CHAPTER 2

Environmental Factors and Observed Practices

By choosing mountainous terrain as a common denominator for design, it is expected that design examples and experience can be shared widely among countries with similar topography. Before exploring the generalizations that can be made based on topography, it is important to note the diversity that other environmental factors may bring to the design.

ENVIRONMENTAL DIVERSITY

While the southern slope of the Himalayan mountain range experiences heavy seasonal rainfall, very little moisture moves past the mountain barrier causing a "rainshadow" to the north. With subtropical conditions on the south side and arid conditions on the north side of the mountains in Nepal, there is tremendous environmental diversity within a distance of a few kilometers. Microclimates are evident in many mountainous areas where the orientation of a valley and the shape or elevation of a foothill may dramatically alter the rainfall from one watershed to the next.

Latitude and location of landmass influence rainfall and climate in general. Tropical areas of extremely high rainfall such as the Philippines and Indonesia and even the southeastern Himalayan region have considerably different design conditions from the arid region of the northwestern Himalaya and the Hindu Kush.

Geological conditions are another important factor. The volcanic soils in Indonesia and the Philippines present totally different conditions for building canals than the sedimentary rock base of the Himalayan region with its glacially formed terrain and river terraces.

A Framework for Considering Environmental Factors

There are many factors or features related to the environment of a system that need to be considered in determining the type of structure that is appropriate. Some factors are common to all hill/mountain irrigation designs while others affect only specific irrigation systems in hilly and mountainous environments, and there are certain features specific to individual structures. Further, factors relate either to natural characteristics or to social aspects. Some features can be modified or altered but there are many over which there is little or no control.

Table 2.1 (page 6) presents a framework for considering environmental factors in the determination of appropriate structures.

SITE CHARACTERISTICS AND DESIGN CONSTRAINTS

Small Systems

To a large extent, topography dictates the size of the command area. Rivers in the larger valleys are usually one boundary that cannot be easily crossed by a canal while steep mountain slopes and deep cross drains are others. Compared to irrigation systems in the plains, systems in the mountains are relatively small and this is a serious constraint on their economic viability. High construction costs resulting from difficult access and technical problems associated with unstable mountainous terrain lead to high costs per unit of irrigated area.

Table 2.1. Factors (from the point of view of the design engineer) that determine the type of structure appropriate for hilly and mountainous environments.

	Natural characteristics		Social aspects	
	More alterable	**Less alterable**	**More alterable**	**Less alterable**
Issues which are common to all hill/mountain irrigation designs	Accessibility	Topography Geology Rainfall Evapotranspiration Hydrology	Management Cropping pattern Farmer-agency relationship Social Organization Funding	Political context History of irrigation Marketing conditions Population density Economic opportunity Social structure
Factors affecting specific hill/mountain irrigation systems	Available hydraulic head Command size Layout Multiple sources	Watershed conditions Environment Slope stability Soil conditions Water availability Sediment load Distance from water source	Local skills Local knowledge	Labor availability Equity (inter- and intra-community) Competing water uses Property relations
Features of individual structures	Hydraulic head Structural design	Vegetative cover Availability of materials	Skills Farmer preference	Past farmer experience

Water Source

Though water is frequently abundant in the large rivers draining glaciers and snowpack on high mountains, it is seldom accessible for irrigation in the mountains without pumping. Larger rivers tend to be deeply incised and require inordinately long feeder canals for gravity delivery of water to irrigable land. The multitude of cross drains and unstable hillslopes limit possibilities of tapping the larger, more reliable water sources.

Where groundwater makes a major contribution to the base flow for the irrigation supply, discharge measurement in the dry season may provide a reasonable estimate of the minimum available water. However, when rainfall and snowmelt are the major contributors of water to the irrigation source, the supply may be seasonal and highly variable. Long-term records are seldom available when making decisions about the design discharge and one-time measurements without other corroborating evidence are unreliable for estimating the minimum available supply.

Because of the topography, pumping groundwater for irrigation is seldom feasible in mountainous areas. However, groundwater from springs is an important water source for many small gravity systems.

Long Canals

As mentioned above, using water from major rivers draining mountain regions is usually not practical. Relative to the area that can be irrigated, the cost of construction and maintenance of a long contour canal required to deliver the water by gravity can seldom be justified. Even when secondary streams and rivers are used as the irrigation water source, relatively long canals are often required to reach the first fields in the command area. Cross drainage and landslide zones make it technically challenging and costly to construct reliable canals with low maintenance requirements. Fortunately, the low discharge requirement for small command areas makes it possible to sometimes use pipes to cross or bypass unstable areas.

Frequent Floods and High Bed Loads

Mountainous watersheds face severe pressure as growing populations remove forest and other vegetative cover. As vegetation is reduced, rainfall runoff is more rapid, increasing the frequency of severe floods. Erosion also increases and the eroded material is moved by floods, causing damage to irrigation structures and clogging canals. Though steep gradient mountain streams have heavy bed loads during floods, the gradient also provides the necessary head for hydraulic removal of the material.

Drainage

Designing a drainage system is not a major issue in hill systems. In most hill systems, natural drains can be used and there is little danger of waterlogging. Since there is sufficient slope, it is often more convenient to direct drainage flows back into the canal where farmers downstream can use it, or to eventually dump the flow into a natural drain. Terminal structures for canals are an important design challenge. Excess water leaving a river terrace, for example, frequently cuts a deep gully and damages fields.

Cropping Pattern

Isolated communities in mountainous areas have, out of necessity, concentrated on growing subsistence food crops. Improved transportation makes growing of crops for specialized market opportunities feasible and, in some cases, desirable for the economic stability of an area. However, farmers recognize the risk involved in dramatic and rapid changes in their cropping pattern and the shift to a market-orientation may take years, or even decades. Planning an irrigation system for market-oriented crops may promise the best economic opportunities for a community but in the transition period, if the system does not support crops traditionally grown, it may not be successful. The design of structures must be flexible enough to take this into account.

Road Access

Even when roads do exist in mountainous areas, they seldom lead to the locations where irrigation structures are to be built. The cost of extending a road along the nearest access to the intake, assuming the intake is the most construction-intensive structure to be built, may be a major part of the total project cost. If it is not practical to build an access road, equipment and materials must be moved by other means, usually carried by man or animal. This is a major consideration in comparing alternative designs.

Unless roads are also used for other purposes, their maintenance becomes a costly burden and they frequently fall into disrepair. Consequently, structures that require materials for maintenance that are not locally available may fail for the lack of timely repairs.

Design Data

When access to a system is difficult, possibly requiring walking, repeated visits are time-consuming and are avoided. In such cases, visits to sites to collect design data and supervise construction are often relegated to junior staff members, and staff lacking experience often draw wrong conclusions while engaged in field investigations. For example, if a stream being used for irrigation has low discharge except during heavy rainfall, the violent nature of floods that move huge boulders along the bed may be missed and the designed structure may be destroyed in the first flood. Analysis of the size and frequency of boulder movement at the diversion, as reported by local people, may provide the best information in such a situation.

System Governance

The capacity to manage operation and maintenance of systems in inaccessible locations is possibly the most important factor that is regularly overlooked in designing systems in mountainous areas. Selection among alternative designs must be made after consideration of the level of technical expertise required for operation and maintenance tasks. Frequently, it is not possible to recruit persons with the necessary skills who are willing to live in an isolated location. Training local persons to manage the operation and maintenance is possible but has implications for design and system operation.

Determination of the necessary management and maintenance skills must be considered in selecting among alternative design options. For example, there are numerous options available for designing a drainage crossing. An inverted siphon is often determined to have suitable operational characteristics and to be the least-cost option. However, if heavy sediment is being transported by the canal or if mischievous children drop stones into it, there must be a means of cleaning the pipe. This may require dewatering the canal for which the proper authority must be communicated. Tools must be available along with the requisite skills to open, clean, and close the cleanout. If all of these factors are not in place, an inverted siphon may not be successful even though under proper management it would be the most cost-effective solution.

Realistic assessment of system management and access to maintenance resources should be considered a part of the design process. In some situations, management structures for a network of canals must be thought out. Improvements at one point along the river can have an impact on operation and maintenance of systems lower or higher on the river.

OBSERVATIONS

While in many countries centrally funded national irrigation agencies are a relatively new occurrence, irrigation development has been proceeding for centuries. In the past, irrigation systems in mountainous areas were often built at the initiative of local rulers and landlords. Many are operated and maintained by the farmers[1] themselves. Some of these systems have failed and disappeared with hardly a trace of their past existence. However, many farmer-managed irrigation systems, though severely tested by floods and landslides, have been continually rebuilt and improved. Though their success is witnessed by their survival, many operate far below their potential. In some cases, poor performance is a result of inadequate management but often, poor access to resources and expertise for maintenance is also a factor.

In the past, it was common for farmers to employ local experts for special tasks such as determining alignment for a new canal, cutting through rock, and building tunnels. Increasingly they are requesting assistance from irrigation agencies for improving the permanence of their structures by using cement, steel, and plastic pipe. The shift to requesting government services is not only due to superior materials but because it can often be obtained free of cost to the local community. A common result is that management of operation and maintenance then shifts to a government agency which lacks the necessary operating budget to deliver quality service.

In many of the best locations for irrigation development in mountainous areas, farmer-managed irrigation systems have already been developed. National irrigation agencies, when asked to further develop irrigation in these areas, are faced with a dilemma. Should they improve what already exists or develop new systems that are more efficient and able to irrigate additional area?

Farmers primarily use locally available materials—earth, stone, and forest products—to build irrigation systems. In the past, engineers viewed the earth canals and unsophisticated structures as inefficient and unacceptable. As a result, irrigation agencies often put emphasis on the construction of new systems aiming to maximize use of the available land and water resources. Recent research shows that despite their crude appearance, some farmer-managed systems are quite effective and efficient during critical water-short periods. In particular, the institutions they have crafted provide an important resource for irrigation development and management. Consideration is shifting away from overlaying old

1 Systems where irrigators control the water from its source to their fields and make most decisions about operation and maintenance, are often called farmer-managed irrigation systems. Some systems operated by farmers have considerable management input from a wider community such as temple priests in Bali or other local-level government agents unrelated to an irrigation agency.

systems with totally new ones to providing irrigators with assistance for improving what they already use. This usually means replacing temporary structures with more durable ones for reliable operation and cheaper, easier maintenance. Assistance that enables farmers to improve management of operation and maintenance is also necessary in many systems.

Results of operating irrigation systems with structures designed and built by irrigation agencies in mountainous areas have been mixed. In many cases, design procedures, the technology chosen, techniques, and norms used are all patterned after those used for large systems in the plains and have not been appropriate. Costs are higher than expected, structures often fail, and irrigation service falls far short of expectations.

When structures in existing systems are upgraded, there is often disregard for the irrigators' knowledge, experience and resources in selecting appropriate new designs. For example, information on irrigation water requirements, hydrology and topography is often collected without consulting local people who have accumulated irrigation experience over generations. Using traditional engineering studies to collect information on the scale and detail necessary for reliable design is far more costly per unit of irrigated area if the system is small and difficult to visit than for large, accessible systems in the plains. Cost of field-data collection is often a prohibitive factor in selection among alternative designs.

Cast-in-place concrete structures and steel gates provide permanence and operational flexibility. However, successful installation often depends upon access to the site by skilled craftsmen with appropriate equipment. Effective operation requires trained staff available on site. When these conditions are not met, performance is compromised and the structure may fail for lack of maintenance.

When a new system is built, operators are usually trained and assigned to manage it. Unfortunately, when the system is in an isolated community, operators remain largely unsupervised. Inexperienced operators must contact superiors at a distant office for permission to change operation and maintenance procedures. Poor communication in this process causes delays unacceptable to farmers. System operators are seldom from the local community, frequently request transfers hoping to get a more attractive assignment, and are often absent from the site for long periods. Each time an operator is transferred, accumulated experience is lost. Operation and maintenance problems in some systems become so severe that management shifts by default to the irrigators.

When an agency is nominally managing a system, irrigators usually lack authority to make maintenance decisions. They seldom have access to the maintenance budget and end up using their own resources to do minimum repairs necessary to keep water flowing. Under such conditions, a system often deteriorates for lack of preventive maintenance. Irrigators who are under the impression that maintenance service is to be provided by the agency that built the system or improved deficient structures in it, understandably become frustrated when services are not delivered or are not delivered at the right time.

Better assessment of irrigation-management realities is needed in isolated mountain irrigation systems. A number of countries have recognized the advantage of local management and are establishing programs for turning over some irrigation systems to water users for operation and maintenance. In addition to issues of irrigation-property ownership, mobilization of and control over resources for irrigation operation and maintenance, collection and control of irrigation fees and other local management concerns and irrigation development programs for isolated mountainous areas need to reevaluate the type of structures built. Will the managers of the system be able to operate the structure successfully? Will they have access to the materials and expertise needed to maintain the structure? Can irrigators afford the operation and maintenance costs? The following chapter suggests that the design process must address these questions when selecting the type of structure to be built.