenance requirements are high. Building a maintenance-free structure or an agency takeover of responsibility for operation and maintenance, may remove an important reason for not overusing water which can greatly reduce the potential of expanding the irrigated area.

Example 5.6 also examines the issue of water rights among systems diverting water from the same river. While it confirms the existence of resistance from farmers to the combining of existing separate irrigation systems, a point that was raised by Jacob in Chapter 4 and also in the case from Peru (Example 5.7), it illustrates a solution arranged by farmers. They modified the diversion weir's scour gate by opening it all the way and inserting boards to create a proportioning weir to divide the water according to rules agreed upon among systems.

In some systems, the problem is obtaining sufficient labor to accomplish the necessary maintenance rather than sharing the water in the source among systems. Ambler (1991a) reports a situation where two contiguous systems divert water from the same source using separate diversions. The second diversion was slightly lower than the first. When the upper diversion structure was improved, it allowed some members of the lower system to also receive their irrigation supply from the improved diversion and they were no longer willing to share in the maintenance responsibility of the lower system. Due to the reduction in available labor the lower system failed. As a result of making improvements in the upper system diversion there was a reduction in the net area irrigated by the two systems.

As pointed out in the case from Peru, when systems are joined, it is assumed that there will be a government agency capable of managing the enlarged system. It has seldom been possible for an agency to accomplish their staffing or funding goals for the less-accessible areas in the mountains. Since each of the systems that was joined already had some type of organization, trying to introduce new management is a "mistake" not readily accepted by the irrigators.

Examples 5.7, 5.8, and 5.9 illustrate the technical aspects of side-intake diversion weirs. While the examples from Peru and Bhutan are of systems where the farmers are responsible for all operation and maintenance activities, the example from Nepal is of a diversion built, operated and maintained by technical staff from the Irrigation Department. It is important to note the difference in size among these systems. The Nepali example is designed to divert 3 m^3/s, the one in Peru for a maximum of 0.6 m^3/s and the one in Bhutan for less than 0.2 m^3/s.

In all three examples, there is a stress on finding the best possible location for the intake. A rock cliff or large boulder that protects the intake structure from flood damage is valuable. A rock cliff may make it possible to use a tunnel to protect the intake channel as it leaves the stream, as in the Nepali example. This is a technique that should be considered more frequently. In addition to protecting the section of channel which is continuously buffeted by floods, it provides an effective arrangement for controlling the amount of water diverted during flood periods.

Discharge and sediment transport characteristics change dramatically at different flood stages. Several examples report one flood depositing material and another removing it from the same location. Diversion structures in many mountain streams and rivers have been buried for periods of time and made inoperable. Others built on recent deposits from a catastrophic landslide high in the watershed are destroyed as subsequent floods remove material until equilibrium is regained.

A number of the examples stress the need to carefully consider the diversion locations of existing farmer-built irrigation systems before proposing new ones. Using their long and intimate experience of repairing their diversions, farmers have shifted their diversions to take advantage of the best location. Sometimes their observations extend over periods of several generations. It is not possible for a brief engineering study to obtain information comparable with such prolonged histories.

A bottom intake design (also known as a drop or tyrolean intake) has been developed for glacial streams and mountain torrents where boulders and rock debris must be passed with minimum obstruction. It is essentially a channel built into the stream bed covered with a heavy trashrack. The channel is perpendicular and the trashrack bars parallel to the flow. The total stream flow passes over the channel and the trashrack admits fine debris with the water entering the channel but excludes all larger material.

Example 5.10 describes a bottom intake built in Nepal. One important feature of this type of intake is the ability to extract all of the water from the source during periods of low flow. In some situations, as in the Nepali example, this is a valuable feature. Gabion and locally built diversions tend to leak unless special measures, such as sealing them with clay, are taken. Most masonry and concrete weirs are fitted with sluice gates which are also notorious for leaking. However, since bed material moves along the river bottom, much of the material smaller than the opening in the trashrack enters the intake and must be removed. This requires a well-designed desilting basin.

Desilting is not mentioned in the Nepali example. Because the stream in the example has extremely high peak flows of very short duration, total silt accumulated may not warrant a desilting basin. However, in streams where flood discharge carries sand and small gravel for a period of several days during flood, handling the silt cannot be ignored.

Structure for Diversion Safety

Small streams in mountainous areas are prone to high fluctuations in discharge. As it is seldom that there are gauging stations in remote areas, it is usually difficult to make accurate flood discharge estimates for designing structures. Example 5.11 illustrates the approach used in designing a spillway to protect an earthen dam used to divert water into a canal. Since the size of a safe spillway could not be determined reliably, a second, self-breaching structure was added as a safety measure. Such an approach requires comparison of the trade-off in cost between building of the breach and lengthening of the spillway. It is an interesting option when the only reliable alternative is to delay construction for some years while flood discharge data are collected.

LIFT SYSTEMS

Example 5.13 illustrates a pumping system designed to lift water from a lake to irrigate hill terraces in China. Because the source of water is a lake, solids suspended in the water are not a problem. However, when pumping from a river or stream, sediment exclusion must be considered because even fine sediment can cause serious wear to pump parts.

Streams and rivers with small watersheds tend to have short periods of flood discharge. An easy solution for sediment exclusion is to simply not operate the pumps during high-flow periods and avoid the major silt load. This is feasible if the rain that causes flooding makes irrigation unnecessary for a period of time. The high energy cost for operating pumps also encourages their shutdown whenever possible. Rivers with large watersheds frequently have long periods of high discharge and heavy silt loads. Often irrigation is necessary long before silt-laden floodwater recedes.

One solution is to use pumpwells with underdrains that filter the water through bed material as described in Example 5.14. This is adequate for low discharge situations but not sufficient for large systems. Various sediment-excluding devices and settling basins have been used for large pump systems. Model studies of intakes are often necessary because the flow pattern and its interaction with sediment is complicated and defies theoretical treatment. Experience from one case is valuable for the next but frequently it is not sufficient. Differences in the geometry and hydraulic characteristics of the river need only be minor to cause major changes in sediment transport.

EXAMPLES OF STRUCTURES FOR WATER ACQUISITION

Example 5.1

Temporary Diversion Structures in Bali, Indonesia

Yves Bellekens[5]

Goal: *To divert water from a small, steep stream with minimum capital expenditure, using locally available materials. Performance is not a goal; the need for regular and speedy rehabilitation of the structure after flood damage is accepted and is compensated by the low cost.*

The Setting

The structure described in this example is in a 380-hectare irrigation system located on the volcanic island of Bali. The latitude is about 8° south and the climate is tropical. The island receives over 2,500 mm of rainfall annually with a short dry season from July through September. A minimum temperature of about 25° C occurs during the dry period. The irrigation system is located at an elevation of about 750 m at the foot of a heavily forested upper mountain watershed of 28 km^2.

Bali is well known for its intensive irrigated agriculture. In general, irrigators live near their fields, which average about half a hectare. Most farmers own their land and, in addition to irrigated fields, many have rain-fed fields. At the lower altitudes they grow clove and banana, and a number of root crops together with maize in rain-fed fields. Rice, grown in level, bunded fields, is the main irrigated crop and can be grown year round. Farmers achieve a cropping intensity of about 225 percent using traditional irrigation practices. Although yields are high because holdings are small, they have little, if any, surplus food production to market.

The Irrigation System

The system described in this example is centuries old. It is owned and operated by the irrigators. At the system level, as in other irrigation systems in Bali, the irrigators have organized themselves into an irrigation association called *subak*. Though

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[5] Senior Evaluation Specialist, Asian Development Bank, Manila, the Philippines. The views expressed in this paper are those of the writer and not necessarily of the Asian Development Bank.

subaks manage irrigation systems and were recognized by a Presidential Instruction in 1984, they are not recognized as corporate entities in the legal sense. For example, a subak cannot borrow money or enter into contracts; individual subak members must do that. The subaks decide upon all matters related to operation and maintenance of the system.

Figure 5.1.1. Locally built stone/brush diversion in Bali, Indonesia. Note the bamboo gabions.

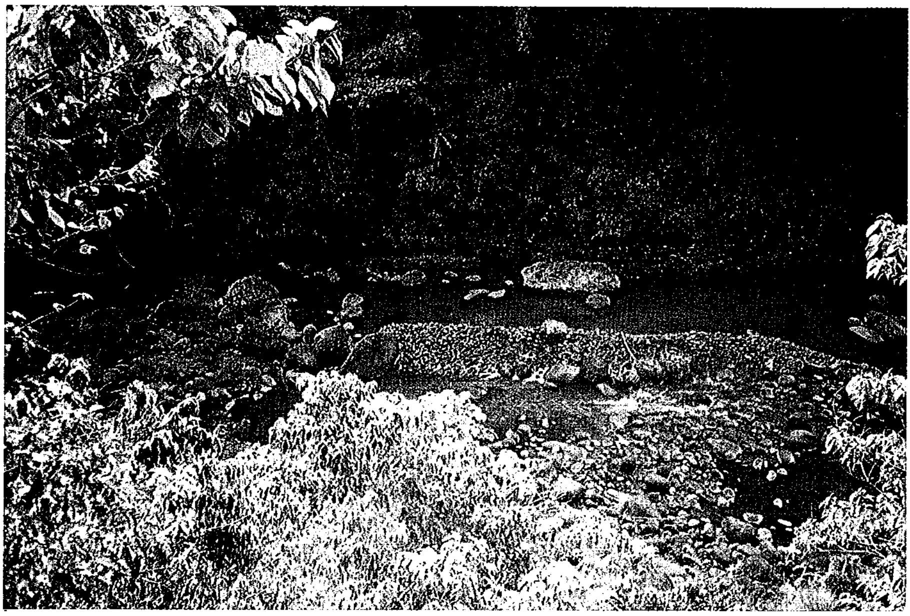

Photo by Y. Bellekens.

The irrigation system is accessible by gravel road to a point about 800 m from the headworks. The headworks is located in a deep narrow ravine. Above the diversion the stream has a steep gradient. There are two waterfalls located only a short distance upstream of the diversion.

Figure 5.1.2. Gabions, built from bamboo and stone, used in the diversion, Bali, Indonesia.

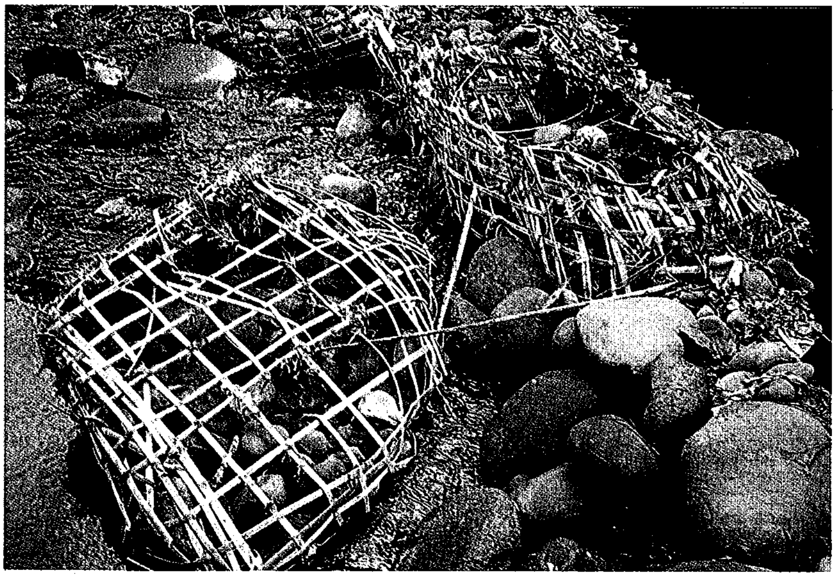

Photo by Y. Bellekens.

The stream is perennial and there is no water shortage in this system. Flood discharge is quite high and destructive. The river carries a heavy bed load of sand and gravel and brings wooden debris from the upper watershed.

Traditional Diversion Structure

The irrigators constructed their diversion largely from boulders available in the riverbed (Figure 5.1.1). To improve the effectiveness, gabion cages were woven using bamboo strips and filled with stones (Figure 5.1.2). When it was necessary to divert additional water, leaves and branches were used to reduce leakage through the boulders.

The temporary weir was damaged with each flood and required repairs many times each year. With a ready supply of material available at the site for rebuilding the diversion, this low-cost (in terms of cash), labor-intensive structure was effective. Though frequent damage interrupted irrigation delivery, the rainfall causing the flood also supplied water to the fields reducing the need for irrigation until the flood passed and the irrigators could again rebuild the diversion. When a government project offered to build a more permanent structure the farmers were pleased. Example 5.3 describes a succession of diversion structures built to replace the locally built weir.

Example 5.2

Diversion Structure in North India

U.C. Pande[6]

Goal: *To divert a substantial quantity of water from a torrential river, using local timber; and to arrange controlled breaching at a chosen part of the structure during flood events, so that the materials and the structure are not entirely lost and the structure can be reconstructed each year.*

The Setting

Irrigation systems in the mountainous areas of Himachal Pradesh and Uttar Pradesh typically command between 10 and 50 hectares. Much larger systems, some up to 12,000 hectares, are found on the piedmont plain below the hills. These systems tap water from the rivers whose entire catchment is in the mountains. The rivers carry high bed loads and form a huge fan as they enter the plain.

The climate is subtropical with most of the approximately 1,200 mm of precipitation falling in the monsoon period between July and September. A hot, dry period of about four months precedes the monsoon season. In the lower valleys, the temperature falls to near freezing in December and January.

The Irrigation System

The diversion structure described in this example is located at the base of the hills at an elevation of about 300 m near Haldwani in the Nainital District of Uttar Pradesh. It is over 120 years old and until the Irrigation Department recently provided assistance by building a permanent diversion structure, the irrigators maintained a temporary diversion structure known locally as a "ghori bund." Many of these structures are still used in this region and in Nepal.

The system supplies supplemental irrigation for monsoon rice. Part of the command area is used for winter wheat, mustard, and vegetables. Some maize is irrigated in the hot, dry season but most of the command area is left fallow during that period.

Temporary Diversion Structure

The diversion taps the Gola River, with maximum floods estimated to be about 4,500 m^3/s. The average monsoon flow is about 150 m^3/s, out of which the canal system draws 15 m^3/s.

In a "ghori bund" diversion structure, wooden logs are lashed together using locally made rope (now wire is frequently used) to form a tripod. Tripods are placed side by side diagonally across the river (Figure 5.2.1). The downstream end of the bund leads water into the canal. The other end of the canal reaches some distance beyond the center of the stream during the rainy season and all the way to the other side during low-flow periods.

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Figure 5.2.1. "Ghori bund" type diversion structure, North India.

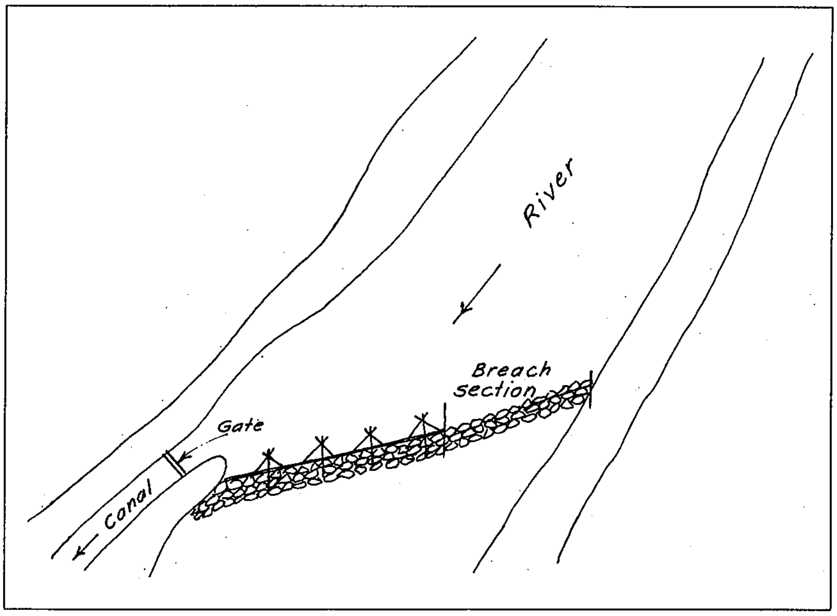

Figure 5.2.2. "Ghori bund" diversion structure on East Rapti River, Nepal.

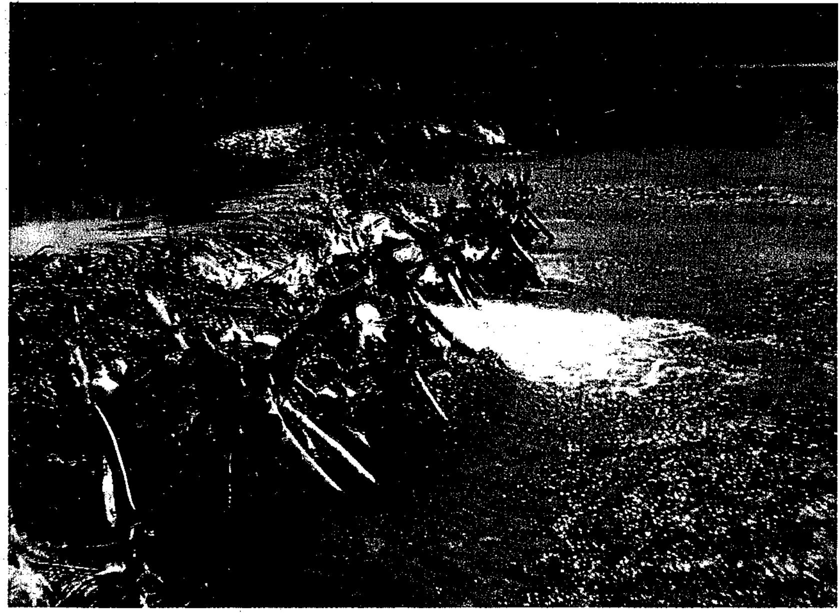
Photo by R. Yoder.

Horizontally placed logs are tied to the tripods at a height of up to one meter above the riverbed. The gap between the riverbed and the horizontal log is filled with riverbed material, tree branches, leaves, grass, etc. The tripod is tilted in the direction of flow to impart greater stability (Figure 5.2.2).

The diversion is deliberately arranged to allow the upstream end to breach first during a flood. The flood discharge can thus pass more easily without destroying the entire structure. It is also more easily repaired as the flood recedes since the height of the structure is less upstream than at the downstream location where water enters the canal. The shifting river channel often requires changes in the layout of the "ghori bund" from one year to the next. Even though logs for constructing these structures are becoming difficult to obtain, many systems in the region still depend upon the "ghori bunds" to divert water from rivers into their irrigation systems.

Example 5.3

Temporary Diversion Structure Replaced by a More Durable One in Bali, Indonesia

Yves Bellekens[7]

Goal: *To replace a traditional structure that required frequent repair and reconstruction, with a permanent structure with low maintenance needs; thus trading increased capital investment for reduced recurrent costs. But farmers who bore the former recurrent costs proved unwilling to agree to contribute to the capital and operating costs of the new, more substantial structure, and community cohesiveness decreased as repair works became infrequent.*

The Setting

This case describes the successive replacements of the locally built traditional weir of Example 5.1. It was first replaced by a masonry weir which was soon washed away by floods. It was then replaced by a more massive reinforced concrete weir. This structure is located just below a ravine located in a V-shaped valley. The stream above the structure is very steep resulting in enormous flash floods. Huge boulders 4-6 m long are moved during exceptional floods (Figure 5.3.1).

Figure 5.3.1. View of location where locally built diversion was replaced by a masonry weir (foreground) and later by the reinforced concrete weir (background) in Bali, Indonesia.

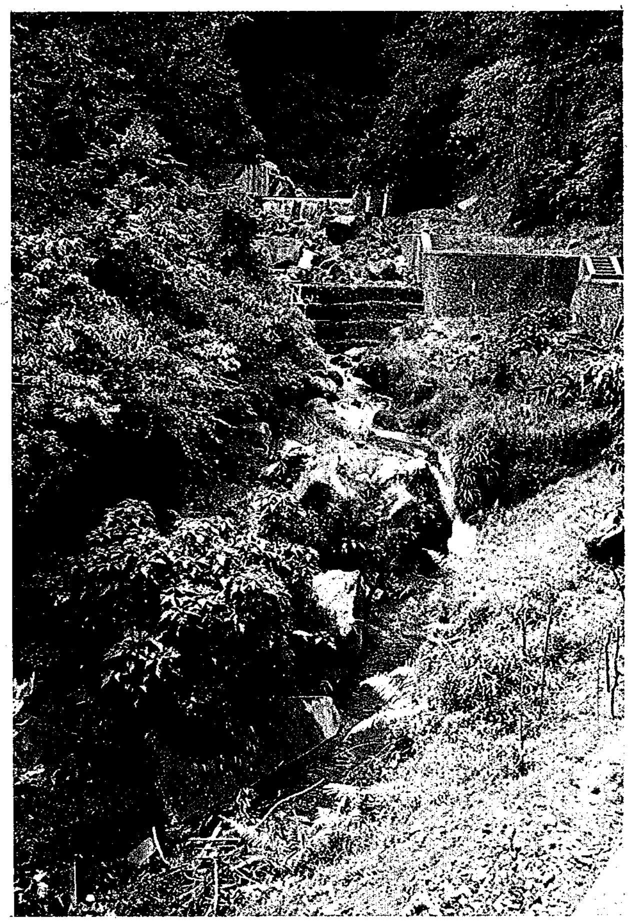

Photo by Y. Bellekens.

Succession of Improved Diversion Structures

The irrigators who built and operated the weir accompanied the technical staff during initial site investigation. They explained that there was enough water to grow a rice crop over the entire command area during any season of the year. They further stressed the awesome magnitude of the floods which frequently took away their temporary weir and how much work it took to restore it each time.

Investigation for building a permanent weir revealed that the steep riverbed comprised a deep layer of boulders, gravel and sand. However, on both sides of the ravine there was solid rock for a good foundation. A topographic survey and sketches were made of the plan, cross section and profile of the ravine, riverbed, and of the size distribution of the bed materials.

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[7] Senior Evaluation Specialist, Asian Development Bank, Manila, the Philippines. The views expressed in this paper are those of the writer and not necessarily of the Asian Development Bank.

Flow data were not available for the river. Maximum flood levels in the river and flood frequency were reported by farmers and verified by marks on the river bank. In determining river discharge characteristics, comparison was also made to other watersheds in Bali with similar size and rainfall patterns where flow measurements are recorded. Results of this analysis indicated that a permanent structure would need to be massive to survive a flood with a one-in-fifteen-year probability. It would require deep foundations and both upstream and downstream protection.

Because the cost of such a structure seemed prohibitive, a more modest structure made of masonry was constructed. The total height of the weir was about 2.5 m. It had a masonry foundation that did not reach solid rock and did not extend more than 2 m below the bed level. Riprap was placed on the downstream side but only protected a few meters downstream of the toe of the structure. The upstream wall of the weir was vertical. During floods, this wall was struck by boulders rolling along the bed. The design selected indicates that the designer perhaps lacked experience with the destructive nature of such a stream given the size of boulders at the dam site. However, they faced the dilemma of prohibitive costs in making a more durable structure.

It initially appeared that this structure was a significant improvement over the existing traditional weir. The irrigators were familiar with masonry construction and could have maintained the structure by themselves except that they did not have the necessary cash for sizeable repairs. Instead, the Department of Irrigation, having built the structure, retained ownership and management of the weir by assigning a gatekeeper at the canal intake. The irrigators who lost ownership and control of the headworks, were, for the first time, expected to pay irrigation service fees for maintenance. The irrigators did not agree that they should pay.

The masonry structure was completely destroyed by a flood two years after it was constructed. The original analysis was correct and a more massive structure was needed if permanence was desired. Figures 5.3.1, 5.3.2, and 5.3.3 show where the masonry structure was located.

During the flood that destroyed the structure, deep scouring occurred in the middle of the riverbed. In the 100 m stretch downstream of the structure, the river eroded to a depth of 3-7 m and moved huge boulders (Figures 5.3.1 and 5.3.3). Further deterioration was prevented by using a series of gabions installed in steps across the river at the location of the washed-out masonry structure (Figure 5.3.2). The site for a new weir structure was selected 160 m upstream of the location of the previous masonry structure and 80 m downstream of the gorge. This location was chosen because solid rock was available on both sides of the stream as well as 2 m below the stream bed, providing the solid foundation lacking in the case of the masonry weir. This location also minimized the weir length.

It was determined that a reinforced concrete weir was necessary to withstand the type of flood that had destroyed the masonry weir. Figure 5.3.4 gives the profile of the new diversion structure and Figure 5.3.5 shows the completed, reinforced concrete diversion structure. The total weir height is 7 m from the foundation to the weir crest. It includes

Figure 5.3.2. Close-up view of location where masonry weir failed. Note gabions used to stabilize the riverbed level.

Photo by Y. Bellekens

Photo by Y. Bellekens.

Figure 5.3.3. Shape and elevation of the masonry weir that was destroyed by a flood, visible on the wall. Large (3-4 m length) stones in the riverbed move during floods.

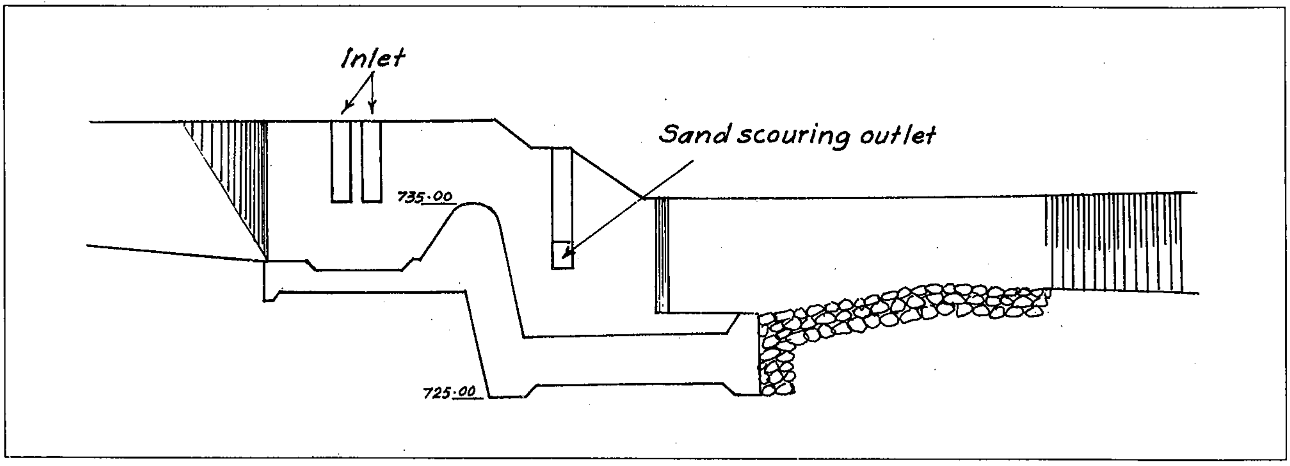
a double-gated intake for controlling the flow into the canal and a system for scouring sand out of the silt chamber back into the stream. The crest is 18 m long. The structure extends more than 40 m from upstream to downstream including 15 m of riprap protection. The 2.5 m deep riprap is composed of stones more than 40 cm in diameter to protect against scouring. The upstream wall of the weir has a 2:3 slope to avoid damage by boulders. The toe of the weir at the downstream end of the stilling basin is 2.5 m deep and heavily reinforced with steel on top.

Evaluation

The reinforced concrete weir structure cannot be compared with the earlier structures that it has successively replaced during a period of six years. It was built without any input from the irrigators. While it would have been possible for the *subak* (irrigation association) to hire and supervise a contractor for constructing the masonry weir, it would not have been able to build the reinforced concrete weir.

As the rains that caused floods which destroyed the traditional weir also provided water to the fields, even with the traditional weir there was seldom a water deficiency. Therefore, the improved structures resulted in very little, if any, production

Figure 5.3.4. Profile of the reinforced concrete weir that replaced the masonry weir. Bali, Indonesia.



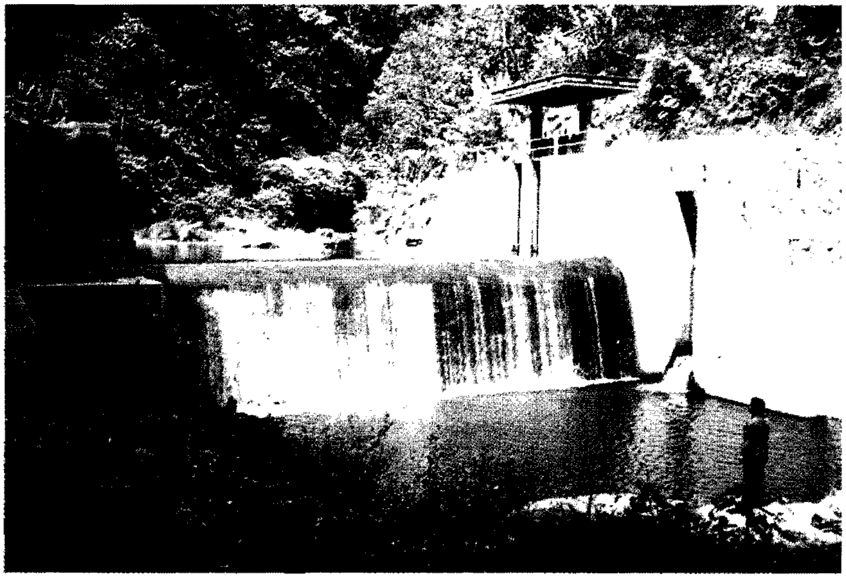


Photo by Y. Bellekens.

Figure 5.3.5. Reinforced concrete weir that replaced a masonry weir destroyed by a flood, Bali, Indonesia.

increase. There has been a reduction in the operation and maintenance labor required by the farmers because the new weir is maintained and operated by the Irrigation Department. However, the reduced operation and maintenance cost is not cash income to the farmers and they remain unwilling to make payments to the government for system operation and maintenance. Therefore, the masonry and reinforced concrete weirs cannot be paid for from increased production and the burden of operation and maintenance costs has been shifted to the government. When compared to potential benefits, the structures are not cost-effective or economical.

The irrigation situation in Bali in the past involved low cash investment in traditional weirs. These required frequent and sizeable participatory community work without outside intervention. Overall, the traditional weir may have been more sustainable, whether from the financial, institutional, or operational perspective. The total loss of ownership and responsibility for operation and maintenance has harmful implications. The subak is estranged from the structure that it must depend upon for successful rice production. Since irrigators are no longer working together to make repairs and thereby relegitimize their property rights as irrigators, the previously active irrigator organization has a much reduced role and the subak is weakened.

Example 5.4

Masonry Diversion Weir on the Pandayora River, Sulawesi, Indonesia

John Williamson[8]

Goal: *To determine site selection and appropriate low-cost design for a durable water diversion weir, using participatory processes. The goal of the engineer in these processes is to advise the farmers, contribute experience and help them to avoid mistakes; but not to take decisions personally. Thus farmer-group responsibility for the consequences is strengthened.*

The Setting

This example describes the design of a masonry diversion weir being used to irrigate 235 hectares (ha) of land in Central Sulawesi, Indonesia. The system is located in a large valley surrounded by mountains, south of Lake Poso at an elevation of about 600 m above sea level. Total annual rainfall is about 4,000 mm with much of it occurring during the rainy season from March to May when the daily rainfall can be extremely heavy. The highest rainfall recorded during a five-year period is 160 mm in 24 hours. Intense downpours of 80-100 mm in a five-hour period are common, and cause the flooding of large areas. Between August and November, the weather is hot and dry.

The system is near a village made up of over 225 families of the native Poso ethnic group. Their experience in irrigation dates back to World War II during which the Japanese introduced irrigation into the region for rice production. All families own some rice fields as well as gardens where they cultivate maize, cassava and vegetables.

This example describes part of the work of the Mayoa Transmigration Project which assisted farmers in building intake works for eleven irrigation systems. These now irrigate 900 hectares of land and benefit 735 families. The Project assisted in the technical design of the intake works and provided materials such as cement and steel. The total outside investment for all the systems amounted to under US$50,000, which is equivalent to US$56 per hectare.

The Diversion Structure

The village chief took the engineer and project staff to the Pandayora River deep in the jungle. This river is about 10-15 m wide and has an estimated flow of 1 cubic meter per second during the dry season. The riverbed in some stretches is straight and flat consisting of sand and silt. In other stretches, the current is more swift and the bed consists of large rocks and boulders, some with diameters as large as one meter.

The village chief showed the project staff an attempt the irrigators had made to divert the Pandayora River by installing wire mesh gabions filled with rocks across the river. The villagers had built the diversion three years earlier using government funds for purchasing the wire. The project failed because water leaked through the gabions. Later, the gabions overturned. An abandoned canal led from this diversion towards the rice fields of the village.

The project engineer and technician along with the village chief and some other farmers walked up and down the river several times discussing proposed locations for a masonry weir. They considered the following factors for locating the weir: First, it should be upstream of the previous gabion structure in order to use the existing canal. Second, the location should have access to both sand and stone, the principal building materials.

Stone was located in the swifter and narrower sections of the river, and sand in the slower and wider stretches. Concem about boulders rolling during a flood made some decide that the weir

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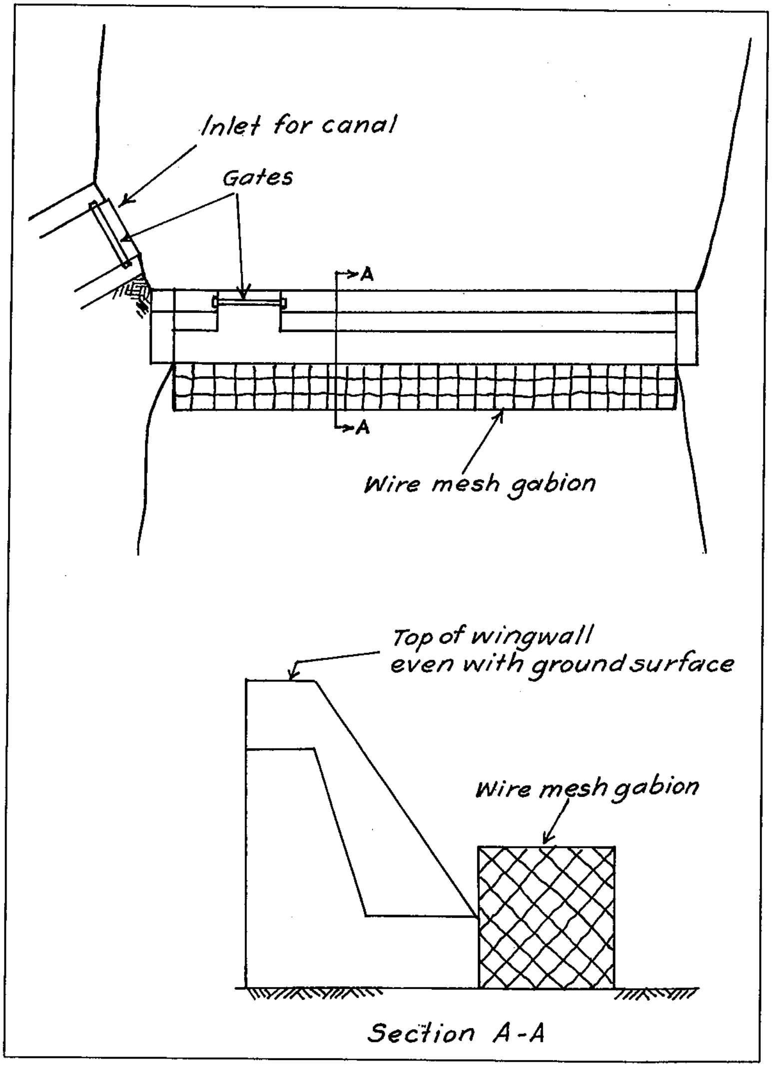
[8] Engineer, Mennonite Central Committee, Irian Jaya, Indonesia.

Figure 5.4.1. Plan and sectional view of the diversion weir with gates, Mayoa Transmigration Project, Sulawesi, Indonesia.



should be located downstream in a flat stretch of the river where velocities were slower and no large rocks are present. Others were of the view that the sides of the river should be well defined and rise steeply so that water would not flow around the ends of the weir.

The decision-making process for locating the weir was important. The engineer's role was to provide technical advice by pointing out the factors which needed to be considered and the advantages and disadvantages of each location. The farmers then decided on the location. The engineer had only limited hydrologic information about the site and knew little about the history, culture, and religious or superstitious or spiritual factors which were very important to the farmers. For example, farmers had rejected one site for weir location because it was too close to a graveyard. The farmers were also encouraged to make all the decisions themselves so that they would feel ownership and take responsibility for their decisions. If problems should develop later, they could not blame the engineer or outsiders for "a wrong decision."

Once the weir location was technical staff and farmers used a hand level to measure the slope of the terrain from the proposed new diversion site to the existing canal. Rough measurements indicated that there was a one-meter drop over the proposed canal length of about 200 m. During construction, the engineer together with the farmers used a 30 m clear plastic pipe to set the levels of elevation on stakes, to guide the digging of the canal. The design discharge was estimated for the 200-hectare command area and two different canal cross sections were determined for different slopes. This was done to minimize canal excavation. With the canal elevation fixed at the diversion, the height of the weir could be set so that the water would flow into the canal.

There are certain trade-offs in the relationship of weir height and depth of canal. A higher weir allows for a shallower canal, but it costs more. On the other hand, while a lower weir costs less, it requires a deeper canal with larger cross section and less slope resulting in more excavation. In the end, the weir height was set at 1.75 m above the riverbed level. This allowed for a flow level of 75 cm to enter the canal, equivalent to normal low season discharge. The riverbed at this location was about 2 m below the ground surface.

The engineer designed the weir based on several principles. First the weir should be heavy enough to prevent overturning at its toe. Second, it should not slide. And third, the weir needs to be protected from water spilling over it and damaging it at the toe. The gravity weir (Figure 5.4.1) is built on top of a larger foundation. Attached to the 50 cm thick foundation are gabions filled with stone. The gabions and the large masonry foundation prevent undercutting by the water spilling over the weir. The gabions are tied into the foundation using 16 mm reinforcing steel spaced every 50 cm.

A 1.5 m wide rectangular gate was installed in the weir and another at the opening to the canal. This idea came from the farmers themselves during the time of construction. The gates allow greater flexibility in controlling river and canal flows. Wooden boards are used for the gates and are operated by sliding them into channels fabricated with 50 mm angle irons.

During the rainy season, when little irrigation water is required, the gate would be partially or completely open. During the dry season, the gate is closed, diverting all the water into the canal. The gate in the weir facilitated the construction. The side of the weir with the gate was built first. Then, when building the other side, water diverted by a temporary cofferdam could flow through the open gate.

Before starting the construction of the weir, the villagers held a religious service at the site asking for God's protection against malevolent spiritual forces. Following the sacrifice of a chicken, work proceeded smoothly, and to date this project has functioned successfully. These ceremonies were another indication that the farmers owned the project.

Nearly the whole village turned out to work. School children were given a holiday and had to work as well. Women assisted in collecting sand and rocks and cooked meals and made tea at the work site. The community organized the work in small groups, and the project took about three weeks to finish. The farmers managed the construction and provided all labor and building materials located near the site. The Mayoa Transmigration Project gave 3,000 kg of cement, 150 kg of gabion wire, and 36 m of 16 mm reinforcing steel.

The diversion weir now irrigates 135 ha of new rice land and, in addition, some 100 ha of previously irrigated rice fields get extra water from this system. The only problem reported was that once, during a flood, water overtopped the river bank upstream of the weir damaging the canal. This happened because the sides of the river banks had not been built up higher than the wing walls which are 50 cm above the weir crest. The farmers repaired this break and raised the river banks to avoid it happening again.

The Mayoa Transmigration Project built similar diversion weirs in nine other locations. Two of these settled and broke. They were later repaired; in one case with assistance from the Mayoa Transmigration Project, in the other by the farmers themselves. There have been no other problems reported after three years. There are several possible reasons for the failures. There might have been water piping under the foundation causing erosion and, eventually, the sliding of the weir. The ground surface in both cases was a clay-sand mixture having a low coefficient of internal friction. Another possible reason for failure might have been neglect in placing gabions at the downstream toe to prevent undercutting. Gabions were not installed at these two sites because stone was not available nearby.

Lessons learned from these failures suggest that a 50 cm deep key or footer should be installed under the foundation to reduce piping and uplift, as well as to prevent sliding. Placing gabions at the downstream toe becomes mandatory. Several weirs have been built according to these requirements in another project without any reported problems.

The irrigation engineer's role as a facilitator is crucial in designing structures. The Mayoa Transmigration Project engineer worked as a consultant to the farmers and not to the Irrigation Department. Since they provided the labor, they often chose the alternative which would use the least amount of labor. Local labor was given freely because the farmers owned the irrigation systems.

A number of factors contributed to the success of the Mayoa Transmigration Project's irrigation program. Building diversion weirs met the important need identified by the farmers, that is, a stable source of irrigation water. Another factor was that responsibility for decision making was in the hands of the farmers themselves. When farmers made decisions they owned up the decisions and took responsibility for consequences—in this case the construction and future maintenance. If the Mayoa Transmigration Project engineer had made the decisions himself the farmers would have blamed all future problems on the engineer and expected another project to fix the problems.

Associated with the level of farmers' involvement is the use of simple technology and designs. Whenever possible, farmers joined in the survey. Simple surveying techniques such as using water-filled clear plastic pipes were used as these were already understood and used by persons with masonry experience. Designs were flexible and changes were incorporated during construction. With local masons who knew how to do masonry and reinforced concrete work, technical supervision by project staff was limited to daily visits.

Designing structures is not merely a technical science of plugging the right numbers into the correct formula. Design of structures should actively involve local farmers' ideas and suggestions. The engineer's role is to solicit and encourage these ideas and help guard against errors.

Example 5.5

A Comparison of Farmer- and Engineer-Designed Diversion Weirs and Intakes in West Sumatra, Indonesia

John Ambler[9]

Goal: *To divert water to individual small irrigation systems, within a set of 60 such diversions along a 16 km steep river course. In this context, the sustaining of traditional sharing of the total water resource in the dry season should be a goal, and new structures have potential for altering this balance. Two alternative approaches are contrasted.*

The Setting

The two diversion weirs described in this example are located in the Tampo Valley in the Lintau Buo Subdistrict of West Sumatra. The water source is *Batang* (River) Tampo, a small mountain stream originating on the flanks of Mount Sago. The length of the stream is about 16 km before it merges with a tributary stream, Batang Pangian. There are over 60 diversion structures along the Batang Tampo stream each serving a distinct irrigation system. The elevation of the farmer-designed irrigation system described in this example is about 350 m and the engineer-designed system is about 1,000 m.

Above the confluence with the Batang Pangian, the Batang Tampo has a total watershed of only about 50 km^2, including one major tributary. As a result, the river rises and falls rapidly with changes in precipitation. Floods strong enough to wash away brushwork and loose stone weirs occur three to four times each main rainy season and about once or twice during the secondary rainy season.

The climate is humid tropical with 1,500 to 3,500 mm of rainfall per year—rainfall being high in the upper part of the valley and low in the lower part. Rainfall is bimodally distributed, with a heavy rainy season occurring from September/October to January and a lesser rainy season from March to April/May. The driest months are June-August, with a precipitation of about 60-75 mm per month, the only months during the year when potential evapotranspiration exceeds precipitation.

During the rainy season, the water supply from Batang Tampo far exceeds crop water requirements in the irrigable area in the valley. During the dry season, all water in Batang Tampo is diverted for irrigation and the river is essentially tapped dry above the point where Batang Pangian merges with Batang Tampo.

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[9] Program Officer, the Ford Foundation, New Delhi, India.

In the systems described here, rice in leveled and bunded terraces is the only irrigated crop. Farmers irrigate for land preparation even during the heavy rainy season. They continue irrigation to retard weed growth which reduces labor inputs. During the drier months, irrigation is essential for the high yields of 3.5-6 t/ha of rough rice per crop upon which farmers have come to rely. Farmers with good irrigation located at altitudes of less than 600 m can get 5 crops of rice in 2 years. The heavy clay soil is well suited to wet-rice growing, and has been supporting this type of cultivation in this valley for at least the last 650 years.

Ownership of irrigated land averages 0.6 ha per family, while those who actually work the fields (owners and sharecroppers) have access, on average, to 0.5 ha. A farm family would also typically have access to 1 ha of unirrigated land. Farmers are heavily tied into the market and use considerable amounts of chemical fertilizers and pesticides, purchase new varieties of seed, and sell rice to private traders or to the government. Accessibility by road is good and many roads in the valley are all- weather roads.

The Irrigation Systems

The farmer-designed weir system has a command area of 20 ha and the engineer-designed weir system 139 ha. Intersystem water rights along Batang Tampo are a major issue, and one that was not recognized by the government when it built new permanent weirs along the river.

Within the command area, water is allocated to individual users normally on the stated principle of equal water for equal area of land. In commands that practice field-to-field irrigation, how this actually works out volumetrically is unknown, but if the area is small (i.e., less than 50 ha), farmers generally do not complain. In systems in which the main canal must traverse a long and precarious slope before reaching the command area, water distribution is carefully monitored and operationalized by measured cuts in wooden proportioning weirs placed at each branch of the canal, with each irrigator being served by an individual terminal canal (Ambler 1991a: 37-52). In both cases, water distribution is normally on a continuous-flow basis, with rotations occurring during land preparation or during times of exceptional shortage of water. In both systems, the maximum discharge into the canal is limited to about 2 l/s per hectare during the rainy season and 1-1.5 l/s per hectare in the dry season.

In systems with government-built weirs, the government pays a gatekeeper to watch over the weir. Farmers themselves monitor the farmer-built weirs and maintain all of the canals. In government-assisted systems, the irrigators are responsible for cleaning the lower portions of the main canal and all branch canals.

No irrigation fee is collected from the farmers. The government-built weirs are the property of the Department of Public Works. These are scheduled to be turned over to the farmers in a phased manner in accordance with the government's new policy of gradually turning over all systems under 500 ha to the farmers. All systems along Batang Tampo—government-assisted or not—were originally constructed, operated and maintained by the farmers.

Conflicts in both types of systems are managed by the farmers themselves. Conflict between systems has become an important issue since the government has converted some traditional weirs into permanent weirs, and effective conflict-resolution mechanisms have yet to be developed.

The government chose to upgrade some of the traditional weirs that were considered to be "leaky." There was a conceptual problem with this perception as it did not fully take into account the fact that water supply during the rainy season was not a real issue, i.e., leaks do not matter, and that intersystem issues were important during the dry season, i.e., leaks in upstream weirs constituted automatic supply for lower weirs. Upgrading certain canals along Batang Tampo exacerbated intersystem difficulties (Ambler 1989 and 1991b).

Farmer-built weir and intake

Experience in building the weir and intake is passed on through generations by showing youngsters how it is done. The only materials needed for maintenance are stone and cement mortar. Village masons are common and cement is easily available and transportable by road to points less than a kilometer from the headworks.

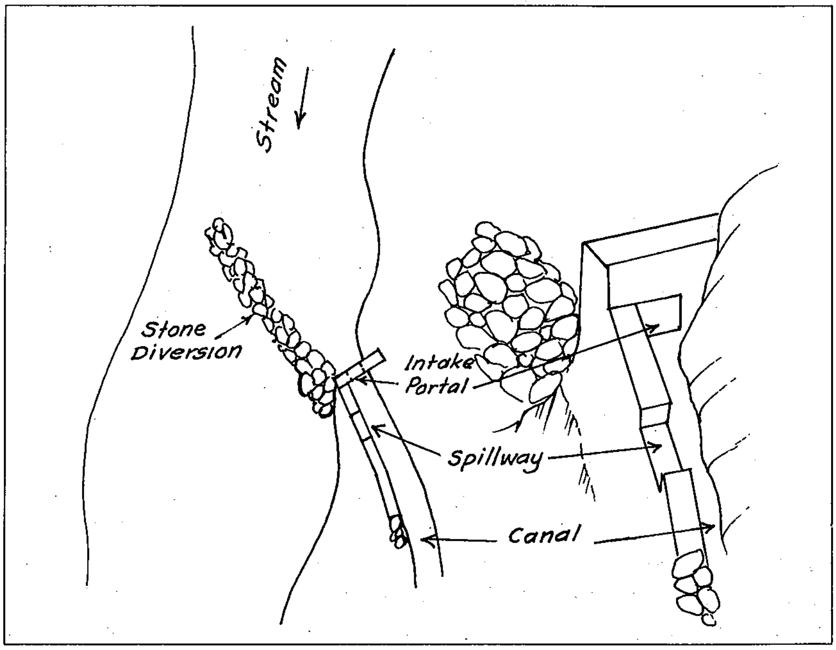


Figure 5.5.1. Farmer-built diversion structure, West Sumatra, Indonesia.

Two options are used for averting possible excess flow from being diverted and from damaging the canal. The first is to construct a portal at the beginning of the canal to limit the amount of water that can enter. The second is to construct the sidewall of the canal immediately after the diversion without any freeboard (only high enough to pass the maximum desirable discharge) allowing the excess water to spill over the sidewall and back into the stream. In some systems, both devices are found, the portal first limiting the water that enters the intake and the sidewall further reducing flow to maintain the appropriate discharge.

The loose stone weir that projects into the river (Figure 5.5.1) is placed at an angle to the flow of water, rather than trying to run the weir straight across to the other bank. Angling it enables it to withstand greater forces than if it were placed perpendicular to the flow of water. Because the banks of the river are not high and the gradient of the river steep, the farmer-designed weirs do not need to be high. The primary function is to divert water to the side of the river without significantly increasing the head where a low-gradient canal leads the water downstream out of the riverbed. It is easy to rebuild these weirs since stones are plentiful in the riverbed.

Another purpose of the weir is to divide the water in the river so that part of it flows to lower systems during the dry season. Formerly local custom forbade putting the weir all the way across this river, to ensure dry season flows to lower canals along Batang Tampo.

The length of the weir jutting into the stream is typically 5-20 m. The weir seldom has a height of more than 0.5 m. The intake portal extends about 0.5 m above the intake wall which is 0.4-0.7 m high. The sidewall, used to spill excess flow, is about 0.1 m lower than the remainder of the canal wall. The masonry wall is constructed at the intake using sand, cement and river stones. A foundation is placed about 0.5 m below the riverbed. The wall contains the portal for limiting water entering the canal.

The structures are small and inexpensive. Total cash construction cost is less than US$100-US$200 for a structure. This amount is easily collected in the form of cash or dried rough rice on a per family basis. Labor for periodic maintenance is provided in equal amounts per family. In systems that use proportioning division weirs, collection of cash or kind is based on the share of water to which each farmer is entitled, while mobilization of labor for emergency repairs is the equal responsibility of all, regardless of size of landholdings or water right.

Operation of these structures is essentially automatic, except when the intake needs to be closed for canal cleaning. Flash floods sweep away the temporary weir jutting into the river, thereby saving the canals. Stones are easily reassembled when the waters ebb. Thus, farmers need not wake up in the middle of the night, rush through the darkness and the pouring rain along slippery paths and bunds, to try to manipulate a headwork gate when sudden and heavy rains come.

Having a weir of loose stones also means that when the discharge in the river is low, the weirs visibly "leak." However, this leakage is intentional, as it allows a significant portion of the stream flow to move downstream to other canals that need it. Thus, embedded into the design of the weir is a set of rights and responsibilities concerning water allocation and distribution that cover long stretches of Batang Tampo, making each canal really a part of a larger network of irrigation systems.

No set maintenance routines are necessary. Adhoc collection of cash is made from farmers if repairs are needed. Operation is very reliable, but because of increasing competition for water in order to grow short-maturing varieties of rice during the dry season, more time is now needed to guard the headworks and negotiate with downstream users who come upstream to ask for water. The headworks cannot be locked so negotiation and the honor of downstream users in not removing too many stones from the weir are important. This added degree of management intensity is not, however, too onerous because of the generally accepted principle prevailing in the valley that those canals located higher along the stream have first rights to water, but that irrigators in these canals also have the duty to moderate their own acquisition of water to take into account the needs of downstream users.

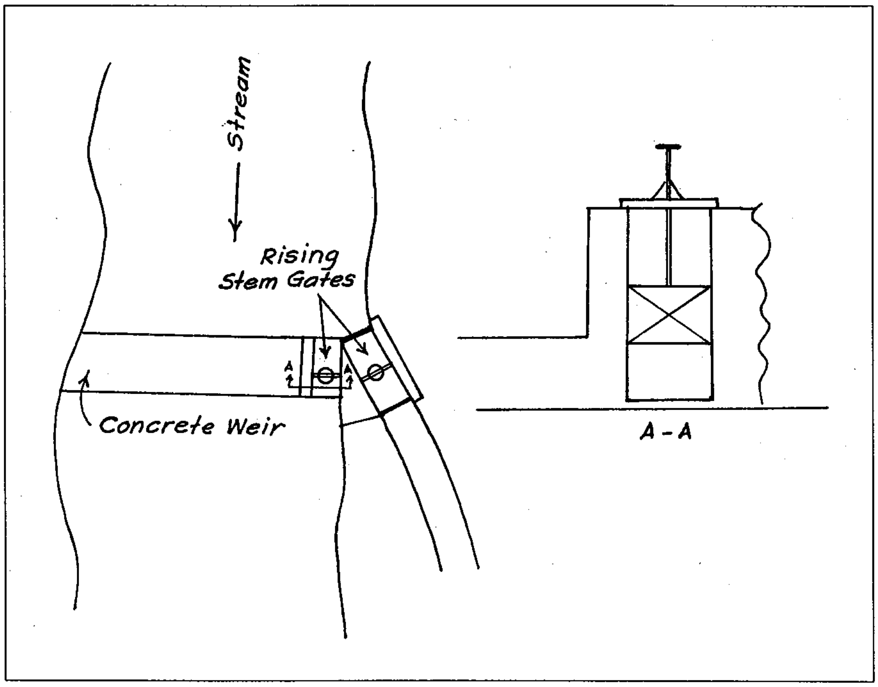
The farmer-designed weir and intake structure work well under the conditions described in the valley because: 1) one cannot overirrigate wet rice in basin conditions where drainage is good; and 2) water beyond the consumptive-use needs of the crop flows down through the system and drops into the canal of the next system below or returns to the river where it is picked up by another weir downstream. Thus, during the rainy season, it does not matter if these intakes allow diversion of more water than the rice crop really needs; while in the dry season, the form of traditional loose stone weir and social mechanisms for allocating and distributing water among the different systems located along the rivercourse ensure locally defined equity within tolerable limits.

Government-built weir and intake

The engineer-designed weir extends across the stream which is about 30 m wide. A foundation must be placed deep enough to provide stability. Two rising stem gates (Figure 5.5.2) are used, one to control the amount of water entering the canal and the other to scour silt and bed material from the front of the intake gate. The intake wall is about 1 m high and the gate towers rise 3.5 m.

The government-built weir and intake are assumed to have a government-paid gatekeeper in charge of operation and routine maintenance. Training in the proper operation of rising stem gates is needed to ensure that the operator does not bend the shaft by turning the wheel the wrong way when the gate is in the "down" position. The gatekeeper must paint the metal parts of the gates and roof over the rising stem apparatus, as well as clean the intake and the first kilometer of main canal. His work is supervised by a junior government officer with high-school technical training. The costs are borne by the government.

Figure 5.5.2. Government-built diversion in West Sumatra, Indonesia.



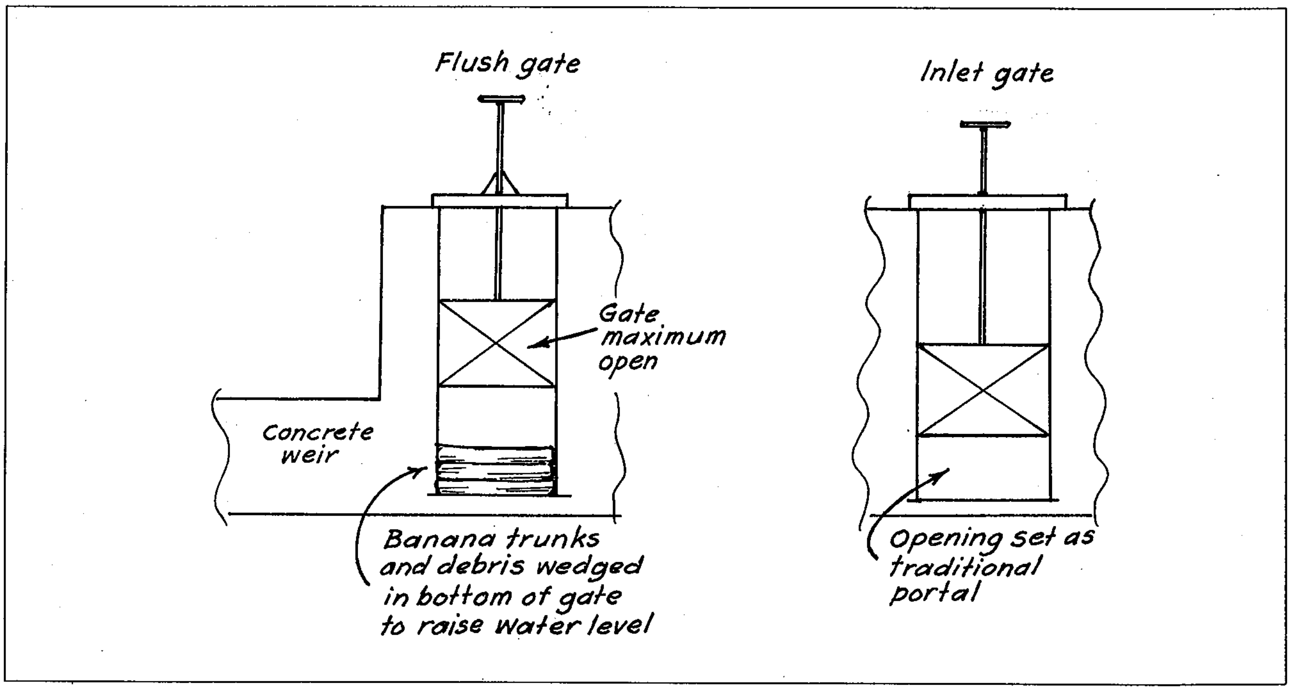
Total cost of the structure is unknown, but it is certainly much more than that of the farmer-built structure. Construction is not as easy as that of the farmer-built structure. Alignments must be precise for the gates to operate smoothly, and the construction of a permanent weir requires some sophistication. As the structure is permanent, the amount of time farmers need to spend on rebuilding the weir and repairing the intake is less.

Although the gatekeeper has a government-built house right near the headworks, he, too, does not like to get up in the middle of the night or to be chained to the headworks 24 hours a day, seven days a week. To allow him freedom to do other things, he has imitated the principles found in the "simpler" farmer-built systems. He lowers the intake gate to a position about 1 m above the bed of the intake, thus forming a portal like the ones found in farmer-built structures. This limits the amount of water that can enter the canal. But the weir is permanent and withstands flash floods. This means that the scouring gate would still have to be operated to allow the water not flowing over the top of the weir to go through the scouring gate and back to the river. If the scouring gate is left closed during flash floods, too much silt would enter the canal and boulders might slam against the intake gate and damage it.

Again, the government-paid gatekeeper takes his cue from the farmers. He raises the scouring gate all the way to the top, thus making the opening as wide as possible. Then, in the bottom of the scouring gate, into the slots where the scouring gate fits when it is closed, he puts a banana trunk and other vegetable debris to make a small sill. The presence of this sill raises the water enough to allow flow into the canal. When the water gets higher, it flows over the sill, or when a flash flood comes, this temporary sill is automatically washed away, thus saving the canal, and making it unnecessary for the gatekeeper to constantly watch the intake. Figure 5.5.3. shows the configuration for this mode of operation.

With regard to intersystem water distribution, this new government-built weir created numerous problems. During the rainy season there was no conflict, as water supply far exceeds water demand, and the new permanent weir does allow more water to be captured, which has benefited some patches of formerly rain-fed land. However, during the dry

Figure 5.5.3. Common operational configuration of government-built diversion intake and scouring gates, West Sumatra, Indonesia.



season, the enhanced acquisition capabilities of the permanent weir allow it to capture more water than its traditional share, to the dismay of farmers in downstream canals. These farmers then appeal to the gatekeeper to release more water. However, the gatekeeper cannot comply without the consent of his superior, who lives some kilometers away, and who is interested primarily in the operations of this particular canal, not in how the larger network of irrigation canals functions.

Thus, the management of the intake is quite different than what was originally envisioned by the engineers, in part because the design itself was predicated on the assumptions that conditions would be similar to those found in flat areas, for which this design was originally conceived. When this system is returned to the farmers for their management, it is likely that the gates will be allowed to rust in the positions described above, as operationally this makes more sense and will require less maintenance. In cost terms, the design was far too elaborate and expensive, and had to be simplified in its actual operation. Furthermore, it created some problems with regard to intersystem water distribution because the engineers did not understand the nature of local water rights and intersystem water allocation mechanisms. These issues will have to be sorted out anew when the system is turned back to the farmers.

It should be noted, however, that in the lowest parts of the valley where intersystem water distribution was not an issue and where the height of the weir needs to be higher to raise the water up over higher river banks, the new permanent weirs from the government have found universal favor with the farmers. Labor to rebuild the weirs used to be onerous, and involved not only stone work, but also cutting large trees as braces, and the farmers have been very appreciative of the assistance.

On balance, it appears that given the particular characteristics of this valley and the nature of the irrigation enterprise, the farmer-built weirs and intakes perform more favorably than the government-built structures. Their major advantages are lower construction costs, cheaper maintenance, suitability for intersystem as well as intrasystem needs, and automatic functioning under conditions of rapidly changing stream discharge.

By being permanent, the government-built weir does reduce labor required for rebuilding the loose stone weir after flash floods and it does allow a slight extension of the command area during the rainy season. It is however, a costly affair, awkward to operate, and ill-suited to dealing with intersystem issues during the dry season. Even its "advantage" of reducing labor needed for rebuilding the headworks, which could be accomplished by all the irrigators mobilizing their labor for one day even before the days of the permanent weirs, may have inadvertently taken away the opportunity for the irrigators to engage in a solidarity-building activity like communal labor. Elimination of this communal labor—which itself is a type of investment in the system that reaffirms particular rights to water—may have translated into more anarchic water distribution by eroding the investment basis for water rights. The effect of this is unknown and it is a potentially important area for further study.

Example 5.6

Management of River Discharge Allocation among Schemes in Bali, Indonesia

Yves Bellekens[10]

Goal: To replace a traditional diversion weir with a new structure that requires less maintenance labor input by the farmers, and to modify the new structure so that it satisfies a complex pattern of intersystem water rights and intersystem drainage flows in both dry and wet seasons. A vital factor in deciding acceptable new arrangements is the existence of a federal farmers' management organization that can represent all affected groups.

The Setting

This example describes the situation in a system in Bali. The general setting is similar to that described in Example 5.1. The command area is fully terraced in parts on relatively steep slopes. It is well-drained and receives return flows from adjacent, small irrigation systems. Drainage water from one system directly enters the distribution system of another without returning to the river or stream. Return flows are an important aspect of mountain irrigation in Bali. Many of the schemes are contiguous or close to one another within single watersheds or adjacent watersheds. This enables excess water used in an upstream scheme to be reused in fields downstream. River flows diverted to terraced rice fields progressively move from plot to plot down the mountain or infiltrate to the lowlands (Figure 5.6.1). Water that infiltrates keeps springs flowing and again becomes a part of the irrigation supply. This ecosystem acts as an extended reservoir from which water is progressively distributed to irrigation systems, interconnected fields and groundwater. A *subak* (irrigation association) manages irrigation activities within a single system and negotiates interconnected linkages with others.

Figure 5.6.1. Terraced rice fields of interconnected systems in Bali, Indonesia.

Photo by Y. Bellekens.

When building diversion structures on mountain streams, it is critical to consider the

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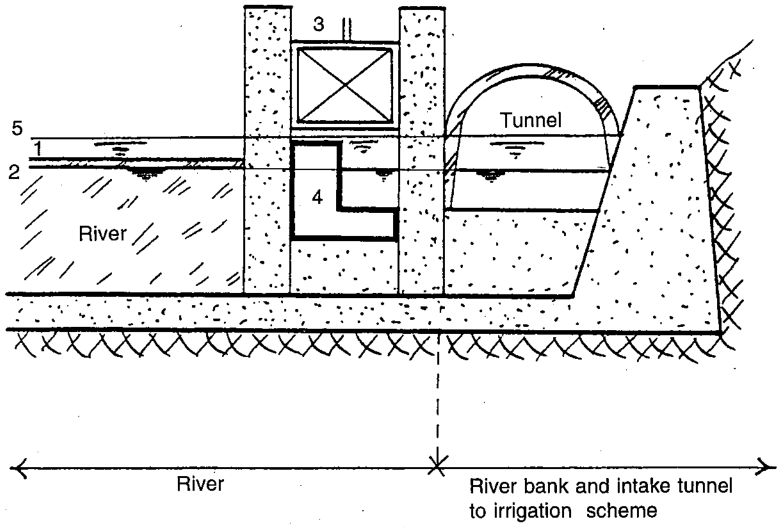
Figure 5.6.2. Modified flush gate to divide water among systems, Bali, Indonesia.



LEGEND

1. Weir crest
2. Water level in dry season
3. Open gate (never used)
4. Wooden planks installed by subak to match the tunnel floor level while still allowing some water to flow down the river for downstream schemes
5. Water level during floods

existing water rights among the different irrigation systems using water from the stream. A water-tight diversion generally does not have appropriate provision for equitable water sharing. Equitable in this case refers to sharing according to traditional water rights which are usually related to many historical factors and frequently do not imply equal access to water.

While there is generally a gate for scouring sediment away from the inlet, this is often not an acceptable device for adjusting the discharge to other systems diverting water from the stream. Frequently, the gates do not function properly because they are jammed open by sediment or a bent spindle. The elevation of the sill of the gate is usually not the same as that of the inlet to the canal, complicating comparison of discharge diverted to that passed downstream. Usually, it is difficult to see the water flowing through the gate and when it is visible, it is difficult to determine the proportion of water being diverted. The flow of water released is not proportional to the gate opening making visual checking of the relative proportions almost impossible. This encourages continual tampering with the gate adjustment. Access to the diversion is often difficult.

The irrigators' preference is for a method that will remain operational and reasonably accurate in dividing flows under fluctuating stream conditions. This example illustrates a modification that farmers made in a gated diversion to allow equitable water sharing within the basin.

The Irrigation System

The major diversion structure of the system in this example was improved by the project. It is complemented by a second (traditional) weir located downstream. The second weir irrigates the lower end of two combined systems. Before the project improved the diversion, these were two independent systems served from two weirs managed by separate subaks. Because the two weirs were traditional stone/brush diversion structures, leakage through the upper one was available for the lower system and others further down the river. The project combined the two systems by diverting water for both of them from an improved weir, sharing the water through a common canal.

A federation of subaks was created on the watershed to cater to the common good of such newly integrated systems. With the project's improved, permanent upper weir, less water is available to the second weir. The federation of subaks decided to revert to the traditional system (abandoned with the advent of the project) of dividing the watershed into three zones, allowing soaking and transplanting of fields in each zone in succession so that the peak water demand is staggered. This system has the additional advantage of eliminating major water-related pests.

During the dry season and when available discharge is scarce, irrigation water is rotated among branch canals and among individual farms within the scheme. While combining the two systems has reduced maintenance labor for both groups, farmers at the tail of the second system are far removed from the new diversion and continue to use their traditional diversion. As a result, the downstream subak requested that the project at times release just enough water past the improved diversion so that the tail-end farmers' requirements can be met by diverting water from their traditional weir. An agreement was reached to share a fixed ratio of water among systems. This was accomplished, as shown in Figure 5.6.2, by converting the scour gate, which was never used, into an opening of the correct dimension by using wooden planks.

Bali has a combination of river weirs diverting water to individual schemes and federations of subaks. This requires management of water and cropping decisions within and among irrigation systems in a watershed and at times even among adjacent watersheds. The mountainous terrain and irrigation schemes that are contiguous down the watershed are situations amenable to intensive irrigation regulation. An integrated physical and institutional infrastructure has evolved in Bali for effectively promoting and sustaining efficient and intensive irrigated agriculture basin-wide.

Example 5.7

Water-Capture Structures in the Peruvian Sierra

Raúl Valcárcel Manga[11] and Pieter van Driel[12]

Goal: *To divert discharges in the range 60 to 600 liters per second, with a structure which will be durable but with little complexity in materials, operation or maintenance, so that it is suitable for use and control by a farmers' organization.*

The Setting

This example describes the 12-year old PLAN MERISS-INKA program. PLAN MERISS is a government program responsible for improving irrigation in the southern sierra of Peru. This is a mountainous region at an altitude between 2,700 and 3,800 m. The mountain slopes are steep and eroded. There are also valleys with low gradients.

There is a rainy season during the months of October through April with the highest rainfall between November and March. It is dry during the rest of the year. The average annual precipitation varies from 600 to 750 mm. The average annual temperature is 13 °C. The highest mean annual temperature is 21 °C and the lowest is 5 °C. During the dry season, the temperature can drop as low as -10 °C at night in the higher areas.

The sources of irrigation water are usually rivers or streams though springs and small lakes are sometimes available in higher areas. The discharge of streams found in the region fluctuates throughout the year. The big rivers carry discharges of up to 1,000 m^3/s, and small rivers 20 m^3/s. In the dry season, discharge decreases to 20 m^3/s and 0.015 m^3/s, respectively. The quality of the water is good. However, if the source is a river, bed load material entering the canal is a problem.

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Major crops in the region are potatoes, maize, beans, wheat and barley. Some vegetables, quinoa and tarhui are also grown. Because landholdings are small and access to the steep fields is difficult, agriculture is not mechanized.

Livestock farming is extensive, though more concentrated in the higher areas, and includes cattle, llamas and alpacas. A major part of the agricultural production is the subsistence of the farmers, and there is little marketable surplus.

The soils, derived from alluvial deposit, are of clay and loam. In some valleys there is a gravel-sand-clay mixture. In general, the soils are suitable for irrigation though with some risk of erosion.

Landholding is quite fragmented. The average size of cultivated plots is less than one-third of a hectare. About 85 percent of the irrigated parcels are less than 0.75 ha. The fields are normally situated at mid-hill with slopes ranging from 1 to 20 percent. Access to most fields is limited to pack-trail.

The Irrigation System

For centuries, the population has been organized in peasant communities with a *junta directiva* (directive assembly). Some farmers owning larger properties do not join communal organizations. The organization is in charge, among other things, of the operation and maintenance of the irrigation systems; no external agency is involved. Therefore, there is a tradition of the users themselves managing irrigation. In a majority of the systems, a system serves one community or one sector of a community. There are also cases where the system includes more than one community. Typically, the area commanded by a system varies between 30 and 300 ha.

The priorities for annual water distribution among sectors of a community are decided by the communal assemblies. Leadership for this is provided either by a water judge or an irrigation committee. Their function is to organize water distribution, to mediate conflicts, to impose sanctions for infractions, and to organize maintenance. The maintenance of the main system (cleaning and small repairs) is carried out during two annual *faenas* (communal labor mobilizations). This is generally done at the time of traditional fiestas before land preparation and again after the rainy season. The faenas also serve as communal meetings where the problems and conflicts of irrigation are discussed. In addition, there are faenas for emergency repairs. The maintenance of the secondary part of the system is the obligation of the users of that part of the system.

Although a water law exists, water rights are clearly established by tradition. Monetary payment for water rights is not practiced. Rather, a "seasonal payment" to reclaim one's water right is made by one's own labor for maintenance and in the form of food and drink during the maintenance faenas.

Irrigation is by gravity flow. Irrigation allows early field preparation, which is important for avoiding frost at harvest time. Irrigation is again carried out immediately after sowing and as supplementary irrigation during dry spells in the rainy season. Irrigation for a second dry season crop is not common. Because of the steep topography, drainage is not a problem. In the rainy season, there is erosion and damage to the canal from runoff.

Design considerations

The management of traditional irrigation systems is based on the community assembly units, each holding traditional water rights. Members of a unit are all irrigators from a single diversion. Traditionally, a dam of stones and *champas* (sod) across the river is used to divert the water into the canal. In the rainy season, the river destroys the diversion and it is constructed again the next year.

The PLAN MERISS program initially used technical considerations in proposing that a permanent intake be built upstream of the traditional diversion. By building a new canal, all of the existing systems could be integrated into one new system and it was proposed that additional land could be irrigated. The objective was to reduce losses in the canal so that all sections of the canal could be guaranteed enough water. It was expected that water would reach the last field, irrigate some additional land, and also permit agricultural intensification by growing a dry season crop.

However, problems with traditional water rights, identification of responsibility for maintaining the new canal and river diversion, water distribution among communities, long distance to the new river intakes, unstable hillsides higher on the slope, and extensive lining of canals and a permanent river diversion that gave the impression that no maintenance was required, were all factors contributing to the failure of this approach. Joining canals implicitly assumed that an agency capable of managing the new system would be present. However, there is no agency able to step in and manage it at the system level and an agency was totally unnecessary since traditional users' organizations existed. The conclusion was that joining existing systems must definitely be avoided where there is an alternative, even if initial costs may be higher.

When it is necessary to join systems because of topography or excessive costs of all other alternatives, three questions must be discussed with the users and if the answers are not satisfactory it is best not to proceed with assistance: Can problems with existing traditional water rights arise and can they be solved? Can operation and maintenance be organized by the users for the new system? Are the users willing to join forces to organize the management of the new system? However, though verbal agreements on these issues may be obtained, conflicts very often persist after the new construction.

The present approach is to provide assistance to the traditional systems so that the improved system will be managed by the same users. Outside intervention only takes place during the improvement phase; not in the operation of the system. In the past, assistance took 5 to 10 years from identification to full operation. Today three to five years is maximum. The most important design considerations are:

- The traditional management unit must be maintained and strengthened to avoid unnecessary conflicts.
- There must be simplification rather than increased complexity in the operation and maintenance of the hydraulic structures.
- Maintenance of the whole system by the users must be possible.
- Assistance should assure a sufficient irrigation supply to meet the water demand of the whole system.

The Diversion (Water Capture) Structure

Consideration of the type of diversion structure is based on the magnitude of fluctuation in discharge of the river and the extent of bed load. Over 90 percent of the diversions are built on small rivers where the discharge varies from 0.1 to 20 m^3/s. In over 95 percent of the cases, the diversion selected is a weir with a gated side intake and a second gate for scouring the bed load. The weir maintains the upstream water level. Both gates function as submerged orifices and are made of metal with hand-wheel operation (Figures 5.7.1 and 5.7.2). The diversion capacity of the structures built by the project varies from 60 to 600 l/s for command areas ranging from 30 to 300 ha.

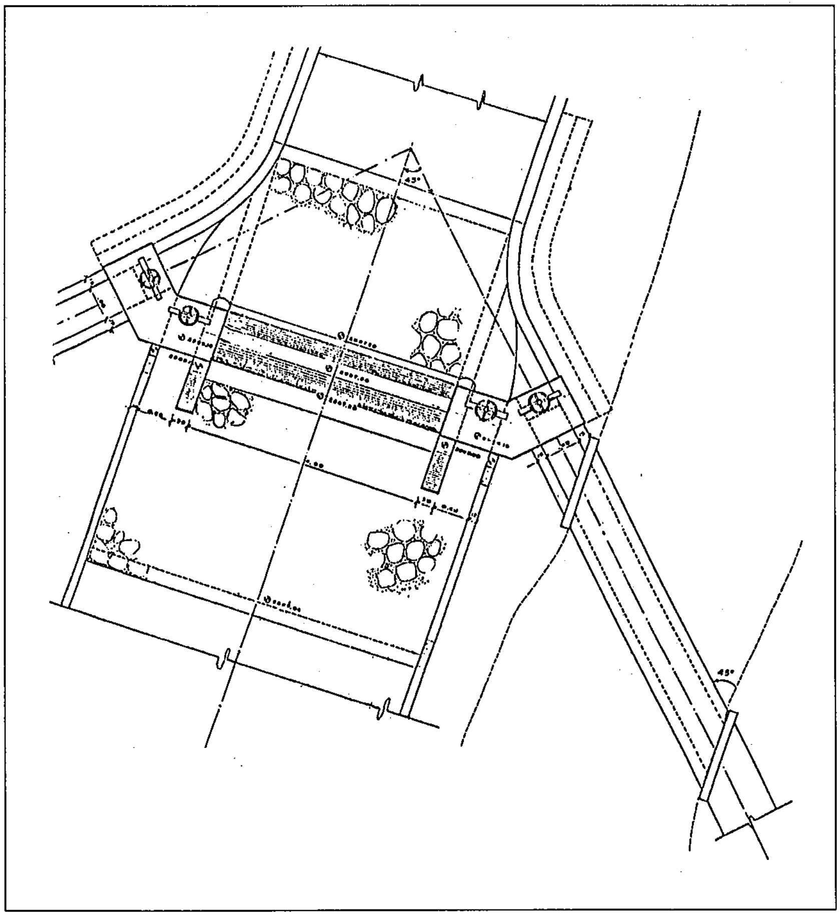
Sediment settles in the first few meters of the canal in a sandtrap and excess water is drained back to the river from a side spillway weir. There are also lateral walls that define the section of the river and protect the river banks from erosion. The riverbed is protected with a concrete floor upstream and downstream of the diversion, with a foundation at both ends to prevent it from being undercut.

Design discharge information is obtained from several sources. The water users have observed floods and can show flood stage marks and allow estimation of the maximum discharge. Periodic river discharge measurements are made over a one- or two-year period. A probability model is used to estimate discharge from data available from nearby watersheds. The maximum estimated flood with a return period of 100 years varies between 5 and 20 m^3/s for the small rivers.

There is a net of meteorological stations in the region. The data from these stations and the present cropping pattern are used to estimate the future water demand, including provision for a future second crop. Demand ranges from 1.1 to 1.8 l/s per hectare for daytime irrigation of 12 hours. The possibility of irrigating a new area is estimated by extending the demand of the existing irrigation and consideration of the minimum river flow.

In the hydraulic design procedure, the dimensions of the orifice are calculated by the formula for a submerged orifice using the design discharge. Estimation of extreme flood discharge defines the level of the top of the protection walls.

Figure 5.7.1. Plan view of diversion structure with outlet on each side of the river (PLAN MERISS-INKA, Peru).



The level of the top of the orifice is placed at the same level as the crest of the dam. The dimensions and geometry of the dam and of the stilling basin downstream of the dam are based on Creager's curve using maximum river discharge. The total width of the structure, including the protection walls, is between 5 and 9 m and its total length varies from 6 to 15 m. The foundation depth is determined by excavating a pit and the dimensions are defined by a normal structural and soil stability calculation procedure. It has been a deliberate policy to oversize the intake for possible future expansion of the irrigation area, in case it turns out that water availability is not a problem. The estimated life of diversion structures is 25 years and it is assumed that the government will again assist in building a new structure.

The costs of this type of diversions, including intake control and regulating structures, vary from US$5,000 to US$10,000 (1992 US$). This depends on local geological characteristics, discharge and width of the river and design discharge. This cost is typically about 5 to 10 percent of the total cost of improvements made in an irrigation system.

Stones, gravel and sand used in construction are generally found in the riverbed at or near the site. Cement must be purchased in Cusco and transported to the site. Sometimes it is necessary to build an access road for motorized transport. On other occasions, materials not locally available are transported to the site by donkeys.

The metallic gates are fabricated by a craftsman in Cusco. Otherwise the construction requires little skilled labor other than masons. All unskilled labor is provided by the users themselves. At the same time the users are trained in making repairs. to provide supervision of layout and However, an engineer is required at the site dimensions of the structure and to provide quality control.

The structure is operated by the users. Operation consists of the following tasks:

- Opening of the intake gate and, as necessary, closing the scouring gate to meet the demand for water.
- Closing of the intake gate when irrigation water is not needed or during maintenance, and during high river flow.
- Opening of the scour gate during floods to pass the bed load downstream.

Figure 5.7.2. River diversion (water capture) structure (PLAN MERISS-INKA, Peru).

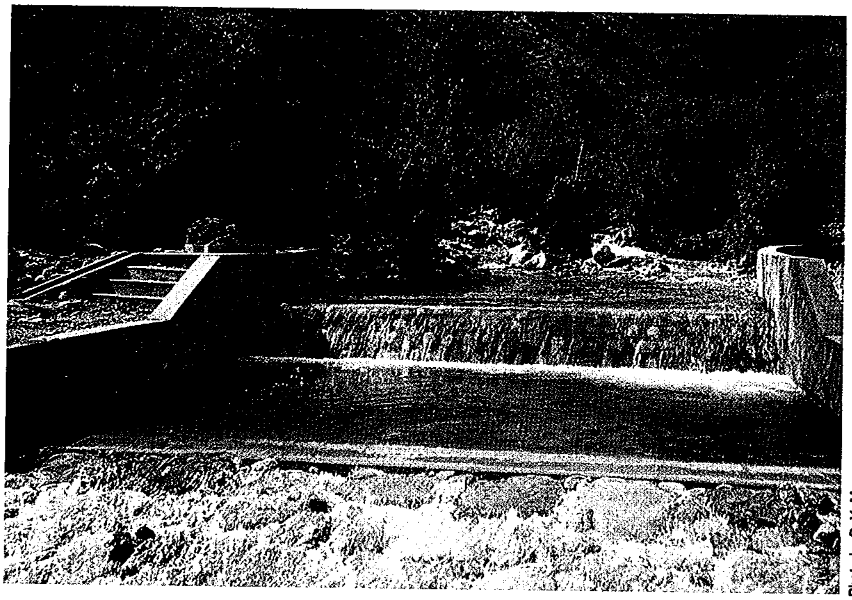


Photo by R. V. Manga.

Since operation is carried out by the users themselves, there is no monetary expenditure by the agency for operation. Generally, the operator is compensated by the community by providing labor for his fields.

Maintenance is generally not complicated. It consists of removing the bed load upstream of the structure that is not washed away by the river. This may be done once or twice each year. The moving parts must be greased and the metal gates must be painted regularly. Maintenance problems arise when gates are damaged. This has happened for several reasons, including improper operation, intentional damage by an irrigator, and by being hit by large stones moved during floods.

A major part of the bed load should be washed through the scour gates by the river. Practice has taught that the location and dimensions of these gates are very important. Locating them on both sides of the weir gives best results and reduces the need for removing bed load by hand. If possible, the structure should also be so located that the intake is on the outside bend of the river. However, this is not sufficient since the hydraulic characteristics of the river change at different flood stages.

Figure 5.7.3. Diversion structure submerged by transported bed material, Region Inka, Peru.

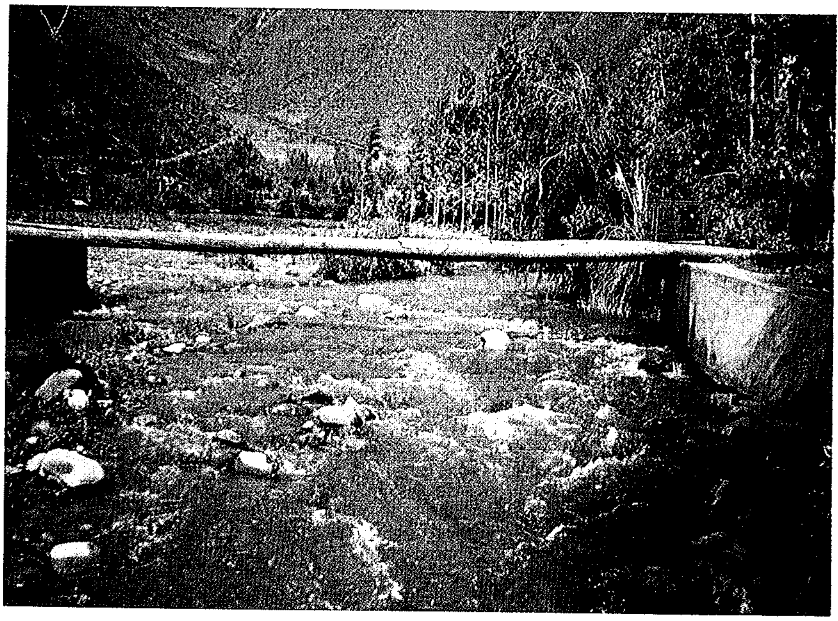
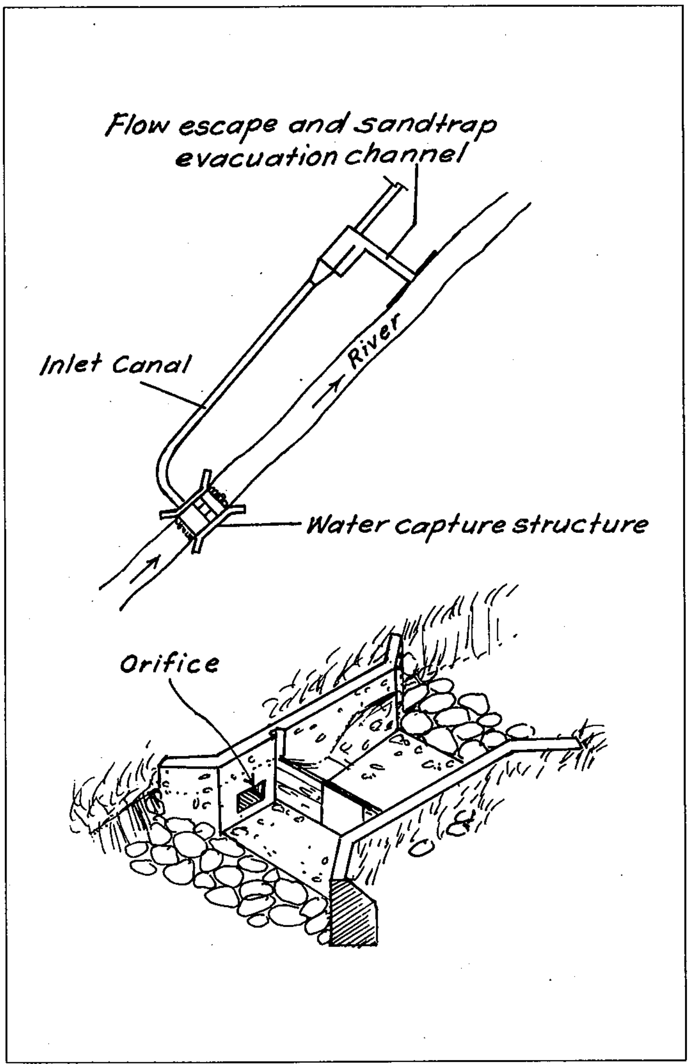


Photo by R. V. Manga.

It has been concluded that the longitudinal gradient of the riverbed is an important factor. The variations in gradient along the river result in sites with temporary accumulations of bed load under mild flood conditions which are again removed under extreme floods.

For example, some structures have been buried by the bed load (Figure 5.7.3). The experience of the farmers is valuable for selecting the sites for diversion structures,

Figure 5.7.4. Suggested design to reduce maintenance (PLAN MERISS, Peru).



because it is based on observation over generations. Traces of the old paths made by riverbed itself are also helpful in this.

Another lesson learned is that when metallic gates are damaged they cannot be repaired by the users.Sometimes this happens when they try to force the gate to close when rocks are lodged in the opening. It is best to use wood for the gates if possible.

Suggested Improvements in the Diversion Structure

Based on the experience of the past twelve years, several improvements can be suggested. The scouring gates should be constructed from wood, but more important, the intake gate can be removed altogether. Instead, an orifice opening without a gate should be used. The size of the orifice should just allow the design inflow when the water level is at the crest of the weir. This will result in about twice as much inflow during maximum floods. The intake flow in the canal can be regulated by the wooden spill gate located at the canal's sandtrap just downstream of the intake (Figure 5.7.4). When no water is needed in the canal, the gate in the sandtrap will be opened to drain the water back to the river. Finally, there should be a scour gate on each side of the structure to facilitate bed-load removal by the river.

Example 5.8

Headworks and Intake Structures in the Chirang District, Bhutan

Ian Smout,[13] R.J. van Bentum[14] and Langa Dorji[15]

Goal: *To divert water from small, steep, variable streams to supply small land units of less than 70 ha, using a standardized design with four size alternatives. The solution combines permanent works, out of reach of flood damage, with temporary, renewable works in the waterway, and a semipermanent foundation to reduce labor in the regular renewal procedure.*

The Setting

Chirang District in southern Bhutan has a monsoon climate with about 80 percent of the annual rainfall occurring between June and September. Mean annual rainfall is about 1,400 mm. At elevations below 1,000 m the climate is subtropical, but this changes to a warm temperate climate above 1,000 m, and frost can occur in the higher irrigated areas.

The main irrigated crop is wetland rice, which is transplanted during June-July after the early monsoon rains have increased river water flows and contributed to land-preparation needs. Some farmers also grow wheat under irrigation in the dry season (November to May), and those in small areas at low elevations manage a double rice crop.

The area is dominated by steep hills consisting of mica, schists, gneiss, phyllite, quartzite and limestone, and valleys have stream bed slopes ranging from 5 to 25 degrees. This results in flashy stream flows with high suspended sediment and bed loads of gravel and boulders during the monsoon.

In the Chirang Hill Irrigation Project, however, catchment areas above the canal intakes are relatively small, so that there is generally a shortage of water for the irrigated area, except during the middle of the monsoon.

The farmers have constructed numerous small canals originating from these rivers across the steep valley sides (cross-slopes generally steeper than 35°), often in unstable weathered material. The irrigated areas are flatter valley slopes where narrow bench terraces have been formed in the shallow clayey silt soils. Irrigated areas are found at altitudes ranging from about 600 to 1,400 m.

A typical farmer owns about 0.9 to 1.2 ha of irrigated rice land, and a similar area of dry land in which maize is the main crop. These crops have generally been grown for subsistence. The area also has good road access which has enabled the export of oranges and the import of rice.

The canals in this area, though they are relatively small, are similar to those built by farmers elsewhere in the Himalayan region. They are earthen canals with simple structures built of stone, earth and timber. From the river source, each canal runs by gravity along the river valley for about 1 or 2 km to the irrigated area. The poor soil banks, steep slopes and rudimentary structures result in high transit losses from the canals.

As well as conveying water from the source, the canal also collects water from the numerous springs, drainage channels and small streams which flow across it. The use of this water is governed by complicated rules and agreements among the farmers. When water is available, it is diverted into the canal, up to the limit of the canal's capacity.

Command areas vary from a few hectares to about 70 hectares, but a typical canal supplies some 10 hectares of land belonging to about 10

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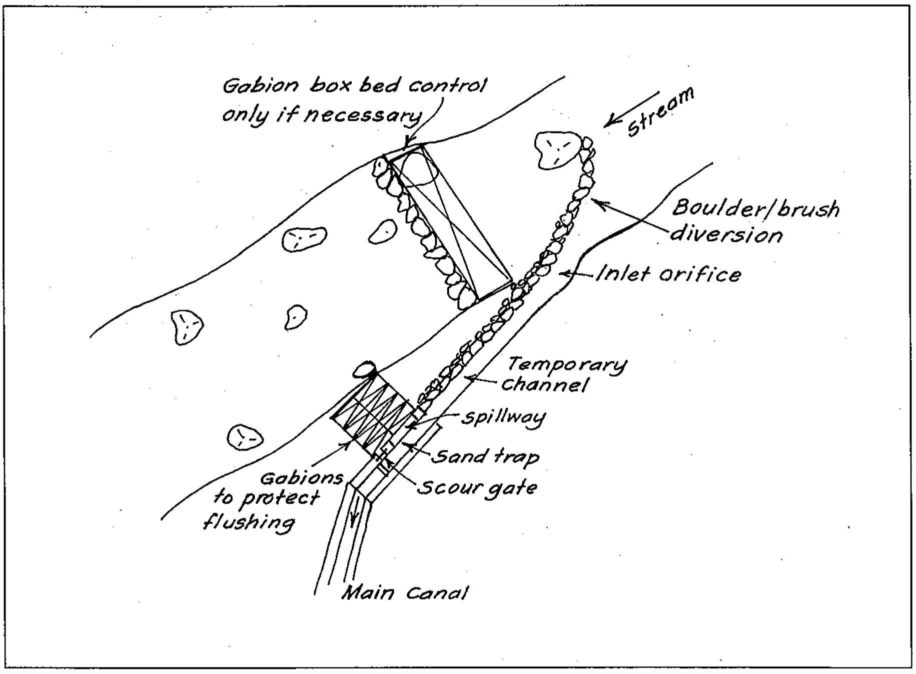
farming families, who are often related. On each canal, the water is generally taken by the farmers in turn, with priority given to the traditional owner or leader. Irrigation distribution is by field-to-field flow.

In the past, the allocation of irrigation turns and maintenance work has been organized by the traditional leader. Under the project, a water users' association (WUA) was set up on each canal, and the farmers elected a chairman, a secretary/treasurer [who collected funds for operation and maintenance(O&M)] and a water guard (who was responsible for O&M). The project provided initial training for these officials and it was intended that the local government extension staff would monitor the canal from time to time after completion of the project. If a serious problem arose, the WUA or the extension staff can call on local government technical staff to advise and assist if possible. Similarly, serious disputes which the chairman cannot resolve are dealt with by the local government. The farmers decided on a water charge to be collected and held by the WUA.

The Headworks and Intake Structure

This intake structure is designed to control the inflow of water from a stream into a gravity canal. It is a standard structure, intended for use on some 80 canals which were to be improved under the project. These canals covered a wide variety of situations, and the structure was designed in four sizes, to cover standard discharges of 26, 56, 104 and 164 l/s, respectively. These corresponded to four different canal sizes.

Figure 5.8.1. Plan view of headworks for the Chirang Hill Irrigation Project, Bhutan.



A permanent intake structure forms part of the headworks together with a temporary channel at the side of the stream to convey water from the diversion to the intake (Figure 5.8.1). The intake structure itself consisted of three parts: 1) a sandtrap to prevent sand, gravel and cobbles from entering the canal from the stream, with a scour gate to enable the sandtrap to be flushed clean; 2) an inlet to the channel comprising an orifice to prevent excessive flows entering the canal at high river levels and a steel gate to enable the flow into the canal to be stopped when not required (especially to exclude flood water with a high sediment load); and 3) a side spillway to discharge flood flows safely away from the canal. The construction material used was cement masonry (random rubble masonry), comprising hard stone with a 1:4 sand cement mortar. The gates were designed for local manufacture from steel.

The standard headwork structures were kept to a few simple works, which the project could construct with its limited resources of technical staff, masons and equipment. These proved to be cost-effective and were also quite simple for the farmers to operate and maintain.

In many cases, the existing intake site was retained. Normally, it had been chosen by the farmers after trial and error and familiarity with the stream from many years' experience, and they had made a good choice. Also, moving the intake would involve difficult realignment of the channel. In some cases, however, the traditional site had been destroyed, or was unsuitable, and a new site was sought. On these steep boulder bed rivers, the main features required were: 1) relatively flat slope (preferably with large boulders), 2) stable banks, preferably with a well-protected site for the intake as, for example, behind a large rock, and 3) straight channel section, giving relatively uniform flow.

Care was taken to site the intake structure where it was protected from damage by the river, as for example, set back from the channel and above high flood level, or on the river bank behind a large rock. Where a rock face was exposed, the intake structure would preferably be built on a solid rock bench to eliminate the need for elaborate gabion construction for the spillway and scour channel. Figures 5.8.1 and 5.8.2 show the gated inlet, spillway, and sandtrap design layout with the gabion protection.

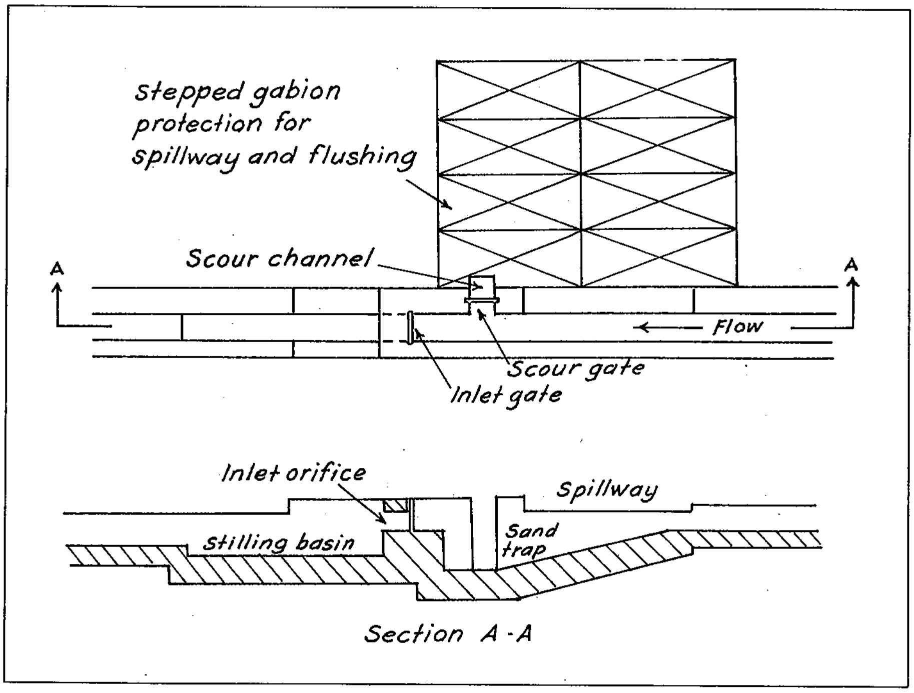
Site investigation included walking the length of the existing canal with some of the farmers, identifying the problem areas, agreeing on the works to be carried out, and collecting information. The latter included examination of the length of the canal and the command area necessary for determining the design discharge of the canal corresponding to one of the four standard canal sizes. Following the standard design, the dimensions of the intake structure were determined directly from the design discharge, except for the scour channel which was site specific.

The recommended diversion structure was a small temporary weir or training bund, made of boulders and brushwood. This was the type of weir traditionally used by the local farmers, and they were accustomed to modifying it according to the river flow, and rebuilding it after it had been washed away.

Small streams at higher elevations had low dry-season flows causing problems of water availability. They were also narrower, with lower peak flows, and generally did not carry such large boulders as compared to the larger streams downhill. Therefore, in favorable locations, a more permanent structure might be durable and cost-effective on these streams.

The proposed solution was a gabion-box bed control with downstream boulder protection to prevent scour under the box, as shown in Figures 5.8.1 and 5.8.2. The gabion box kept the bed level stable so that villagers could build a boulder and brushwood bank on top to divert low flows. Use of gabions was preferred to cement masonry, as gabions are more flexible. However, the bed load at times of flood was likely to damage the gabion wire, so the structure will have a limited life.

Figure 5.8.2: Gated intake, spillway and sandtrap design used in the Chirang Hill Irrigation Project, Bhutan.



In general, cement masonry or concrete diversion structures are not recommended in rivers with beds of movable stones and boulders. This rule is based on experience elsewhere —many diversion structures have been destroyed on hill streams in the past. All the streams in the Chirang area had beds of movable stones and boulders. In these circumstances, rigid obstruction in the channel would be prone to failure due to bed movements and impact from boulders. Also, bed material would accumulate behind a weir, raising the upstream bed level as well as the high flood level, thus reducing its effectiveness as a diversion structure.

A channel was needed to convey water from the diversion structure to the permanent intake structure which was built in a secure and stable position. This channel, therefore, usually ran from low water level to above high flood level downstream. As any permanent channel would be prone to damage during flood flows a temporary channel was used. This was partially excavated, with an outer bank of boulders and brushwood which was built by the farmers and rebuilt as necessary. Upstream of the intake structure a gabion or dry stone orifice block was provided in all cases to protect the structure from flood flows.

The permanent intake structure, as normally constructed, is shown in Figure 5.8.2. The intake structure was required to control the flow water and sediment into the channel. It was designed to satisfy the following objectives: 1) minimum width to suit restricted sites, 2) capable of being closed when irrigation is not required, 3) if left open during floods, prevent peak flows from passing down the channel and, instead, divert them over a spillway, 4) trap bed load and remove it easily by opening a scour gate, and 5) reasonably simple and cheap to construct.

The structure comprised a gated intake, spillway and sand trap. It was of the same width as the standard canal and it included a broad-crested weir-cum-gated orifice for controlling inflow to the channel. If desired, a gauge could be set with its zero at weir crest level to measure the head over the weir and hence calculate discharge.

The orifice prevents floods from entering the channel, and diverts excess water over the spillway. Bed load brought in from the river would be deposited in the small sand trap below the weir crest, and could be scoured back to the river by operating a scour gate. The structure was made of cement masonry (random rubble masonry), with gabions used to route the excess water back to the river. The gabions also protect the foundations from erosive river flows and act as a retaining wall.

Where possible the intake and sandtrap are built on rock so that river scour is avoided and flows from the scour gate do not undermine the structure. The structure required a scour gate to flush the sand trap, and an intake gate on the orifice to the canal. The scour gate had the more critical specification, as it would normally be closed and had to withstand a head of up to 1 m in normal operation, without excessive leakage. This can be a serious problem at times of low water availability from the river. The intake gate was less of a problem as it was normally open during operation. When closed, the head across it would typically be less than 0.50 m and minor leakage would not be a serious problem.

Other irrigation projects in Bhutan used steel gates which were manufactured within the country, and it was decided to use steel gates on this project as well. Alternative materials such as wood or concrete were unsuitable for the scour gate because of leakage. Wooden intake gates would have had a very short life. Precast concrete gates and matching frames might have been feasible for the intake gate, with the structure revised to accommodate them. The gates are shown in Figures 5.8.3 and 5.8.4.

The intake was arranged with a sill directly under the inlet gate. The sill was designed as a broad-crested weir that would allow a flow of 125 percent design discharge to pass freely before the orifice control came into effect. It was thought that farmers would object to the restriction of flow through the orifice under normal conditions, and that this should only take place at peak flows. The crest length and height of the inlet weir were set from standard hydraulic recommendations to perform satisfactorily over the range of flows, so that the weir could be used for flow measurement if required. The downstream stilling basin was also designed to standard criteria for a drop structure.

The stability of the walls was the main concern in the structural design. The design was prepared for the condition with the canal empty and surcharge provided by an earth slope above the canal at a maximum slope of 1:1. Stability against overturning was provided by the 5:1 backslope on the wall. In practice, structural failure appeared more likely to arise from occasional powerful land movements than from design loads such as these. Failures will occur in such circumstances, requiring major repairs, and it is probably not cost-effective to try to prevent this.

Figure 5.8.3. Looking downstream at the silting chamber with spillway visible in the foreground, just upstream of the scour gate on the right and inlet gate on the left, Chirang Hills, Bhutan.

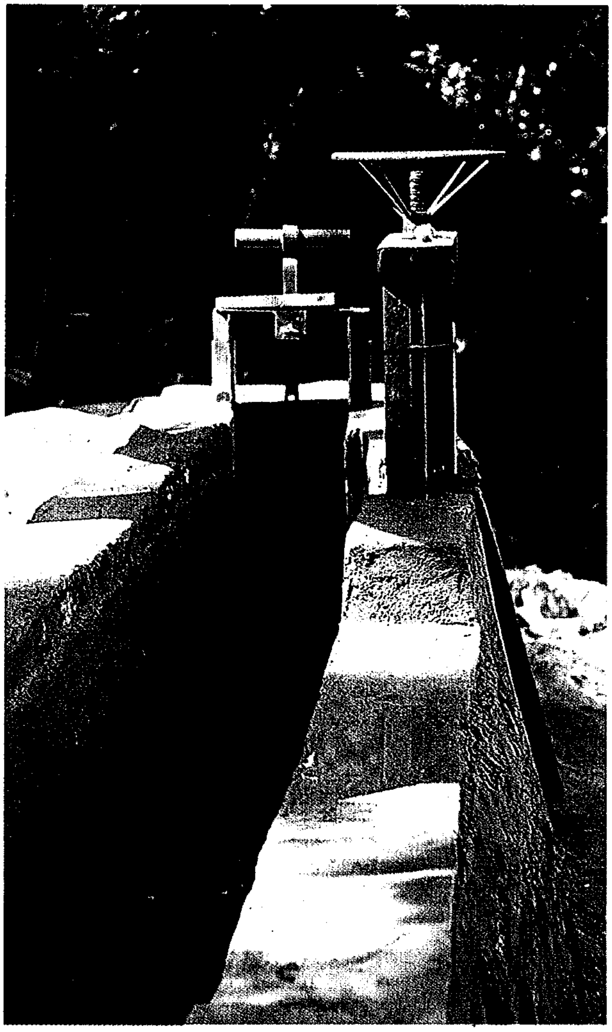


Photo by I. Smout.

Although the design sandtrap width is the same as the channel width, the inside width of the sandtrap is often increased on site to 0.5 m so that space facilitates masonry work.

The intake gate is a vertical lifting gate of steel plate running in a narrow groove formed by two standard angle sections separated by a narrow flat plate. Below the gate, a flat sill was used, rather than a groove which could get filled with sand and gravel giving a poor fit and leakage. The handle was made of standard steel pipe, and a pin was used through the stem and frame to hold the gate open.

The scour gate was designed with similar grooves and a flat sill. A central spindle was used for lifting the gate with a wheel and drive nut. The nut was of bronze to prevent corrosion and held in position by a seat which was welded to the top of the gate frame.

The temporary diversion bank and headreach channel needed regular attention to deliver the required flow to the intake. Otherwise, the main maintenance requirements were to fill any scour holes at the headworks with large stones, to grease the stem of the scour gate twice a year, and to remove rust from the intake gate and scour gate and apply paint. It was recognized that the farmers would have difficulty obtaining a suitable paint to apply to the gates each year as recommended.

Figure 5.8.4. A view of the outlet side of the scour gate, Chirang Hills, Bhutan.

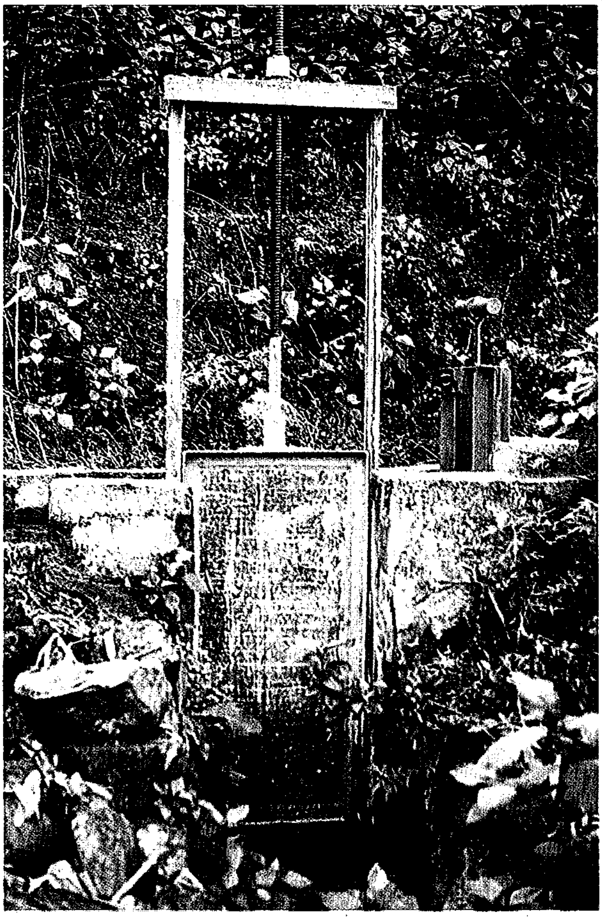


Photo by I. Smout.

Evaluation of Structure

One problem was that the temporary upstream diversion bank became infested with crabs, which broke any mud seal between the boulders and caused high rates of seepage through the structure.

The intake structure was operated satisfactorily by the farmers. It was found that during the monsoon, the sandtrap filled up rapidly and the scour gate had to be opened daily to flush it clean.

The main problem was with the gates. The welding of the seat of the nut proved inadequate to secure the scour gate, and a number of gates became inoperable after this failure.

Example 5.9

Side Intake with Settling Basin, Palpa, Nepal

Achyut Man Singh[16]

Goal: *To divert 3 m^3/s of water from a steep and variable river that carries flows up to 400 m^3/s with a high content of boulders, using a permanent structure in the context of joint farmer/agency management. To minimize vulnerable structural intervention in the waterway, a side intake with tunnel was chosen.*

The Setting

The Rampurphant Irrigation System is located in the sub-Himalayan hills known as the Mahabharat Range at an elevation of 300 to 500 m. The annual rainfall is about 2,000 mm. Over 80 percent of the rain falls during the monsoon from June to September. It is cool from October to March with only a few winter showers. The pre-monsoon period from April to May is hot and dry with strong thunder showers just before the monsoon.

It takes about one day to walk to the irrigation system from the nearest road. The command area consists of river terraces formed by the Kali Gandaki River. The command area is incised by a number of local streams forming deep gullies. Farmers have used these streams to irrigate about 275 ha in the area of the new system, which has a total area of over 600 ha.

The Irrigation System

The irrigation system, completed in 1989, was constructed by the Department of Irrigation. Operation and maintenance are being carried out by the Department, but a water users' association has been formed and the system is expected to be jointly managed by the Department and the users in the future. At present, irrigated rice is grown in just over half of the command area, with the remainder cultivated to rain-fed maize during the monsoon. Farmers grow some wheat during winter. The average landholding in the command area is about 1.2 ha.

The system consists of a side intake, settling basin, main canal and five branch canals. The capacity of the main canal is 3 m^3/s and water is augmented from two streams that the canal crosses. The total length of the main canal is 22 km. The total length of the branch canals is nearly 15 km. Construction of the branch canals has not been completed, and this has severely affected the distribution of water. Construction of laterals has been left to the farmers and has not been completed.

The diversion structure is on the Nisti River with a catchment area of about 180 km^2. This is a medium-size hill stream with a minimum flow of 0.9

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[16] Senior Divisional Engineer, Department of Irrigation, Pokhara, Nepal.

m^3/s in the dry season and a maximum of 400 m^3/s in the rainy season. When in flood, the stream carries a heavy bed load including boulders. The side intake does not obstruct the flow and maintenance has been minimal at the intake.

Floods have caused damage to the covered canal protection in the headreach portion. However, the most difficult problem is a landslide-prone area near the headworks through which the main canal passes. During the 1991 monsoon, a large landslide occurred. When it was partly cleared, another slide completely covered the canal. This could not be removed in time to save the rice crop.

The Intake Structure

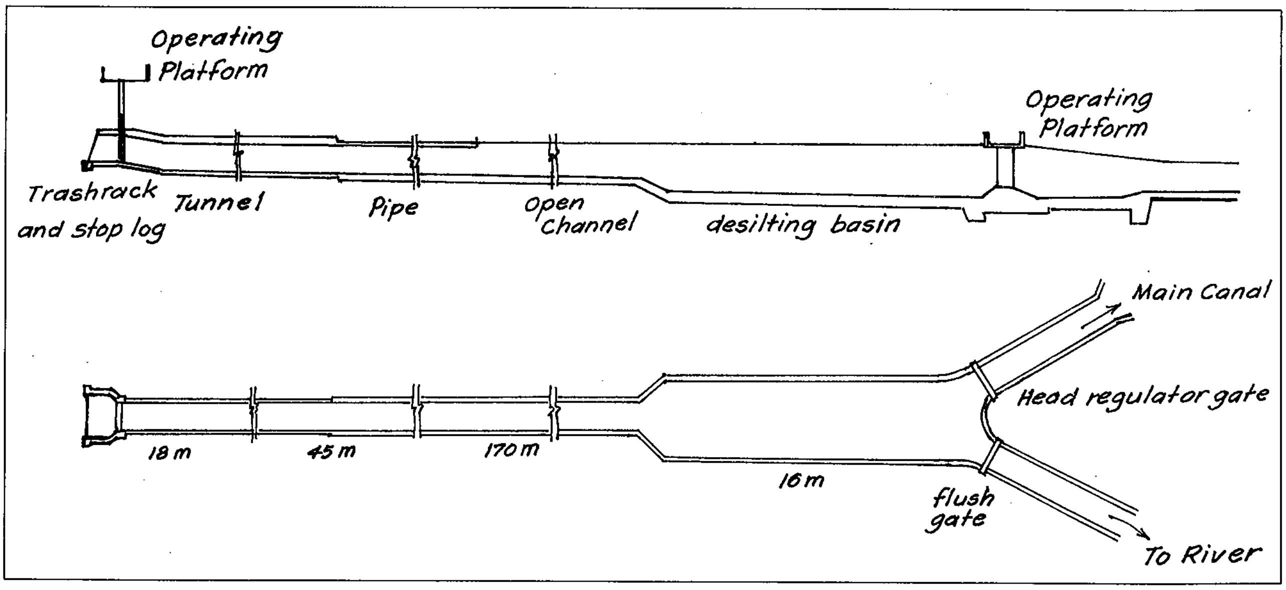
The nature of mountain and hill streams and rivers varies according to the steepness of the bed slope and the bed load characteristics. Any diversion structure built creates high turbulence and causes scouring. In some cases, the bed load causes a high level of abrasion. The hydraulic characteristics of a river change with different flood stages. Bed material deposited during one flood may be removed by the next.

Experiences in Nepal show that structures built across wild mountain rivers require significant maintenance and there is a high probability of damage each year. If the water can be diverted without any effect on the river regime or disturbance to the flow pattern, less maintenance will be required. Trench-type intakes have been introduced in a number of hill irrigation systems in Nepal and are functioning satisfactorily.

The Rampurphant System headworks site was selected because of the rock formation. Hard rock was exposed on both sides of the river. Initially, a trench type headwork was proposed because of the good foundation and because it would cause little disturbance to the river flow. However, when the site was examined by a team of experienced engineers, they suggested a side intake. They found that a deep natural pool at the bend in the river with a nearly vertical wall of hard rock provided the ideal situation for a side intake.

Figure 5.9.1 gives the layout of the Rampurphant headworks. The rock wall on the river side was cut into a bell-mouth shape to accommodate the trash screen and regulating gate. Reinforced concrete walls were constructed to fix these into place with masonry projection on the river side. Water is conveyed from the intake through an 11 m tunnel and then through a covered masonry canal into the desilting chamber about 250 m from the intake. The settling basin is 16 m long and 4.2 m wide. Two gates regulate the desilting. One is a scour gate for removing the sediment from the chamber and the second controls the discharge allowed into the canal.

Figure 5.9.1. Side intake with settling basin, Rampurphant, Palpa, Nepal.



The design discharge of the intake, tunnel, and canal to the desilting chamber is the sum of the design discharge of the canal and discharge required to scour the silting chamber. The settling basin was designed to trap sediment that enters the canal through the trash screen. Gravel up to 2 cm and coarse sand accumulate in the desilting chamber and are scoured out regularly.

The necessary cement and reinforcing steel had to be transported by porter from the nearest road head, about 20 km away. Hence the structure and the system as a whole constitute a comparatively expensive endeavor.

While the system has been shut down due to the landslide problems mentioned above, the intake structure has gone through several years of successful operation.

Example 5.10

Bottom Intake, Bauraha, Nepal

B.B. Gurung[17]

Goal: *To divert water for a 50 ha system from a steep, variable river with flood velocities of 4 m/s and high content of boulders and large debris, using a permanent structure in the context of operation and maintenance by farmers only. Capital expenditure on a permanent structure was needed because a traditional structure was requiring 3,000 person-days per year of maintenance, and excessive quantities of scarce forest products.*

The Setting

This example describes a bottom intake constructed by a collaborative program between CARE International in Nepal and the Agricultural Development Bank of Nepal in the Rapti Zone of the far western region of the country. The two organizations worked together in a program for improving existing farmer-managed irrigation systems and assisting farmers in building new systems whose operation and management are the responsibility of the farmers.

The irrigation system diverts water from the Bauraha River in the foothills of Siwalik Range on the left bank of the Rapti River. The Bauraha River provides a perennial water supply. The river originates in the Siwalik Hills which are steep and highly erodible. Over its 12 km length, the Bauraha River drops in elevation from 800 to 300 m. At the location of the diversion, the riverbed is made up of boulders. During the rainy season from July through September, the river carries a huge bed load. During floods, gravel, big boulders and often tree trunks are moved. The flow velocity in a flash flood exceeds 4 m/s with tremendous energy to wash out everything in its way. In the local language, the word “bauraha” means “mad” since the river behaves like a “mad dog.”

The Irrigation System

The history of this system dates back about half a century. A traditional farmer-built intake of stones and branches diverted water into the canal. The 3.5 km long earthen canal had several wooden aqueducts to cross small streams. There are two villages in the command area, which cover about 50 ha. Maintaining the intake was a major problem for the community since it got washed out many times each monsoon. Repairs to the intake alone required roughly 3,000 person-days of labor each year. The farmers claimed that all the villagers,

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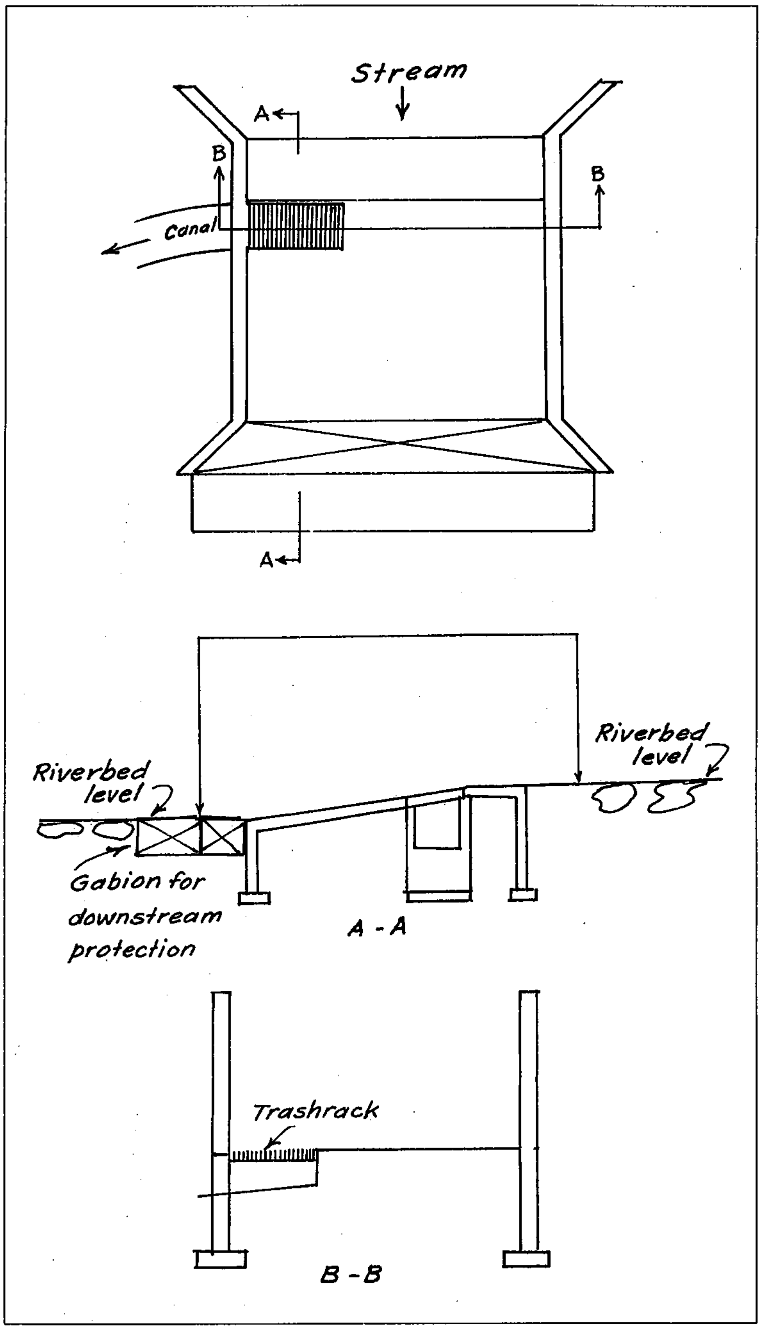
[17] Irrigation Engineer, CARE International in Nepal, Kathmandu, Nepal.

Figure 5.10.1. Bottom intake headworks, Bauraha, Nepal.



regardless of age and sex, had to work day and night "like in a battle" to keep the system working. In order to repair the intake, each year, about 300 bundles of bushes and trees were required causing deforestation in the watershed.

Bottom Intake with Trashrack

With the imperative that operation and maintenance of the system would remain in the hands of the farmers, three options were considered for improving the diversion structure: 1) a gabion weir, 2) a masonry weir with gates, and 3) a masonry weir with bottom-intake trench and trashrack. Since the low flow during the dry season is only 30 l/s, it was decided that a gabion weir would not be appropriate because losses by seepage through the structure would be unacceptably high. Moreover, gabions are not a permanent solution for such a wild river as the Bauraha and would need to be replaced every few years, which would be difficult for the irrigators.

Analysis was made of a masonry weir with gates. This was compared to a bottom intake with a trench and trashrack. The following points were considered:

- The Bauraha River carries sand, gravel, boulders, and sometimes tree trunks at flood velocities that exceed 3 m/s. This could smash the gates and other structures that are exposed. The trench-type intake is less exposed and can pass floods more easily.
- Gates need to be operated and are often inaccessible during floods. The trashrack used in a bottom intake is self-cleaning and does not require attendance during floods, making it suitable when the headwork is inaccessible and far away from the community.
- Gates are often tampered with and frequently broken. It is difficult for irrigators to maintain or replace gates. The trashrack of a trench-type intake can also be broken by huge boulders unless it is designed to withstand the largest load. However, there are no loose parts which can be stolen since it is welded into one integral section and grouted into the body of the weir.

- The trashrack for the bottom intake in this example was much cheaper, US$100 versus US$670 for a comparable gate.
- There is appreciable leakage through gates which can be serious when the dry season discharge is extremely low. A bottom intake solves all leakage problems.
- The operational platform and support structure for a gate are expensive and not needed for a bottom intake.
- A trashrack can be designed to operate satisfactorily even when the velocity is greater than 3 m/s.

The bottom intake was selected as the best option for the Bauraha River. The general features are given in Figure 5.10.1.

Figure 5.10.2. Trashrack after fabrication, Bauraha, Nepal.

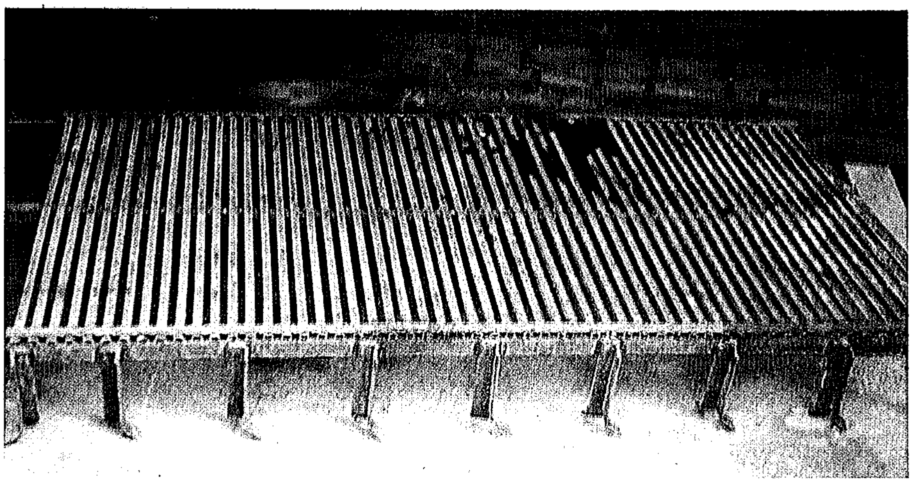


Photo by B. Gurung.

Figure 5.10.3. Bottom intake in operation, Bauraha, Nepal.

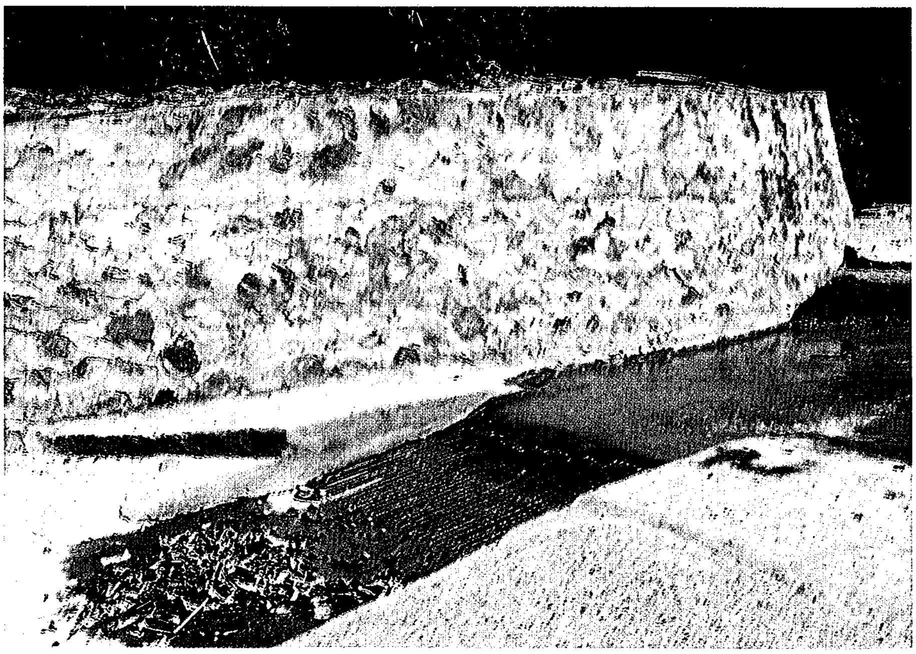


Photo by B. Gurung.

The trashrack for the bottom type intake was made of equally spaced 20 x 30 mm "tee" bars placed parallel with 15 mm openings between bars (Figure 5.10.2). The bars were welded to a frame at the ends. The design discharge was 200 l/s. With 0.7 m long bars, the trashrack needed to be 1.5 m wide to accommodate the design flow.

The trashrack was placed on the top of the trench made in the body of the weir. It was placed at a slope of about 1 to 10 in the direction of flow. Figure 5.10.3 shows the bottom intake in operation.

The total cost of a bottom intake structure with a 20 m long weir and a trashrack 1.5 m by 0.7 m (0.7 m in the direction of water flow) was US$10,000 (1989 US$). This cost includes the reinforced concrete weir and both upstream and downstream cutoff walls. The system has functioned through two monsoon seasons without problems.

Example 5.11

Spillway for Dam across a Small Stream at Wayura, Sulawesi, Indonesia

John Williamson[18]

Goal: *To protect an earthen dam, which had already been built by farmers and had been damaged by flood over-topping, on a stream whose flood flow was unmeasured. The solution incorporated a spillway and a 1.5 m breaching section in the 60 m long dam, but the farmers did not know the concept of a planned breach and implemented it incorrectly.*

The Setting

This example describes an irrigation structure for a system in Central Sulawesi, Indonesia. It is from the experience with the Mayoa Transmigration Project mentioned in Example 5.4. The project was located in a large valley surrounded by mountains, south of Lake Poso, at an elevation of about 600 m above sea level. Total annual rainfall is about 4,000 mm with much of it occurring during the rainy season from March to May when daily rainfall can be extremely heavy. The highest rainfall recorded during a five-year period was 160 mm in 24 hours. Intense storms of 80-100 mm in a 5-hour period are common, flooding large areas. Between August and November, the weather is hot and dry.

Farmers taking part in the irrigation projects included transmigrants who have moved from other Indonesian islands such as Java, Bali and Lombok as well as local Poso farmers. Most have had extensive experience with irrigating rice.

The Irrigation System

The water source in this example was a small stream coming from a flat swamp with a small watershed area. The stream had low flows of less than 0.1 m^3/s but a flood discharge of some hundred times that. The farmers attempted to control the stream with an earthwork dam and a crude wooden spillway. The spillway was a wooden structure with stacked wooden branches and logs which break during a flood. If the flood was too great for the breach, then part of the earthen dam would also break. Farmers spent large amounts of time repairing these dams following floods. In some instances, frustrated farmers abandoned the dams because the cost of maintenance was too high.

While the farmers were limited in developing their irrigation scheme due to a shortage of capital and a lack of technical expertise, their initiative in constructing the dam demonstrated enthusiasm and willingness to mobilize labor and management resources.

The Spillway and Breach for the Wayura Earth Dam

When the Mayoa Transmigration Project Irrigation Program was underway, one of the first villages to ask for assistance was Wayura. This village was made up of persons who fled from religious violence in southern Sulawesi during the 1960s.

Wayura farmers had recently built an earthen dam across a swamp to raise the water level in order that water could flow into a newly built canal for their new rice fields. The earthen dam measured over 60 m in length and 2 m in height in the deepest section. Farmers built the dam using materials available at the site such as clay reinforced with tree trunks. Seventy persons built the earth dam in four days' time.

The Wayura farmers built the dam largely on the initiative of the village head without any technical assistance from outside. These farmers

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[18] Engineer, Mennonite Central Committee, Irian Jaya, Indonesia.

had little experience with irrigation and no experience in constructing dams. They had not built a spillway structure, and the dam broke once when flood waters crested over the lowest part of the dam.

When investigating the dam, the Mayoa Transmigration Project technical staff was impressed by the large amount of labor already mobilized for constructing the dam and for digging the canal. The obvious problem which had to be overcome was that of controlling floods too large to pass into the canal.

No stream flow data were available. The watershed drainage area of the stream was also difficult to determine and flood flows were impossible to ascertain. The engineer listened to the farmers explaining their problems. Everyone agreed that a permanent masonry spillway should be built which would allow flood waters to bypass the dam. The engineer, however, was not able to determine the length of spillway required for this dam when no historical data or other information were available to determine the size of the maximum flood.

The engineer and farmers walked about on the earthen dam to determine the best location for building the spillway. If it was built in the middle where the dam was the highest, obviously the spillway would be large and therefore expensive. At the side of the dam, a small gully went around the dam, rejoining the stream about 75 m downstream from the dam. The farmers and the engineer chose this location since it required the least amount of work.

The engineer proposed that a five-meter long spillway be built at the side of the dam (Figure 5.11.1). The spillway itself was only 50 cm high. Wing walls on either side were 75 cm higher, thus allowing a discharge 75 cm deep and 5 m wide to pass through during a flood. The spillway level was set to allow all normal flow to enter the canal. Farmers carried 3 m^3 of stone and sand a distance of 5 km from the quarry to the dam location for construction. The Mayoa Transmigration Project contributed 320 kg of cement.

Would the spillway be large enough for the worst flood? If it was too short, then the dam would again overtop and possibly break. The engineer suggested that a section of the dam be constructed in a way that it would breach with minimum damage to the structure if the spillway could not handle the flood. Few farmers understood what he meant, since they had never seen such a structure.

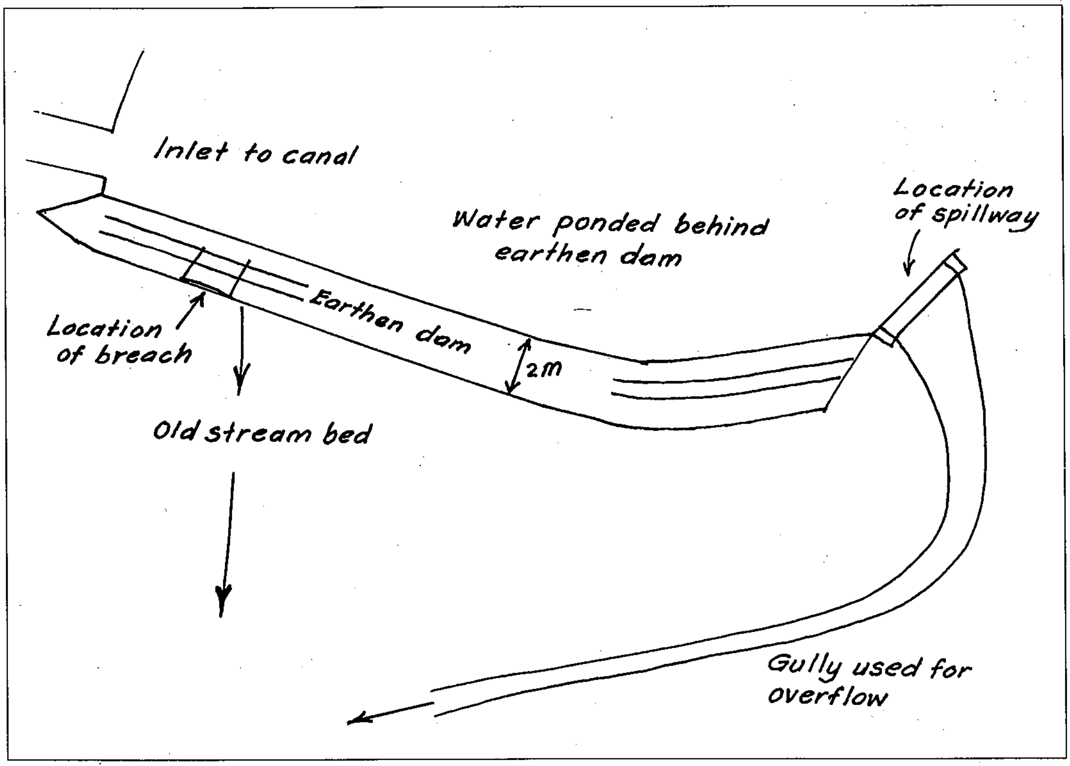
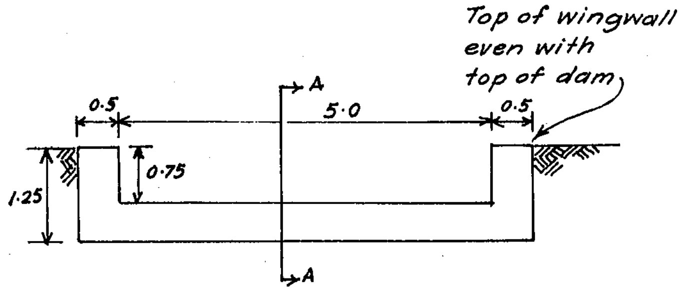
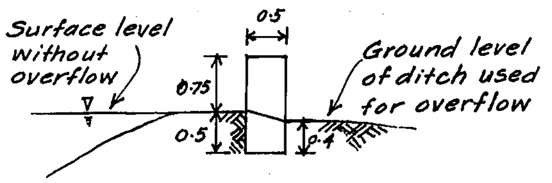


Figure 5.11.1. Layout of the spillway and breach structures for the Wayura Irrigation System, Sulawesi, Indonesia.

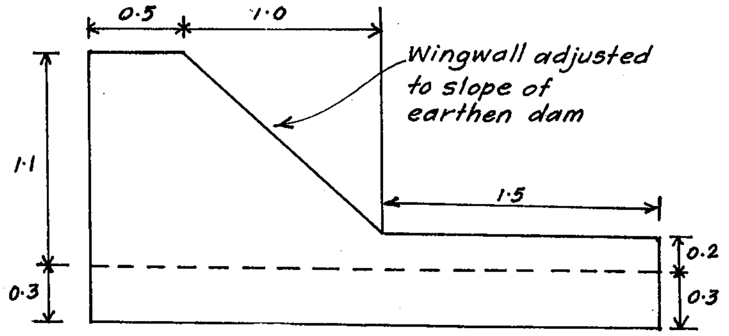
Figure 5.11.2. Details of the spillway and breach structures for the Wayura Irrigation System, Sulawesi, Indonesia.



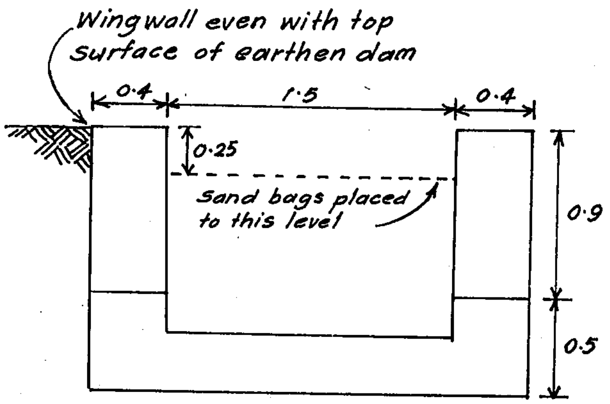
SPILLWAY: VIEW FROM UPSTREAM



SECTION A - A



BREACHING SECTION: SIDE VIEW



BREACHING SECTION: VIEW FROM DOWNSTREAM

A breach structure consists of a masonry opening in the dam 1.1 m deep and 1.5 m wide which can then be filled with sand bags. The side wing walls are even with the top surface of the earthen dam. The sandbags fill the breach opening to a level 50 cm above the spillway and 25 cm below that of the top of the earth dam (Figure 5.11.2).

A breach has the advantage that it will open automatically during a flood, thus saving the earthen dam. During a flood, after the water level rises 50 cm above the spillway, water will begin to flow over the sandbags in the breach. As the water level continues to rise, more water will flow over the sandbags causing them to open up, allowing more water to pass through. When the flood is over, only the breach has to be repaired by replacing the sandbags.

The spillway is working according to plan. Flood waters pass over the masonry spillway and no longer through the earth dam. The diverted flood water began to erode the gully and farmers placed logs along the gully to help dissipate the energy of the swiftly flowing stream.

Several months after construction of the spillway, the farmers built the masonry breach. It was built in the widest part of the earth dam very near the former stream bed. The breach was built in the downstream part of the dam, leaving the front part intact. The masonry wing walls and floor were built according to plan. However the breach was never filled with sandbags and the upstream part of the dam was never opened to expose the structure. Since the farmers never understood the concept of the breach, they never completed it. So far the breach has been unnecessary since the spillway has been able to control all of the flood water.

Example 5.12

Silt Excluder for Lift Irrigation System in Himachal Pradesh, India

U.C. Pande[19]

Goal: *To protect the capital equipment in a lift-pumping station, by removing sediments from water which is diverted from a silt-laden river, before the water is pumped up 48 m to supply an irrigated area at a higher elevation. The management context is that the government pays for the structure but wishes it to be operable by the farmers.*

The Setting

A large number of lift irrigation systems have been built by the Department of Irrigation and Public Health of Himachal Pradesh in North India. Some of the systems built recently have received foreign donor assistance. It is envisaged that ultimately farmer-irrigation committees will be given the responsibility of water distribution and system operation for these schemes. This example describes a silt exclusion device for the Sia Bhardwan Lift Irrigation System in the Balh Valley.

Over the past 16-year period, the average annual rainfall in the Balh Valley has been 1,350 mm. Much of this falls during the monsoon from June through September. For example, rainfall in July and August averages 400 and 350 mm, respectively while in the months of October through December it is only 10 to 15 mm/month. The climate is subtropical with summer temperatures moving up to 35 °C, and from December through January temperatures dropping as low as 0 °C.

The fertile Balh Valley has always been a granary for the princely state of Suket. Suket was merged with the Mandi District of Himachal Pradesh after India attained independence. As elsewhere in this northern Himalayan state of India, Balh Valley has been served by numerous farmer-managed irrigation systems since ancient times. Most of the farmer-managed systems are operated and maintained by farmers without any intervention from the state.

Following the earlier success in growing and marketing apples from this hilly region, farmers in the valleys are shifting from cereal to vegetable cash crops. Wherever vegetable crops have been established, income has improved greatly. This has led to a demand for enlarging irrigation facilities for areas where land is suitable for vegetable production. Many government and private tubewells have been installed in the valley.

The Irrigation System

The Sia Bhardwan Lift Irrigation Scheme was built recently. The system is in Mandi District near the town of Sundernagar. A temporary earthen embankment is made annually to divert water from the Suketi River into a lined channel. The design discharge is about 225 l/s. The channel leads the water to the sedimentation tank and then on to the pump station. Three centrifugal pumps of 100 hp each are installed to lift the water 48 m. A 450 mm diameter pressure pipe is used to deliver the water from the pumps to a small sump at the highest point in the command area. Field channels radiate from the sump to cover the entire 227 ha command area by gravity flow. The command area is spread over 5 villages and ranges from 800 to 825 m in elevation.

The Suketi River carries a large amount of silt, especially in the monsoon season. The sedimentation tank is necessary to remove the silt before it reaches the pumps. Silt removal is

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[19] Irrigation Consultant, New Delhi, India.

necessary to reduce the wear on the pumps. It was also determined that spreading such a high amount of silt on the fields would reduce soil quality.

The Sedimentation Tank

As it was intended that eventually the irrigation system would be managed by the irrigators, it was important to design a settling tank that is effective in removing the silt but does not require specialized training for operation.

The tank is divided into two main compartments each having a series of baffle walls that divide it into six sub-compartments (Figures 5.12.1 and 5.12.2). The river water enters one end of the tank from the feeder canal and travels through all of the compartments. This gives sufficient time for sediment particles to settle.

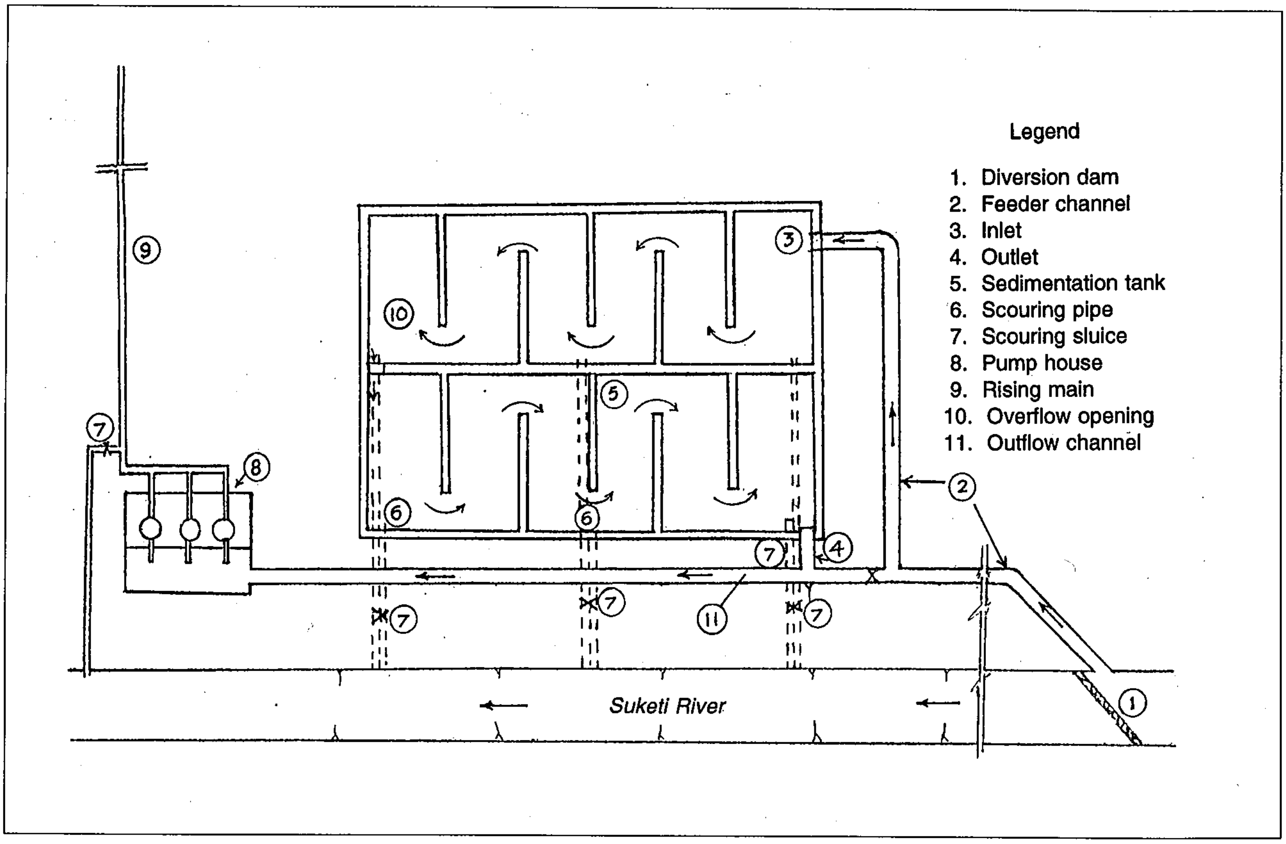
A circular opening at the top of the central wall in the last of the first six sub-compartments allows water with a reduced silt load to enter the second compartment. A similar opening in the last sub-compartment leads the water back into the feeder channel which delivers the clean water to the pumps.

A scour pipe is located below the tank and connected to various compartments by a sluice valve. This is used to periodically flush out the silt that accumulates in the tank. During the monsoon, flushing must be done each day.

The sedimentation tank has substantially reduced the amount of silt reaching the pumps. The flushing arrangement requires no special skill. Thus the two main design considerations are adequately fulfilled. However, the tank is an expensive structure. If flushing is not carried out regularly the silt will deposit and set so that a great deal of manual effort is required to remove it.

Because the government provided all the funds for its construction, and considerable time and motivation are required to operate the

Figure 5.12.1. Schematic layout of the sedimentation tank in the Sia Bhardwan Lift Irrigation System, Himachal Pradesh, India.



sedimentation tank properly, there is some doubt as to whether the irrigators will be willing to take over its operation. Hopefully, the prospect of economic gain from the project and the need to preserve land quality will provide the necessary motivation.

Figure 5.12.2. Sedimentation tank of the Sia Bhardwan Lift Irrigation System, Himachal Pradesh, India.

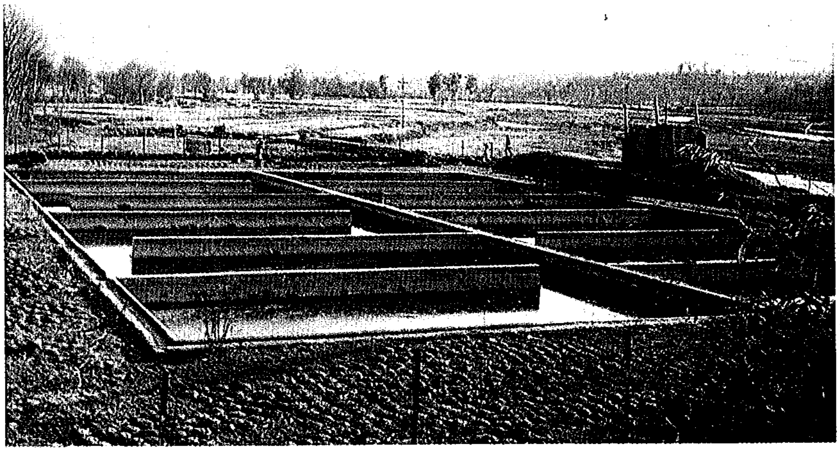


Photo by U.C. Pande.

Example 5.13

Fumeiyi Pumping Station, Yunnan Province, China

Liu Zhaoyi,[20] Li Jishan[21] and Wang Demao[22]

Goal: *To lift water from a lake to irrigate 780 ha of mountainside land, to a total elevation of 36 m, combining flexible water delivery with minimization of cost, in the context of subsequent management of the facilities by the village local government unit. The solution involved lifting in three stages to different tracts of land, thus reducing the energy cost of operations.*

The Setting

Fumeiyi Irrigation District covers six villages and irrigates about 780 ha. It is situated in Yinqiao Village, Dali County, Yunnan Province, in the southwest part of China. The elevation of the irrigated land is between 1,975 m and 2,004 m. It is terraced from west to east with a slope of just over 1 percent. There is no apparent slope in the north to south direction. The Dian-Zhang highway passes through this district and there is a road network for tractors. The major crops in this area are rice, corn, wheat, beans and rape with an average total yield of about 12,000 kg/ha per year.

The climate is subtropical monsoon with an annual mean temperature of about 15 °C. The annual precipitation is about 1,200 mm with over 85 percent of it concentrated in the period from May to October. The annual evaporation is nearly 1,200 mm. There is danger of frost on about 140 days.

In one out of every four years there is spring drought which delays the transplanting of rice. Such delays can cause the plants to be harmed by low August temperatures in the later stages, thus

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reducing yields; these low temperatures in August occur in about 35 percent of years. Early summer drought occurs about twice every five years and seriously reduces the output of wheat, beans and rape.

In this example, it is not possible, due to topographic features, to divert irrigation water by gravity. Instead water must be pumped from a lake, Erhai Lake. The terrain and hydrological conditions make it impossible to construct reservoirs.

The Fumeiyi Pumping Station was completed in 1991. This is a three-stage pumping unit. The first-stage unit is located at the side of Erhai Lake. It irrigates 238 ha and supplies water to the pumps of the second stage. The second stage irrigates 260 ha and supplies water to the pumps of the third stage which irrigates 286 ha. The static design head is 11.0 m for the first and the second stages, and 13.7 m for the third stage pumps. Farmland at the highest elevation in the district can be irrigated when the pumping station is running at the design output.

Figure 5.13.1. Front view of the second-stage pump station, Fumeiyi, Yunnan Province, China.

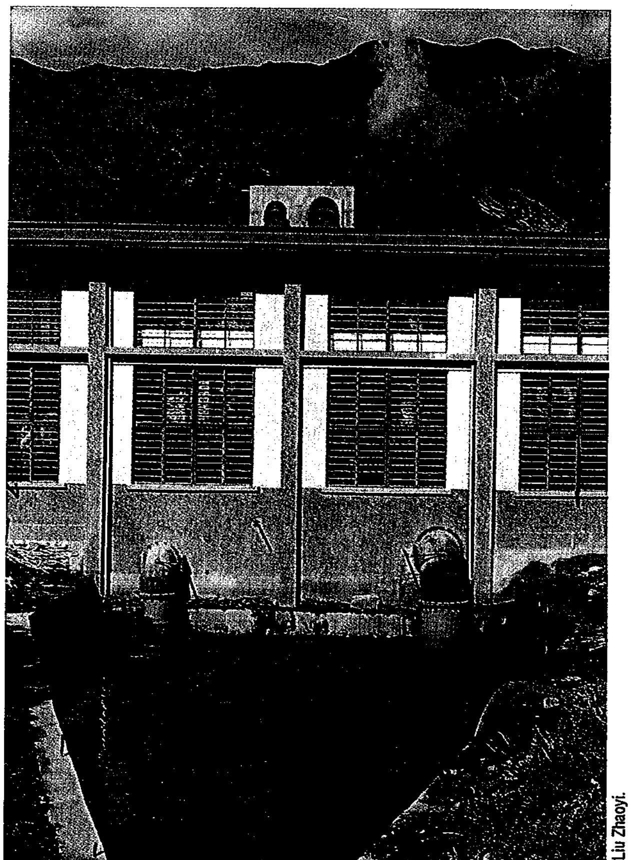


Photo by Liu Zhaoyi.

The three-stage scheme was based on the least power method, a compromise between minimizing the capital cost and minimizing the running cost. The irrigation water requirement for a given area of land in the district depends upon numerous factors. The total water requirement of crops during the growing season and the peak daily water demand were determined by an experimental station located in the neighboring irrigation district and by discussion with experienced farmers.

A total flow rate of 2.1 m^3/s was determined to be 95 percent dependable for irrigation. The discharge of each station was computed as a percentage of the area irrigated by each. The actual discharge of each station should be slightly greater in order to facilitate operation and regulation of discharge in the entire system.

Horizontal, volute, mixed-flow pumps were selected because of their high efficiency and convenience in installation and maintenance. Three pumps, two identical and slightly larger than the third were used in the first stage, and two pumps of different sizes were used in each of the other two stages. The type and size of pumps used were specially selected in order to make management of operation more flexible. Operational experience has shown that the pump selection and matching were a success.

To illustrate the design, the second-stage pumping station consisting of a pump house, intake and discharge chamber are described here. Figure 5.13.2 shows a plan and profile view of the pump station. Figure 5.13.1 shows a front view of the pumphouse. The arrangement of the suction and discharge was set in the direction of flow to reduce energy losses due to vortex and deflection of flow.

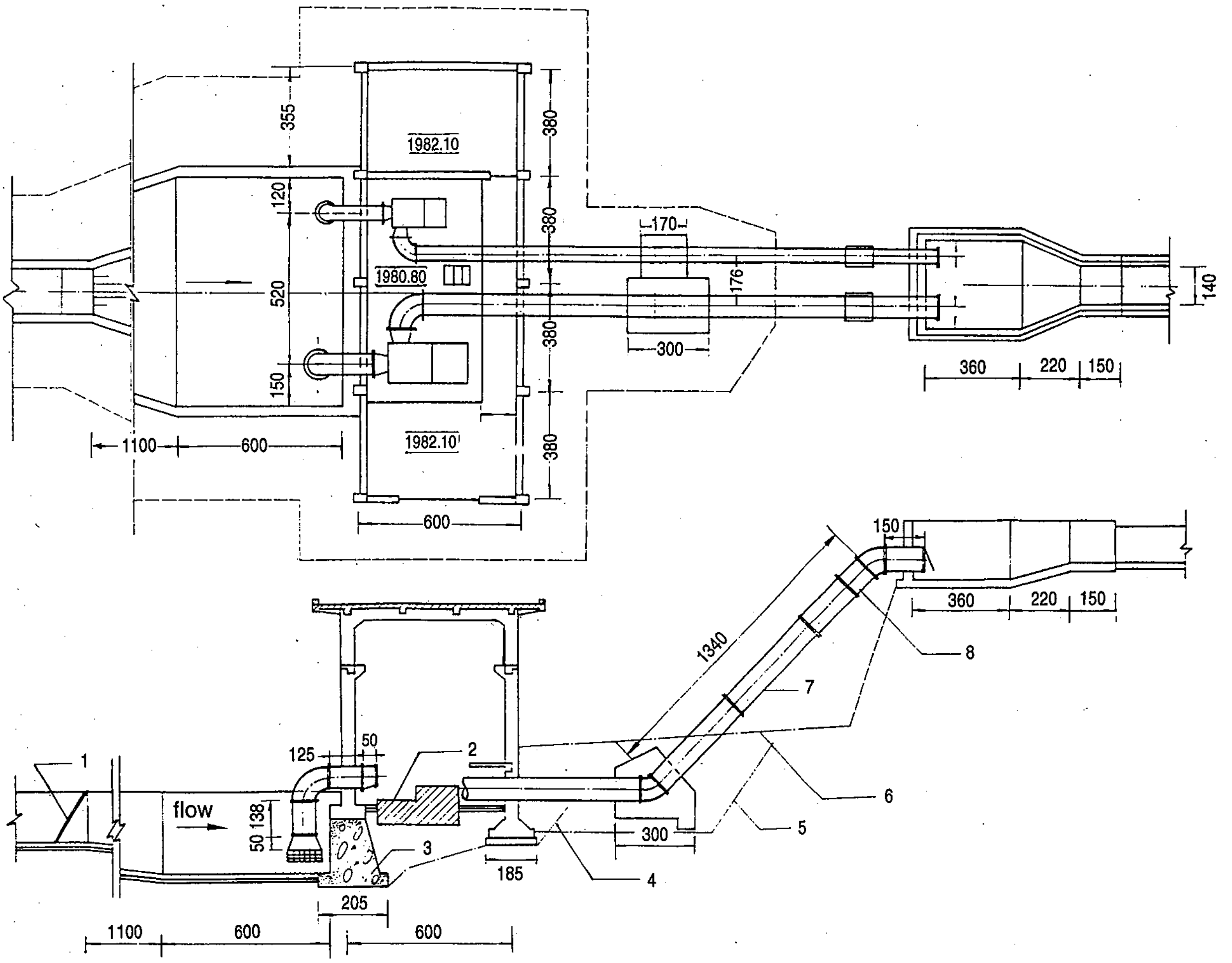
The discharge pipe passes through the back wall of the pump house, and is connected to a 45° bend which is fixed in a concrete pillar. The rest of the pipe is straight and is laid on a slope. Another 45° bend is used to connect it with the discharge chamber.

Separate suction and discharge pipes were used for each pump. The total length of a discharge pipe is about 23 m. The diameter of the discharge pipe is 500 mm for the smaller pump and 800 mm for the larger one. The suction pipe is about 4 m long and 800 mm in diameter. A strainer was installed at the inlet of the suction pipe to prevent trash from entering. A flap-valve was used at the outlet of a discharge pipe to prevent reverse flow. To reduce losses, no foot-valve was installed at the inlet of a suction pipe and a vacuum pump was used to prime the pump.

The technical and administrative affairs of the Fumeiyi Pumping Stations are supervised by one section of the Water Conservancy Bureau of Yinqiao Village. A computer program was developed to minimize energy consumption per unit volume of water pumped and to balance discharge among stations. Optimal operation charts and tables were prepared so that technical staff of the stations can select the best operation scheme and minimize the time needed to start and stop pumps.

The technical staff working at the pumping stations manage and operate them according to the "Technical Management Code For Pumping Stations" issued by the Ministry of Water Resources and Electric Power. This code was prepared to improve the technical conditions of pumping stations.

Figure 5.13.2. Plan and cross section of the second-stage pump station, Fumeiyi, Yunnan Province, China.



1. Trashrack
2. Foundation of pump
3. 100 # concrete
4. Sand and gravel refilling
5. Contour of excavation
6. Original ground
7. Discharge pipeline
8. Length—flexible joint

Example 5.14

Streamside Pumpwell, Rajasthan, India

Christopher Scott[23]

Goal: *To lift water from a sediment-laden stream with a wide range of discharge variation, for a small irrigated area of about 10 ha, in the context of operation by a local community with principally female labor. The solution involved a well at the stream bank, tapping the subsurface flow as well as the stream flow by a system of underdrains containing graded stone filter materials to restrict sediment from entering the well.*

The Setting

The streamside pumpwell is an intake structure for upland lift irrigation particularly suited to conditions where variabilities in discharge, stage and sediment load are high. The setting is in the village of Dolpura in the Aravalli Hills of southern Rajasthan, India. A pumpwell was constructed as part of a lift irrigation scheme. The project was supported by a local nongovernmental organization (NGO) and the irrigation system is managed by farmers.

Average annual rainfall in Dolpura is 600 mm, with extremely high variation in the annual rainfall. By far, the major portion of the annual total occurs during the June-August monsoon. Occasional winter rains in December do not generate significant surface runoff. Surface flow in the Wagwara Nala, the site of the Dolpura pumpwell, is about 2 to 10 l/s from September through May, although baseflow is considerable. Rainfall-intensity data for the area suggest that the 25-year maximum discharge in the stream is as high as 400 m^3/s. Based on calculations using Manning's equation, the major flood in June 1988 (not exceeded since 1973, according to local residents) had an estimated discharge of 200 m^3/s. Sediment load in the stream during heavy monsoon discharges is high. After three deficient monsoons, the flood of 1988 deposited 30 cm of sediment in the reservoir just upstream of the pumpwell. Variabilities of discharge and stage, coupled with high sediment load, posed the most important physical design criteria for an intake structure.

Agriculture in Dolpura is largely subsistence-oriented. With high rates of male migration south to Gujarat for employment, women have become the primary agricultural laborers in Dolpura. Labor mobilization is most difficult in the pre-monsoon season, which coincides with the season of food shortage.

Irrigable landholdings are small, averaging less than 0.2 ha per household, although landlessness is uncommon. Based on ten years of experience in community forestry, irrigation from private wells, and the construction of a community center for meetings, a viable community organization exists in Dolpura with equitable and participatory decision-making structures. For this reason, irrigation system operation has a high degree of flexibility.

Dolpura is distant from urban centers, making pump repair difficult. The clogging of intakes, pump impellers and distribution pipes has been a problem in the past. This, and labor constraints in the pre-monsoon period when maintenance of irrigation structures is routinely carried out, make ease of maintenance the primary design consideration from the perspective of management capability.

The Irrigation System

The pumpwell is sited between two reservoirs on the Wagwara Nala. The upper reservoir has a catchment area of 9,500 ha and a storage capacity of 165,000 m^3 while the lower reservoir is considerably smaller in capacity. The primary

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function of the two reservoirs is to raise water levels in numerous wells scattered throughout the village. Supplemental irrigation from wells using traditional animal-draft lifting devices as well as government-subsidized diesel centrifugal pumps is common in Dolpura.

The elevation of the command is approximately 300 m, with lift to the command area ranging from 23 to 25 m, depending on the stage of the stream. A 10 HP diesel engine powers a centrifugal pump, which lifts water via a 75 mm PVC pipe. The command area is 9.6 ha, and is to be expanded to 12 ha. The command is situated between a sloping rock outcrop and a natural ravine; field drainage is not a problem. Soils are silty and sandy loam. *Kharif* (June-October) crops in the command include maize and alfalfa, while *rabi* (November-February) crops include wheat, gram and mustard. Dolpura is not on an all-weather road, and is distant from markets; nonetheless, the men have expressed interest in growing onion, garlic and turmeric for the market.

Surface water rights among irrigation systems are not clearly defined and downstream residents of the Depur village have voiced concern that the Dolpura reservoir would diminish supply to their reservoir. Monsoon surface discharge and perennial base discharge appear to be high enough, however, to satisfy both demands.

Given the relatively equitable distribution of land, allocation of irrigation water within the system is done on a landholding basis. Irrigation water is managed by a water users' association (WUA), with a pump operator in charge. The NGO that supports the project also gets involved in conflict resolution, which has been an issue in the past.

The entire village provided 25 percent of the labor costs of reservoir construction through *shramdan* (voluntary labor). The remainder of the construction and capital costs were provided by the NGO. Minor maintenance is performed by the WUA, although major maintenance has been provided by the NGO. Irrigators cover the operating costs.

Some contiguous streamside land had high production potential with bunded fields and good soils. Households with such land sought an alternative to individual irrigation from private wells. Irrigation by *chadas* and *rahat* (Persian wheels and skin bags raised by oxen) is extremely time consuming. The few households that own pumps draw down water so quickly that everyone loses out, despite recharge from the two reservoirs. With constraints on labor mobilization for maintenance, Dolpura residents expressed interest in community-based irrigation. Because the community organization already had a participatory decision-making process, it was felt that community-based irrigation would be more viable than irrigation from private wells.

The Streamside Pumpwell

In upland streams and rivers, lift irrigation intake structures may encounter operational problems caused by extreme variabilities in stream discharge, stage and sediment load. Surface intakes are unreliable in streams with significant seasonal fluctuation in discharge. Floating barges are expensive, and there is risk of total loss. Excavated, open lift points are quickly filled in with sediment. In addition to addressing such physical constraints, the design of a reliable intake structure must take into account local-management capability and labor constraints and consider the trade-off between initial investment and long-term maintenance.

Several alternatives were considered: deepening open field wells; drilling a tubewell; lifting directly from the stream and from pumpwells without underdrains, or from pumpwells with underdrains. Open field wells 8-15 m deep are rapidly drawn down due to low recharge rates in the semipermeable rock. Recharge from the reservoirs is not rapid enough to allow irrigation of the entire potential command. Additionally, fluctuations in water levels exceeding the suction lift of centrifugal pumps often necessitate costly moveable pump platforms. Submersible pumps are not an option in that Dolpura has no electricity nor are submersible pumps subsidized. The cost of drilling a tubewell for irrigation of 10-12 ha is prohibitive, particularly given the shortage of drilling equipment during the 1986-88 drought.

It was determined that the Wagwara Nala is the only low-cost and reliable water source. Previously constructed open lift points in the stream filled in rapidly with sediment. Pumpwells were also constructed in earlier work carried out by the NGO. However, without underdrains, the water within each well was quickly drawn down. The incremental cost of constructing sidewalls and underdrains (Rs 10,000 or US$700 in 1988) was equivalent to five years of maintenance expenditure for an open streamside well. On the basis of these facts the decision was made to construct a pumpwell with underdrains as shown schematically in Figure 5.14.1.

Maximum and minimum stream discharges were determined from villagers' memory as well as from hydrological calculations using interpolated rainfall-intensity data. Villagers' recollections of high and low stage levels, as well as descriptions of baseflow availability, were invaluable sources of information for the design process. Irrigation lift and distribution points were surveyed to determine lift elevations as well as the total command area. A team of villagers using tape measures ascertained the dimensions of individual holdings, getting average length and width for irregularly shaped holdings. These results tallied well (within 25% error) with the topographic survey.

Local masons involved in the construction of the upper reservoir weir were adept at slaking lime, overseeing the mortar mixing, laying the coursed stone masonry, and generally offering design and construction advice. Because the quality of local stone and sand was poor, construction materials were trucked in from varying distances. The cost differential between lime and cement is considerable in Rajasthan. For this reason, cement was used in the mortar only for the submerged foundation, in a sand-cement ratio of 4:1, while lime was used for the superstructure, in a sand-lime ratio of 6:1.

The pumpwell was sited directly below the command against a rock outcrop to prevent damage from undercutting. The well and underdrains were excavated and blasted to a depth below the stream bed of 3.00 m and 1.50 m, respectively (Figure 5.14.2 [a]). The underdrains were excavated with a slight slope to allow flow into the well. The underdrains were filled with layers of crushed stone, gravel, and sand, respectively, from bottom to top. The graded fill reduces the entry of sediment into the pumpwell and obviates the need for sediment traps. Additionally, where the well is built in rock, the underdrains reduce drawdown during pumping.

The sidewalls were constructed with inner walls having a slight batter (1:10) to withstand hydraulic forces exerted during high-flow periods as shown in Figure 5.14.2 (a). The crest width of the walls is 0.50 m. The sidewall and pump house were designed with a freeboard of 1 m above the high-flood level over the lower dam. Where the underdrains lead into the well, recharge openings with stone lintels were provided as shown in Figure 5.14.2 (b). The 2.00 m width of the underdrain was designed assuming that in low-flow periods, only base flow is available at the phreatic surface 1 m below the stream bed. Underdrains were extended into the stream bed until they reached the permeable substrate of the stream bed which carries baseflow. The underdrains of the Dolpura pumpwell are 5.00 m in length.

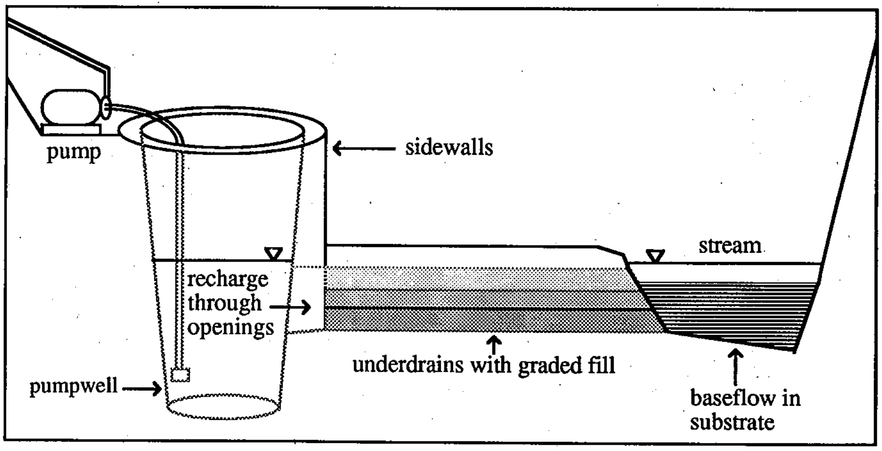
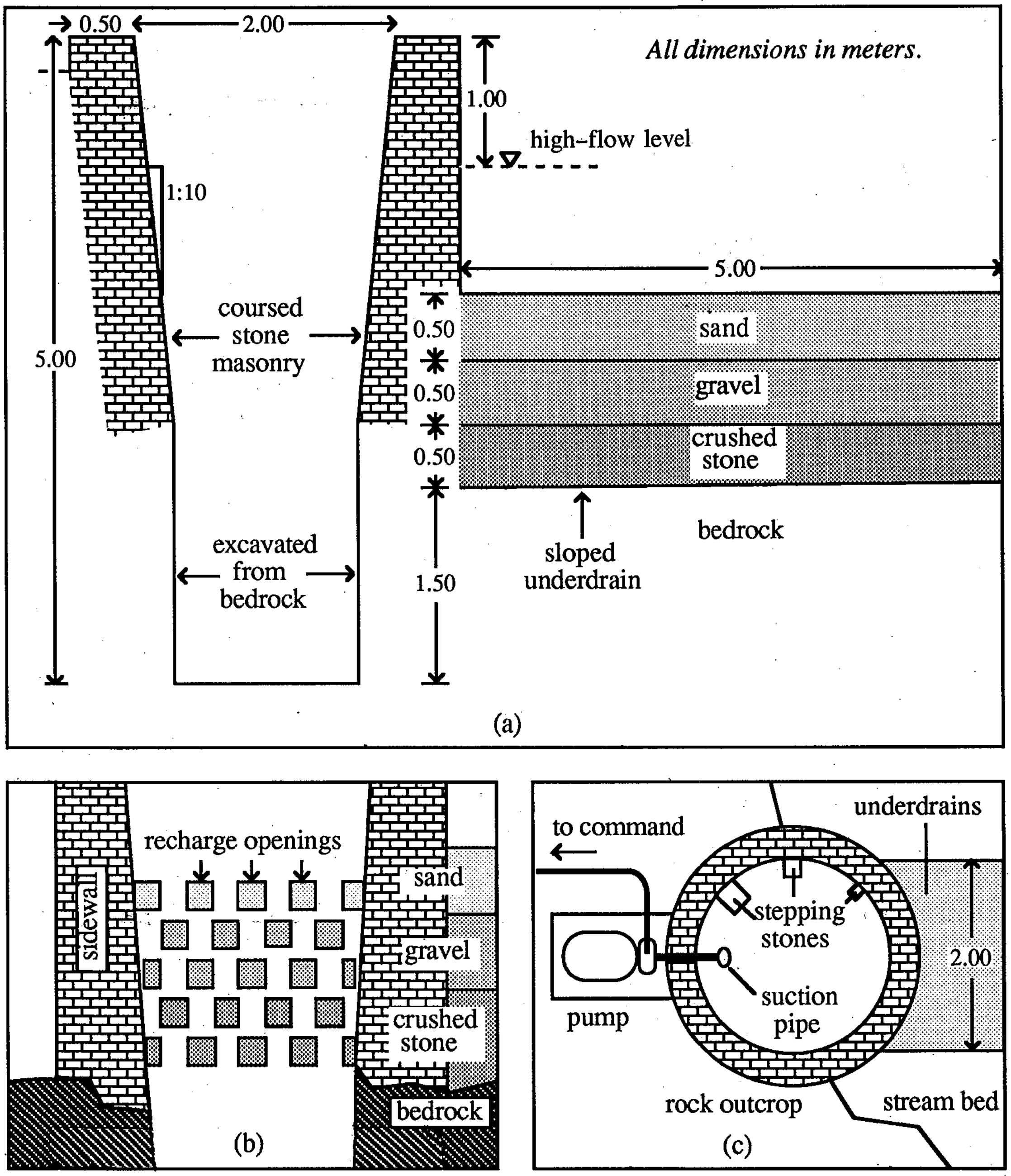


Figure 5.14.1. Schematic view of the streamside pumpwell at Dolpura village, Rajasthan, India.

Figure 5.14.2. Details of the well and the underdrain in riverbed, in vertical section, (a) and (b), and the pump arrangement (c) of the Dolpura Irrigation System, Rajasthan, India.



Crude spiral stepping stones down the inner walls were provided for access to the pump suction pipe and footvalve as shown in Figure 5.14.2 (c). As designed and constructed, the pumpwell cost Rs. 30,000 (US$4,300 in 1988).

A primary objective of constructing the Dolpura pumpwell was to reduce annual maintenance. The alternative would be that women clear the intake of sediment every year during the pre-monsoon season. Despite the grading of the material filled in the underdrains, sediment will no doubt gradually find its way into the pumpwell. Crude spiral stepping stones were provided for the periodic removal of sediment.

The pumpwell in Dolpura was sited at a major rock outcrop to reduce the risk of bank undercutting. Major maintenance will be required if the superstructure is damaged by heavy flows, or by debris falling from unstable slopes (e.g., talus and alluvium subject to undercutting). The designer must assess the risk of major damage and alternately allow for periodic reconstruction (with the mobilization of labor and capital resources this implies), or design a reinforced structure.

The pumpwell constructed in Dolpura worked without problems during the first year of operation, 1988-89. No significant drawdown occurred, although the 1988 monsoon rains were above average. The pumpwell was effective in reducing maintenance expenditure. The real test, however, will be to see if the pumpwell reduces maintenance expenditure in the following four years, and later, as anticipated.

It should be noted that as a permanent intake structure, the pumpwell is clearly not suitable for streams with major bank undercutting. In such cases, a horizontal well with slotted intake pipes leading from the saturated stream bed region to the protected lift point may prove to be more effective than a permanent pumpwell.

Example 5.15

Float Superficial Water Withdrawal Inlet

Liu Zhaoyi[24] and Wang Changde[25]

Goal: *To modify a conventional low-level outlet from a reservoir, so as to ensure that water flowing into the irrigation system is always drawn from near the reservoir surface; and thus to increase rice yields by some 17.5 percent by arranging that they are not irrigated with cold water in their early stages.*

The temperature of irrigation water may directly influence the growth and yield of rice. Research results indicate the most suitable water temperature for the growth of rice is in the range of 25 ° to 30 °C. Providing water within this temperature range is a problem particularly when water is delivered from a reservoir. If the depth of water in a reservoir is more than 30 m, the temperature of water in the bottom layers is generally 4 ° to 12 °C.

In China, most reservoir outlets deliver water from the bottom of the reservoir and the low water temperatures result in reduced yield. In hill and mountain districts, the irrigation systems are small and the canals are not long enough for the water to be heated as it flows from the reservoir to the fields.

Modifications have been made to reservoir inlets to allow the warmer water from the upper part of the reservoir to be used for rice irrigation. Several types of structures have been designed for this purpose, including the inclined penstock intake and various types of superficial water withdrawal tower intakes. This example describes the float superficial water withdrawal structure built to modify the deep inlet of the Paotong Reservoir.

The Setting

The Paotong Reservoir is situated in Yongxong County, Jiangxi Province, on the south bank of the Yangtze River in its middle reach. The nearby Lushan Mountain on the north is a famous tourist attraction. Boyang Lake is on the east. The irrigated area is hilly with a higher elevation on the west than on the east. The elevation of the command area

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ranges from 30 to 50 m. A small stream with an annual mean runoff of about 8.52 x 10^6 m^3 passes through the irrigation district. At Paotong Village a dam was built on this stream to form the Paotong Reservoir.

The climate of the region is continental subtropic. The annual mean temperature is 17.4 °C with about 95 days of frost. The annual mean sunshine is 1,940 hours and the annual rainfall averages just over 1,600 mm. Forty percent of the rainfall occurs between May and July. The soil of the area is dominated by brownish red soil with medium fertility. Rice is the main crop in the area but rape, wheat, cotton and sweet potato are also grown.

The Reservoir and Irrigation System

The Paotong Reservoir was built in 1967 by constructing a 30 m high earth dam. The normal water depth is 22 m and the storage capacity below the normal water level is 5.14 x 10^6 m^3. The maximum water depth is 24 m and the storage at that level is 6.5 x 10^6 m^3. The catchment area of the reservoir is 12 km^2.

The original inlet structure was a deep outlet culvert with an inclined gate. The gate rotates about its axis when operated by a hoist. A 150 kw hydropower station is immediately downstream of the dam and it uses irrigation water to generate electricity. The maximum discharge rate of the outlet culvert is 2.4 m^3/s. The system irrigates about 540 ha covering five villages.

According to the records, the Paotong Reservoir water surface temperature is about 23°C to 26°C from May to October. At the same time, the bottom temperature of the reservoir is 10°C to 13°C. Until 1982, all of the water used for irrigation was drawn from the bottom of the reservoir. This water being 10°C to 16°C colder than the surface temperature was harmful to the growing rice and delayed the ripening.

In the winter of 1981, the original deep inlet was reconstructed and a float superficial water withdrawal inlet was installed. The inclined gate was not modified and remains the means of controlling the inlet.

The Float Inlet Structure

The main factors in selecting the type of modification to be made to the inlet structure were cost and convenience of getting the work done. The original deep culvert outlet has the control gate installed immediately on the upstream end without a tower for access. The float superficial water withdrawal inlet was the easiest method of making the modification for drawing water from the top of the reservoir.

The float superficial water withdrawal inlet consists of four primary parts (Figure 5.15.1). The float is made of two reinforced plastic tanks with a steel platform over them. Each tank has a volume of 2.5 m^3. A hoist is installed on the platform to regulate the distance of the inlet from the surface.

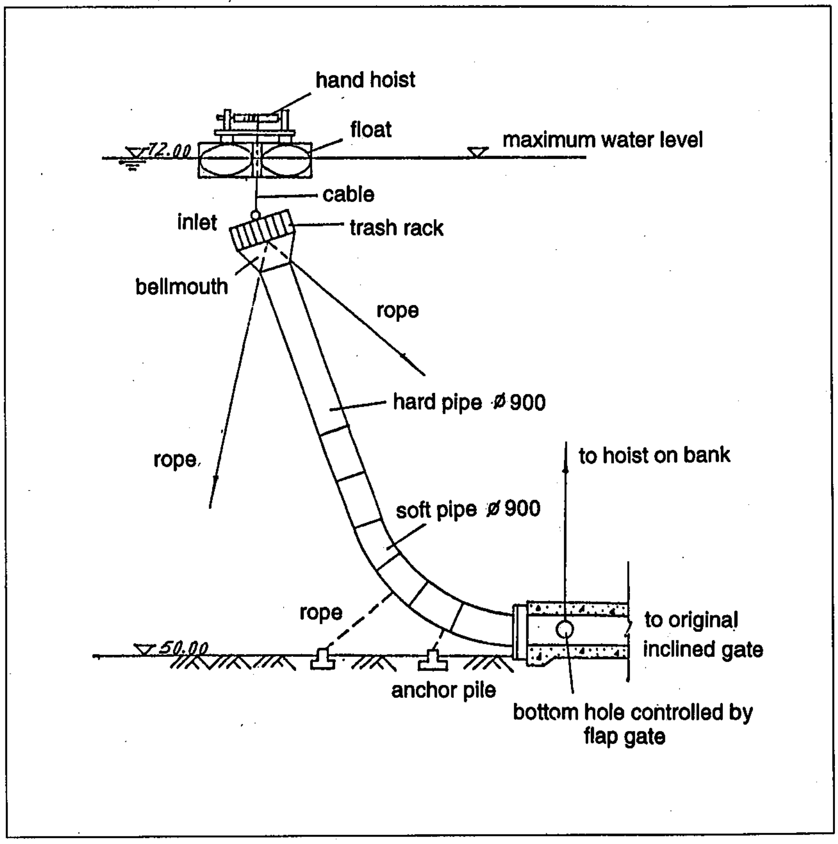
The inlet section is composed of fabricated steel shaped into a bellmouth intake and includes a trashrack. A steel ring is fixed on top for attaching a cable which connects the inlet to the float. The lower end of the inlet is attached to a rigid pipe.

The rigid section of pipe is made of fiberglass reinforced plastic and is 900 mm in diameter. Six rubber pipe segments, 900 mm in diameter and 2.7 m long, form the flexible center section of the inlet pipe. The rubber pipe segments are joined to each other by steel casing pipe segments. The center 2 m part of each rubber pipe segment is reinforced with a 5 mm diameter spring steel wire. Joined together, the rubber pipe segments form a 16.2 m long flexible pipe. The upper end is joined to the rigid fiberglass pipe with a flange plate.

The lower end of the rubber pipe segments is attached to a reinforced concrete pipe by a flange plate. The reinforced concrete pipe section is 3 m long linking the flexible rubber pipe to the original inlet culvert. A flap gate, 700 mm in diameter, was installed in the concrete pipe to allow draining of the reservoir in case of an accident.

The two main hydraulic parameters considered in the design of the float inlet were the diameter of the pipe and critical submergence depth to avoid a vortex forming that would allow air to be drawn into the pipe. The critical submergence depth was found to be 0.4 to 0.6 m and the total headloss 0.3 m, with an inlet diameter of 0.9 m and a flow velocity of 1.5 m/s.

Figure 5.15.1. Float superficial water withdrawal inlet installed in the Paotong Reservoir, Jiangxi Province, China.



After modification of the inlet structure, the temperature of water was about 10 °C higher than the temperature at the bottom of the reservoir. In June and July, when the early rice was irrigated, the temperature of irrigation water could be as much as 16 °C higher than the temperature at the bottom of the reservoir. It was found that the rice yield of fields near the reservoir increased more than of those farther away. At a distance of 2 km from the reservoir, the yield was found to be 17.5 percent more than that before the inlet modification.

Divers observed deformation of the flexible pipe at reservoir depths of 15 and 20.5 m. They found that at a depth of 15 m, a fold occurred between the fiberglass pipe section and the rubber pipe. Most of the rubber pipe was, therefore, still on the floor of the reservoir. At a depth of 22 m, the fold moved to the joint between the second and third rubber pipe sections and the remaining sections were still lying on the reservoir floor. This indicates that the rubber pipe needs to be reinforced so that it will provide a long smooth bend as intended instead of a sharp fold.