Designing Irrigation Structures for Mountainous Environments

A Handbook of Experience

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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.

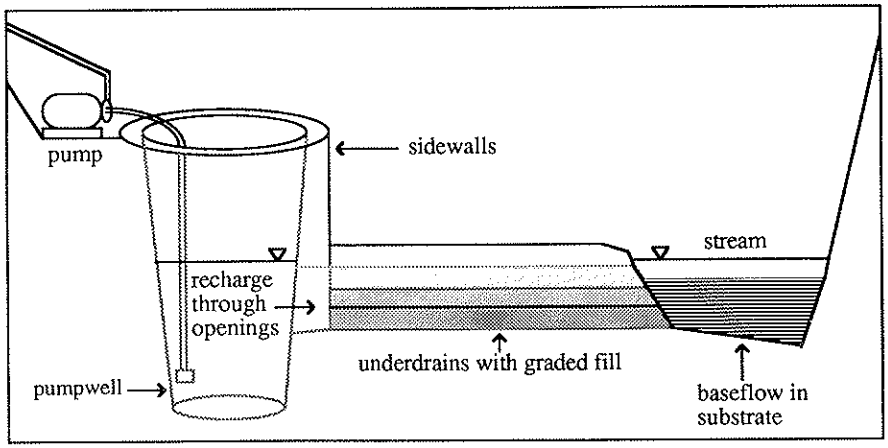
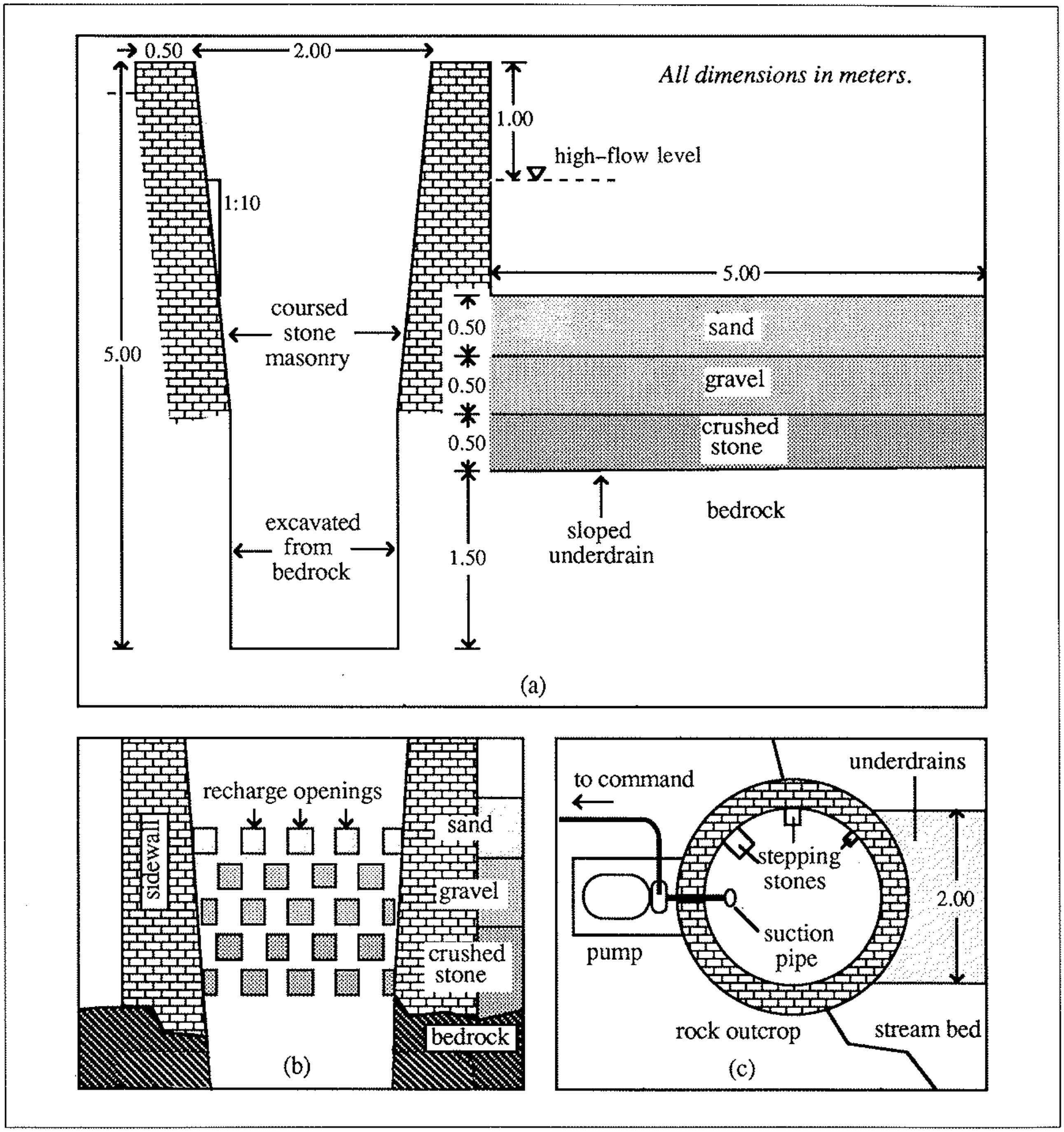


Figure 5.14.1. Schematic view of the streamside pumpwell at Dolpura village, Rajasthan, India.

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.

pump performance state that the pumping head varies directly as the square of the impeller speed. The pump speed can be changed by using variable speed drives on motors, or by using variable frequency drives that change the motor speed by changing the electric cycles. An alternative to using variable speed or variable frequency drives is to install two or three smaller pumps instead of one large pump. When operated in series, the total pumping head is the summation of the individual energy heads.

Example 7.8

Discharge Regulator for Pressurized Systems in Haryana, India

Christopher A. Scott[61]

Goal: *To reduce conflicts over water shares by incorporating a visible water measuring device in a 38 ha irrigation system where water is delivered to the fields by buried pipelines under gravity. The system is very deficient in water, and the chosen device worked until a drought year, when some irrigators damaged and bypassed it. The damaging action may indicate that the water sharing principle was not in conformity with the power structure of the irrigating community.*

Timed rotational irrigation can result in conflict if the discharge in the conveyance system is perceived to vary. The technical solution to equitable distribution under timed rotation is to measure and regulate discharge. Measuring devices which appeal to irrigators' common sense are crucial in this regard. Examples include simple flumes and proportioning weirs to measure and divide discharge in open channels. However, in upland irrigation systems where pressurized delivery is common, the measurement of discharge can be difficult.

This example describes the initial success and subsequent failure of an open flume with a rectangular notch weir to measure discharge in a low-head pressurized system. The example shown in Figure 7.8.1 is from Dhamala village in the Shivalik Hills, Haryana, India.

Set in a flume, the weir measures discharge which is regulated by manual operation of the valve of the structure's intake pipe (Figure 7.8.2). The flume is amenable to public inspection (and to tampering). It also acts as a sediment trap for discharge entering the distributary pipe from the main reservoir. However, periodic maintenance is required.

Built in 1983-84, the pressurized, gravity irrigation system in Dhamala is jointly managed by local users and the Forest Department. The flume performed well for several years when the system operated on a timed rotational supply (warabandi) basis. Gradually, however, the supply became more demand-based. In the summer of 1988, when the reservoir dropped to its lowest level ever, the discharge regulator was tampered with, as evidenced in Figure 7.8.1, where a hole made near the base of the weir can be seen. Nevertheless, the benefits, compared to the cost of the structure estimated at US$150 in 1990, do appear to have justified its temporary use.

The Setting

Average annual rainfall in Dhamala is 1,100 mm. At an elevation of approximately 600 m, potential evaporation exceeds rainfall in all the months except July and August. The predominant silt loam and silty clay loam soils have low infiltration rates

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(2 to 7 mm/day in undisturbed, saturated conditions), and pH values as high as 9.4. Drainage from agricultural land is a problem. Steep slopes with degraded natural vegetative cover generate high runoff in intense monsoon downpours. In 1982, erosion rates in the catchment areas above Dhamala were as high as 900 t/ha per year. The grazing of livestock in the watersheds has exacerbated degradation.

Kul (open-channel) irrigation from the Kaushalya River, which emanates from the Himachal Himalaya, is historically practiced only in the neighboring Lohgarh village. Prevailing water allocation practices in Lohgarh are based on landholding, with distribution on a warabandi schedule of timed rotations. At the tail of the kul, Lohgarh receives significantly less than its allocated share of water. Lohgarh kul irrigators often seek to increase their share of discharge by creating temporary obstructions to increase the head, and correspondingly the discharge, at their takeoff.

Dhamala has a mixed-caste composition, with agriculture dominated by Jat Sikhs. Landholdings in Dhamala average less than 1 ha per household, with just under 60 percent of all households owning no land at all. Comprising 12 percent and 13 percent, respectively, of the average household income in Dhamala, agriculture and livestock both rely on irrigation. In an average household, 70 percent of the income comes from household members working in nearby urban areas. Agriculture in Dhamala is a mix of market-oriented and subsistence production. Dhamala is located on a permanent road, with easy access to several urban markets.

Sale of milk is an important source of income. The primary kharif (June-October) crops are maize, rice and sugarcane while rabi (November-March) crops are wheat and berseem. Field preparation involves deep tillage and the incorporation of large

Figure 7.8.1. Discharge regulator for pressurized distribution system in Haryana, India.

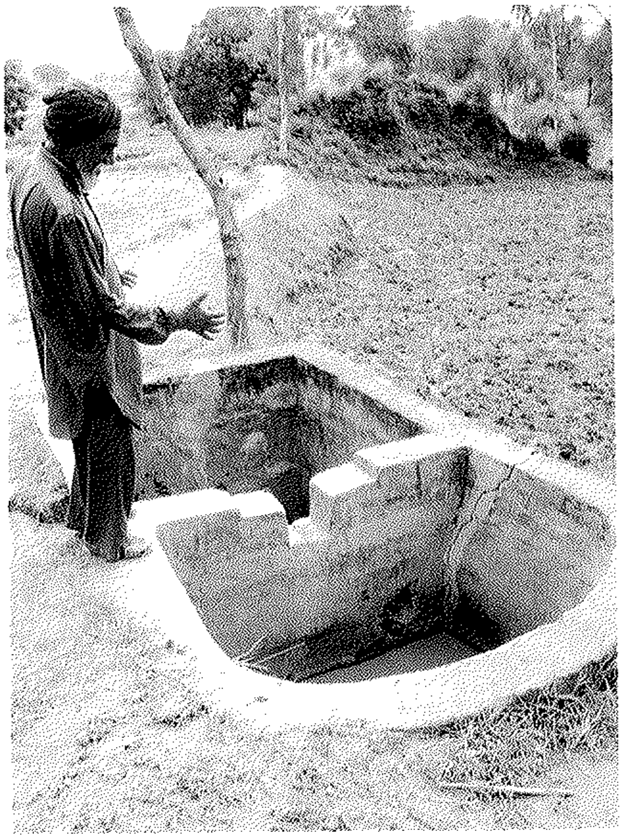
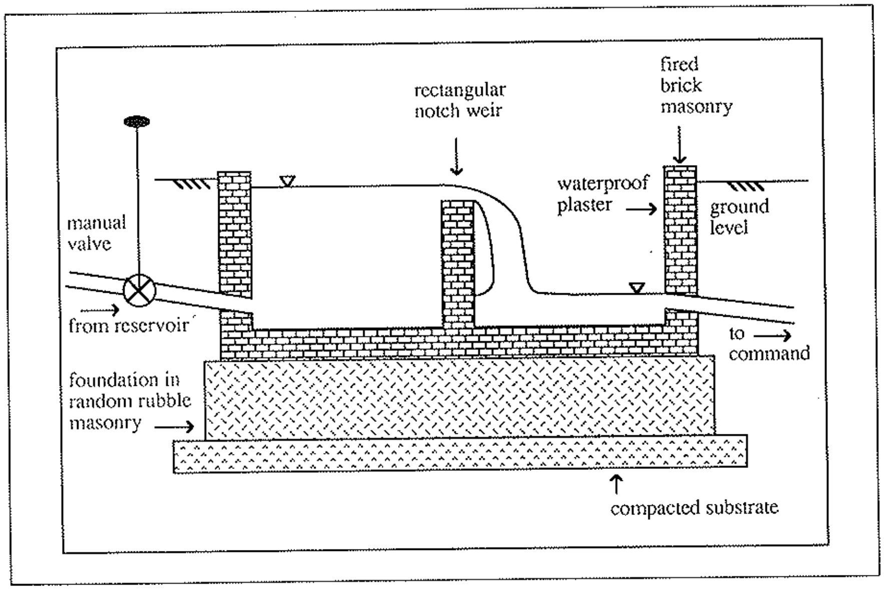


Photo by Christopher Scott.

Figure 7.8.2. Longitudinal view of a discharge regulator for a pressurized distribution system.



quantities of farmyard manure, available because livestock are stall-fed. Nitrogen fertilizers are used primarily for cash crops, particularly sugarcane. Whenever possible, fodder is cultivated in the pre-monsoon season. Water, however, is the input constraining agricultural production.

In 1976, a rainwater harvesting dam was built in the adjoining Sukhomajri village. In 1982, the first of Dhamala's two reservoirs was completed. The introduction of irrigation has had two important impacts, both with design implications. The first relates to the growing capacity for the local management of irrigation and forest resources. At the time of a field study in 1990, the villagers had eight years of experience with irrigation management. The second impact of irrigation, which is related to management capacity, was conflict over water. In the absence of historically defined water rights in Dhamala, influential households have sought to establish preeminence by capturing water. In 1989-90, for instance, three landed households received no water at all, a fact which resulted in major confrontation. The Forest Department's role in system management is primarily conflict resolution. To maintain a perception of equity, the department had to mediate among adversarial groups so that each received its allocated share. From an operational perspective, it was of crucial importance to control water distribution according to allocated shares in a manner which intuitively appealed to the concerned groups, until water rights were established and the supply increasingly became demand based.

The Irrigation System

An integrated watershed management program was started in Sukhomajri and Dhamala in 1976. Conservation agreements on forest use were negotiated with villagers prior to the provision of irrigation. In this sense, irrigation was used as a bargaining chip to achieve wider watershed land use planning objectives. After extensive soil and water conservation and reforestation work was implemented, earthen dams for harvesting rainwater were constructed in the hills above Dhamala in 1982 and 1983.

With catchment areas of 16.0 ha and 3.0 ha, the reservoirs have storage capacities of 6.7 ha-m and 1.3 ha-m, respectively. Supplemental irrigation was made available to potential command areas of 38 ha below the large reservoir and to 5 ha below the small one. Water flowed from the reservoirs to the commands through buried concrete pipelines. Transmission losses were high due to faulty and leaking joints in the concrete pipes. Subsequently, PVC pipes were introduced. Assuming full reservoir capacity and a conservative estimate of 10 percent combined losses, totals of only 16 cm and 23 cm of irrigation are available in the respective command areas. Because of the large potential command areas in Dhamala (the ratio of catchment to command is 1:2.3), the irrigation system is greatly water-deficient. Additionally, with the reduction in runoff due to water conservation in the catchments, water scarcity will increase.

Equal irrigation to all households regardless of landholding (*haqbandi*) was tried, but has been largely unsuccessful. It has been found that landless households are unable to trade water. Additionally, the time-based charge for water (Rs 3/hour; US$1.0 = Rs 16.70 in 1990) has not been collected, due to the perception among irrigators that the operating costs of gravity systems are low.

During the initial stages when Dhamala inherited rotational water supply based on the area of landholding from adjacent Lohgarh, maintaining a constant discharge was essential. During this period, the flume was operated according to its design objective. Over time, however, water rights became established in Dhamala with influential households with larger landholdings dominating irrigation distribution. Given the mix of income sources available to most households in Dhamala, other households turned increasingly to livestock farming and various forms of wage employment. The impact on irrigation was a gradual but definite transition to a demand-based supply. The flume was unable to meet this demand and was consequently altered.

Design of the Discharge Regulator

Detailed topographic surveys were carried out in Dhamala to determine the hydraulic extent of the command area, based on the maximum and minimum head available from the reservoir. Bounded on two sides by uphill slopes and on the third by a ravine, the command poses some topographical obstacles to open-channel distribution of irrigation. It was decided in 1983-84, when the irrigation system was constructed, that distribution would be through buried pipelines. However, it was deemed necessary to install a measuring device to be used in the mitigation of disputes over allocated distribution. Since the weir concept appealed to villagers' intuitive sense and required little extra operational effort, it was incorporated into the distribution system design. An alternative would have been to install an in-line flow meter. However, as an invisible "black box," this would have been bypassed by irrigators even more readily than the flume.

As the structure in Dhamala dates from 1983-84, a number of the design decisions taken then are not apparent now. It appears that a rational design procedure for discharge regulators and distribution structures in general should, at minimum, have the following steps:

Step 1: Ascertain the initial management capability and operating schedule. Project how these may change for future system management and operation.

Step 2: Acquire the data required for structural and hydraulic design including the diameter, slope and type of pipe both from the reservoir and to the risers, and minimum and maximum total head.

Step 3: Determine the range of hydraulic head at the structure's intake, including pipe friction and minor losses.

Step 4: Design the total height of the structure and width of the notch. The thickness of the partitioning wall must be adequate to support a man's weight (for sediment removal).

Step 5: Design the outlet in such a way that friction and outlet losses are minimized and the hydraulic head is maximized.

The construction should be done by local masons under the supervision of the irrigators to ensure the latter's satisfaction with the leveling and the dimensions of the notch. The flume in Dhamala was constructed of fired brick in cement mortar, with a rich cement-sand plaster to ensure waterproofing. Given the vertical forces exerted when the structure is in operation, an adequate foundation must be provided. This should be of random rubble masonry after sufficient wetting and compaction of the substrate. Adequate curing of the plaster is essential to prevent cracking and leakage. In Dhamala, the foundation was insufficient and curing was inadequate; hence the crack seen in Figure 7.8.1.

Operation and Maintenance

The pipe from the main reservoir leads into the bottom of the intake chamber of the flume, which has a rectangular notch weir to measure discharge (Figure 7.8.2). The valve in this inlet pipe to the flume is adjusted so that the operating head reaches the top of the weir notch. Except for the opening and closing of this pipe valve, the structure itself requires no operation.

Because sediment inflows from the reservoir are high, maintenance must be carried out on a routine basis. As the total capital cost of the structure is relatively low, major as well as minor maintenance can be performed by irrigators. However, the irrigation system in Dhamala is still viewed as state property and irrigators often do not take action until they are certain the Forest Department will not carry out maintenance.

Evaluation

In the summer of 1988, the reservoir storage dropped to a record low level. Irrigators needed to water their meager fodder crops to sustain their livestock through the drought. As the operating head in the system was insufficient to allow flow through the measuring flume, they initially tried to deepen the weir notch (Figure 7.8.1). Later, a hole was opened at the bottom of the partitioning wall. Since 1988, flow through the flume has entirely bypassed the weir, and passes directly through the hole. Because direct flow entails a lower water level in the flume, leakage through the crack in the sidewall is also minimized. The structure now meets the operational requirements of irrigators.

The flume did perform according to expectations in the short term. The long-term failure may be attributed to shortcomings in the recommended design procedure. Step 1, relating to current and future management and operation, was not given adequate consideration. The experience of adjoining Lohgarh might have indicated that irrigation would be dominated by influential households. Step 2, concerning physical design, was not addressed with the result that the concrete pipes of the distribution system had to be replaced with PVC pipes. Finally, minor losses in the system reduced the operating head below the level required for discharge through the flume, indicating that Step 3 was not followed.

Given the limited number of households with land in the command, water rights have gradually become established. Consequently, the operation of the system has shifted from a fixed-time rotational supply to a more demand-based supply. Tampering occurred during the summer season when the reservoir head was insufficient to allow discharge over the weir. Additionally, the structure cracked due to settling and leaked considerably. In essence, the discharge regulator did not have the flexibility to meet changing needs, which is the reason why irrigators have adapted it to meet their new operational requirements.

The low cost of the structure justifies its temporary use. During the six to seven year period of fixed time rotation, the distribution structure is reported to have performed well. The function of the rectangular notch weir in ensuring a perception of equity among irrigators was instrumental in mitigating disputes over water. For this reason, the flume should not be viewed as an outright failure.