CHAPTER 4

Approaches to Design

The design of any engineering structure has to be undertaken with proper regard for the context in which that structure will be placed, how it will be used and maintained, and so forth.

This chapter brings together four different contributions. The purpose of each is to orientate the designer and to assist in forming the appropriate set of attitudes towards the problems that appear in the mountain context. Again and again, as in the case studies that follow in later chapters, the interactivity of the physical and social contexts is emphasized. Designs that consider one but not the other have a strong tendency to fail.

The first of the four contributions that make up this chapter contains the eight maxims for successful design developed by Basil Jacob in Nepal. These provide a set of short and memorable guidelines for evading several of the most frequent errors. They are followed by another short list of rules which were formulated in a Workshop of the Farmer-Managed Irrigation Systems (FMIS) Network at Chiang Mai in 1989. These are rules for FMIS in general; but are readily transferable to the mountainous environment where most systems are farmer-managed. This is followed by an account of the principles of Risk Engineering, given by the International Centre for Integrated Mountain Development (ICIMOD). This methodology involves the use of assessments of risks as a determinant of design, which is highly relevant to mountainous environments where risk of physical catastrophe is common.

Finally, the chapter presents a checklist, developed in the Kathmandu Workshop, showing a classification of the types of irrigation structures which are commonly encountered in mountain irrigation systems. This handbook has not captured examples of actual structures in every one of these classifications, so the list may be useful in indicating where gaps remain.

DESIGN AND MANAGEMENT INTERACTION

The failure of many irrigation structures is not due to incorrect hydraulic or structural design but because they cannot be operated or maintained at certain times. Often, it is difficult to identify the adverse conditions during the design period. Following a narrow canal bank on a sunny day in the dry season does not instill a vision of a path so difficult that it cannot be safely followed in the rainy season, making a gate at the headworks inoperable. An engineer who has not experienced the transformation of a babbling brook with clear, clean water to a crashing torrent impossible to cross within minutes of a heavy rainstorm may find it difficult to believe in this transformation.

One theme that runs through the lessons and many of the examples in subsequent chapters is the need for a partnership between the designer and the irrigation system users. Generally, neither has access to all of the essential information or resources. However, as a team working collectively, they control more of the necessary ingredients for a successful design than either would have done working alone.

MAXIMS FOR EFFECTIVE DESIGN IN FARMER-MANAGED IRRIGATION SYSTEMS IN REMOTE HILLY AREAS OF NEPAL[3]

Dialogue with Farmers to Avoid Faulty Design

Figure 4.1 shows a flow-dividing structure built near the tail end of the main canal in an irrigation system. The structure was broken by the farmers because it failed to deliver the required amount of water to the two branch canals below it. Why did the design fail?

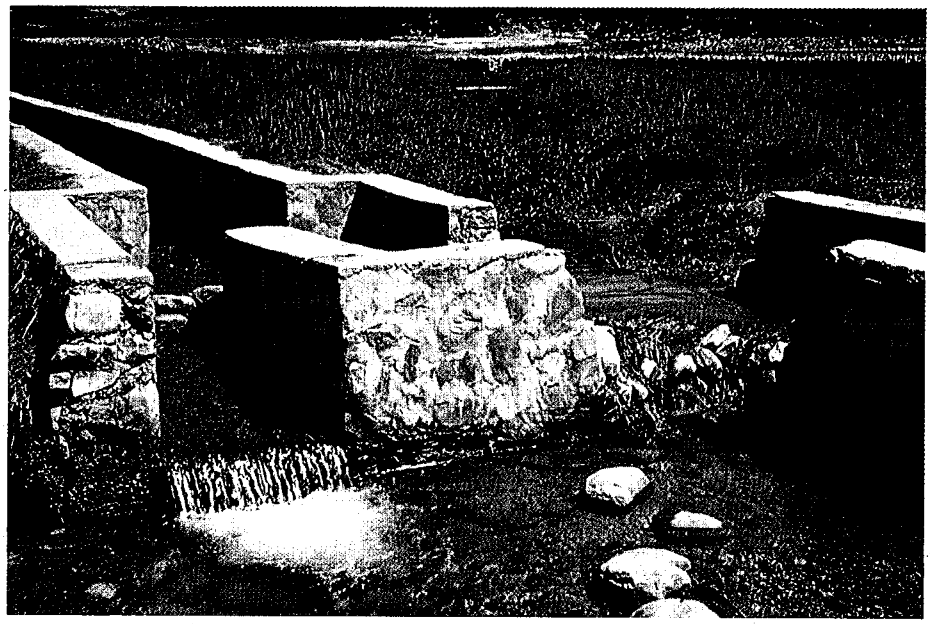

Photo by Basil Jacob.

Figure 4.1. Damaged flow-dividing structure.

The two branch canals below the structure serve two distinct command areas of approximately the same size. The designer assumed that he could allocate the available water according to land area and designed a structure to divide the flow from the main canal equally between the two branch canals. What he did not know, or try to find out, was that even for the same crop the two command areas required different quantities of water from the canal.

Maxim 1: No matter how large or small a structure, farmers must always be consulted about the type of structure they need and how they plan to operate and maintain it.

One command area is in the lowland and benefits from the rather abundant supply of groundwater seeping from several natural springs located there. The other command area depends on the canal for its entire water supply. Farmers had agreed not to divide the water equally based on their experience of the different water requirements of the two areas.

One Problem Solved, Another Created

A new structure can solve an existing problem but may create an even more dangerous situation if operation and maintenance rules relating to the structure are not properly followed. Figure 4.2

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[3] Based on a paper presented by Basil Jacob, Training Adviser, Capacity Building Project of the International Labour Organisation Special Public Works Programme, Kathmandu, Nepal, at the Workshop on Designing Irrigation Structures for Mountainous Environments, Kathmandu, Nepal, 13-17 January 1992.

Figure 4.2. Partially blocked pipe.

Photo by Basil Jacob.

shows the outlet end of a concrete (hume) pipe that crosses an area prone to land slides. The pipe is partly blocked and the discharge greatly reduced.

Farmers had built an open canal along this alignment. Frequent landslides occurred because canal water seeping into the soft soil below the canal made the slope unstable. Each time the slope moved, the canal had to be redug. The farmers requested a solution that would reduce their maintenance work and make the canal more reliable. A five-meter long pipe was installed as a solution to the problem.

Since no landslides occurred during the next cultivation season, the farmers no longer worry about this area. They do not seem to realize that because of their neglect another problem is building up. The pipe is gradually choking up with canal-borne silt and soon the canal banks upstream of the pipe will breach. The resulting erosion to the slope could cause major damage to the canal.

Long pipes that replace open canals in landslide areas are a source of potential danger, especially when they are laid at mild slopes. Short pipe crossings such as the one shown in Figure 4.2 should be acceptable provided that desilting is done regularly, not just twice a year when the whole canal is cleaned as is traditionally practiced by hill farmers.

Maxim 2: When proposing a new design, make sure that traditional village practices are compatible with it. If not forewarn the users of potential dangers.

A Good Concept Will Not Work if Poorly Implemented

Figure 4.3 is a gated rain water escape built in a rather remote location. For it to function, the gate must be removed at every occurrence of a heavy downpour of rain. Rain water escapes are very essential structures in mountain irrigation systems. During heavy rains, contour canals act as catch drains intercepting rainfall runoff streaming down the hill slope. The rain water entering the canal must be safely channeled into an existing natural drain or it will breach the canal bund. However, it is unlikely that anyone will hurry along a slippery path when lightning is flashing, even during the daytime, to open the gate when it rains. At night the gate will never be operated.

Figure 4.3. Gated rain water escape in remote location.

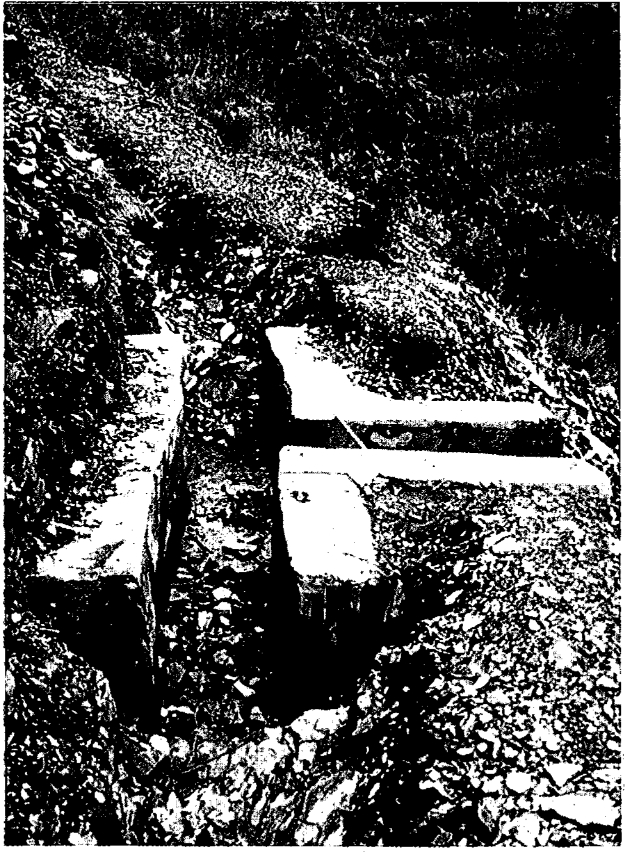

Photo by Basil Jacob.

Maxim 3: Accept traditionally proven and time-tested local design concepts. Modify them if necessary but stay within limits acceptable to users by not imposing difficult operational procedures.

The farmers are very much aware of this danger, and often have incorporated simple and effective designs, which are acceptable to all users, to overcome the problem. They may intentionally weaken a short segment of the outer canal bank so that it will breach at the proper place. Another practice is to use a hollow tree trunk aqueduct to limit the flow. Excess water can safely spill as it crosses a ravine. Frequently, where a side stream crosses the canal as a "level crossing," the outer bank is made to breach easily when water enters from the stream. These designs are fully automatic in the sense that farmers do not have to rush to the structure to open a gate or to cut a canal bank to let the rain water escape.

After a rainstorm has passed the farmers must go and repair the breach. While this is an annoying, labor-intensive nuisance, it has a low cost. Such methods have many generations of testing behind them. By building escape structures with gates, building escape structures in wrong locations, or providing too few escapes, design concepts that have been proven successful over centuries are being neglected.

Strengthening weak segments of a canal, replacing traditional aqueducts, and replacing level crossings with a superpassage can increase the risk of rainfall runoff entering and breaching the canal. Gated escapes built in remote locations impose a difficult operational procedure that is likely to fail.

Use Methods and Materials that Enable Farmers to Continue Operation and Maintenance

Landslides are natural phenomena that mainly occur because of the effect of weathering on exposed land slopes. They can be triggered by sudden changes in the moisture levels of the soil slope. Some are also triggered when the base of a slope is eroded by a stream or river.

Some landslides start small; it may be possible to prevent these from becoming larger if correct remedial measures are taken. Some landslides are so large that no human intervention can prevent their occurrence.

Farmers often know how severe and frequent landslides are that affect their canals. They often devise temporary measures to carry the canal water across such areas. These temporary structures are made with local materials and are reused every time a structure needs to be rebuilt.

It is best to avoid severe landslide areas, but if that is unavoidable, the design should be of a temporary nature until the area stabilizes. Rigid structures such as concrete pipes will be difficult to rebuild if there is slope movement and the farmers will need to request assistance again. Plastic pipes are easier to shift but plastic sheet and other flexible materials can also be considered. Reforestation and other bioengineering measures should be encouraged to stabilize the area if possible.

Maxim 4: Do not build structures that shift the responsibility for operation and maintenance to the government and other external agencies.

Minimize Dependency on Imported Materials for Repair and Maintenance

Loss of canal water due to excessive seepage is a major problem in many farmer systems. Engineers often recommend cement-masonry lining indiscriminately without exploring other possibilities such as mud, mud brick or stone, and slate lining. Since it is impossible to cover or protect long lengths of masonry or concrete lined canals from falling rocks, they will inevitably be damaged in the course of time. Figure 4.4 shows damage to a masonry canal due to falling rock. Cement is needed to make the repair. It is likely that this portion will never be repaired and may eventually lead to a major canal breach.

If local materials were used for lining, the farmers would be able to repair the damage themselves. Mud, slate and stones are generally locally available but farmers are not always skilled in using these materials effectively. Every assistance project that involves construction should ensure that local skills are upgraded to use local building materials effectively.

Maxim 5: Designs must be made with repair and maintenance needs in mind. Whenever possible, the use of local materials in canal construction should be promoted. Transfer the technology and skills necessary for repair and maintenance of the system during the construction phase.

Large-Scale Construction Upsets the Ecology of the Hills

Typically, farmer-managed irrigation systems in the hills are small. To expand the command area, farmers often build an additional parallel canal from the same source instead of trying to increase the capacity of the existing canals. They realize that in addition to creating water rights issues, wide canals are risky to build on steep hill slopes. Frequently, designers recommend the widening of existing canals without considering these consequences.

Existing canals should be widened only if absolutely necessary. Alternatives such as the deepening of the canal and using the excavated material to strengthen the outer canal banks should be implemented instead. The objective should be to keep the mountain slope on the upper side of the canal intact if at all possible.

Large canals on steep hill slopes require the removal of huge amounts of soil. Disposing such large quantities of excavated soil is a difficult task and, usually, it is just thrown downhill destroying existing vegetation and increasing the risk of downhill erosion. Fresh cutting of hill slopes increases the risk of canals choking up due to minor landslips. This is one of the major reasons for canal breaching.

Visit the Irrigation Project when the System is in Use

The need for improvement, repair, or replacement of a canal or a canal structure is more evident if inspection takes place while it is in operation. It also makes it easier to decide on the type of improvement necessary. When new structures are to be built, it is best to visit the location during a storm. This will facilitate the decision on the type of drainage crossing, for example, or the location of a side intake on a river bank.

Figure 4.4. Masonry lining damaged by falling rock.

Photo by Basil Jacob.

Farmers often come up with long lists of needs, improvements and unrealistic priorities if they believe they will get them free. Certain powerful groups within the farmer community may try to distort the priorities for their own benefit. Improvements based on unrealistic needs and priorities do not benefit the system as a whole. Correctly timed field surveys, therefore, can help designers check the validity of farmer priorities and decide on the type of design most suited for a given situation.

Maxim 6: Build small, strong civil works in the hills. Disturb stable slopes as little as possible.

Maxim 7: To understand the real problems, time field visits to see the system in operation under its most difficult situation. This will help in selecting a suitable design for solving the problem.

Quality Construction is Necessary to Implement Long-Lasting Design Improvements

Hill farmers are eager to make long-lasting improvements in their irrigation systems. Forest products that they use to repair and replace their temporary structures are increasingly difficult to obtain. They would like to have structures such as wooden aqueducts replaced by more permanent structures. Reinforced concrete is an affordable, appropriate construction material. It is resistant to hard wear and is long-lasting provided good quality control is assured during construction.

A good design combined with proper quality control during construction can produce a more permanent solution. Figure 4.5 shows a reinforced concrete aqueduct built in a remote hilly area. The T-beam is an economic design section. Good workmanship and careful supervision has made this unique construction in a remote area feasible. On the other hand, poor quality control or sloppy workmanship will cause a good design to fail.

Maxim 8: Good quality control and workmanship are necessary to make full use of the strength and durability of imported construction materials (cement, steel and plastic).

CHARACTERISTICS OF GOOD DESIGN PRODUCTS

A number of characteristics of good design products have been identified at a workshop on *Design Issues in Farmer-Managed Irrigation Systems* (Yoder and Thurston 1990). Five of them are particularly relevant to designs in mountainous areas.

Figure 4.5. Reinforced concrete T-beam aqueduct combining good design and workmanship.

Photo by Basil Jacob.

Simplicity

The design product needs to be simple so that all users can understand and participate in its operation and maintenance. Complex designs sometimes relegate irrigation users to the observer status, causing delays and frustrations while they wait on agency staff or trained operators. Such frustrations sometimes lead to irrigators breaking or removing structures, leading to the impression that farmers are not cooperative.

Equity

The irrigators' understanding of equity in an existing system or between systems has often evolved over a long period of time and usually reflects the water rights resulting from the initial investments in irrigation development by their families. In some cases, equity in water distribution also accommodates differences in soils or topography. However, what irrigators consider equitable among themselves often does not imply equal water to each farmer or equal water to each unit of land. If the design outcome does not reflect the irrigators' rationalization of equity, conflict is likely to follow. On the other hand, there is concern that unjust access to resources may waste crop production opportunity and should not be accepted automatically. It is suggested that negotiation and agreement on allocation of water shares be made prior to providing assistance. Provision must then be made in the design of structures to verify water delivery according to the water shares. Negotiation regarding the contribution of each of the farmers toward cost can strengthen the negotiated settlement regarding water rights.

Affordability

Designing low-cost structures not only makes it possible to extend financial support to more systems, but it also encourages mobilization of the users' own resources. When the irrigators, not an outside contractor, contribute the labor, they identify the irrigation facility as their own rather than that of a government agency and are better able and more willing to take care of everyday operation and maintenance. The process of investing in the improvements creates rights which also establish operation and maintenance responsibilities.

Flexibility

Irrigation systems must respond to the changing needs of the water users including those of future generations. The physical design must allow for flexibility in operation to accommodate high and low flows, rotation, crop water requirements, and flood/drought conditions. A good design can also accommodate multiple uses (agriculture, domestic, fishery, livestock, gardening, nurseries, and tourism enterprises) of irrigation water. A good design can also accommodate fluctuations in the community's ability to mobilize resources for operation and maintenance.

Redundancy

A good design allows for use of multiple sources of water. Irrigators consider it important to use all available water sources. Drainage from one area may be the source of water for another, making it desirable to combine conveyance and drainage functions in the same channel. Farmer-designed structures tend to allow alternatives for temporary repair and continued operation even if there is partial failure. This concept needs to be incorporated in engineering designs.

RISK ENGINEERING APPLICATIONS IN MOUNTAINOUS ENVIRONMENTS[4]

Good engineering design considers alternative options. One method involves the evaluation of alternative designs by looking at the risks that they face and the potential harm that they could cause. Risk engineering is a method for systematically examining every component of a design problem, assessing the hazards involved, and assigning tolerable levels of risk (potential of the hazard times value lost if failure occurs) to the infrastructure being built. Equally important is that this approach also allows evaluation of the risk to the environment by the implementation of the design.

Hill Irrigation in the Context of Nepal

About 83 percent of Nepal's land area is mountainous terrain with steep slopes and narrow valleys. Agricultural and hence irrigation activities in the mountains are confined to the Siwaliks in the south and the Mahabharat Range of the lesser Himalayas in the north (Figure 4.6). The Siwaliks comprise the youngest geological formation in the range and are represented by easily erodible rocks like sandstone, siltstone, conglomerate, etc. The Mahabharat Range, with elevations up to 4,000 m,

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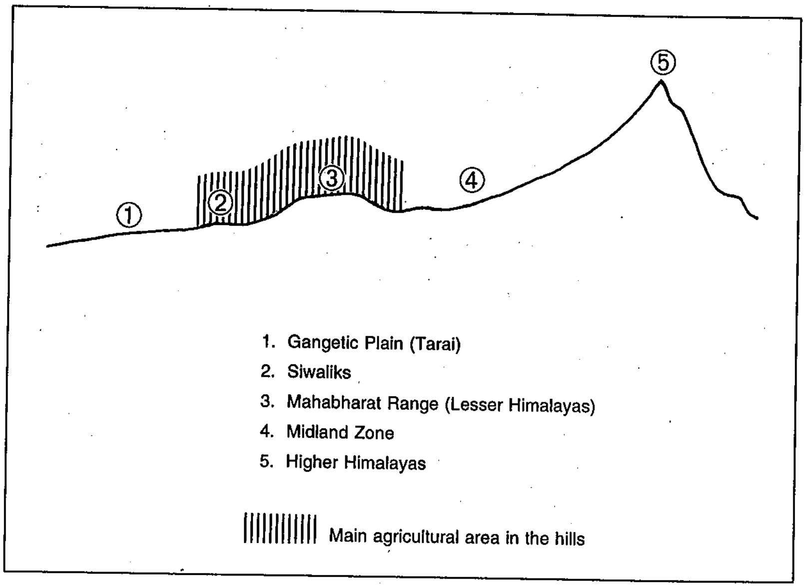
[4] Based on a paper presented by Birendra Deoja, Deputy Director General, Department of Roads, His Majesty's Government of Nepal, and Yuva Raj Adhikary, Divisional Engineer, Department of Irrigation, His Majesty's Government of Nepal, at the Workshop on Designing Irrigation Structures for Mountainous Environments, Kathmandu, Nepal, 13-17 January 1992.

is composed of partially metamorphosed sedimentary rocks which are relatively more stable than the Siwaliks but are also active. Because of the dynamic behavior of Nepal's hills, agriculture suffers from problems of gully erosion, debris flows, soil and rock slides, rock toppling, etc.

Figure 4.6. Typical geological subdivisions of the Nepal Himalaya.



Source: Adapted from Mountain Risk Engineering Manual, Part I (ICIMOD 1991a).

Status of Irrigation Development in the Hills

About 435,000 hectare (ha) out of 10 million ha in the mountainous region are potentially irrigable. Out of this area, 208,000 ha receive supplementary irrigation during the wet season but only about 83,000 ha are estimated to receive irrigation for more than one crop.

Though there is no uniformity in type or standard of structures constructed in hill irrigation projects, Table 4.1 gives the kinds and numbers of structures that are typically required in hill irrigation systems.

Table 4.1. Typical structures in hill irrigation systems in Nepal.

Structure	Requirement
Intake	1 per project
Superpassage	1.6 per km of canal
Aqueduct	0.8 per km of canal
Drop	0.5 per km of canal
Escape	1.0 per km of canal
Footbridge	2.0 per km of canal
Dry boulder wall	70 m per km of canal
Gabion wall	12 m per km of canal
Hard rock cutting	86 m per km of canal
Cement-masonry lined canal	75 m per km of canal
Covered canal	3 m per km of canal
Cement-masonry one-side wall	27 m per km of canal
Cement-masonry retaining wall	13 m per km of canal

Source: WECS 1990.

Problems Related to Hill Irrigation Development in Nepal

The effective operation of irrigation systems in the hills is a challenging task. Appropriate technology has not been adopted to solve these complex problems and many systems are not functioning at the desired level of efficiency. The traditional way of planning irrigation schemes in the hills is deficient in solving problems related to the slope environment. It also fails to recognize that irrigation is not only the domain of civil engineering but involves geology, hydrology, land-use planning, and farm organization and management.

Irrigation in hilly areas must be designed in the context of uncertain knowledge about slope stability. Geologically active hill slopes are continually under the process of weathering, erosion and uplifting. This constantly changes the stability of the slope. Hence, decisions about canals and structures to be built must be based on risk assessment.

Risk Engineering

Hazards and Risks

Mountain irrigation projects must be planned and constructed under uncertain conditions because of natural variables and limits to the rigor of investigation. To account for these uncertainties, risks that are likely to occur due to hazards have to be assessed. This section deals with the assessment of hazards and risks of hill irrigation projects for selection of canal alignment, design approach to mitigate residual hazards, and construction of selected projects minimizing environmental degradation. The following definitions are used:

> *Hazard is the probability of the occurrence of a particularly damaging phenomenon which causes a certain degree of loss or damage.*
>
> *Risk is the hazard times the potential worth of the loss.*

Risk Engineering Applied to Hill Irrigation Development

Mountain Risk Engineering which is defined as "the science and art of engineering mountain infrastructure by giving consideration to natural and human processes, and the tolerable risks to and from infrastructure." It is an integrated approach to solving the infrastructural engineering problems of hilly and mountainous areas.

Mountain risk engineering is a resource optimization tool at both the network level and the project level. At the network level, the following criteria are applied in deciding on a project: 1) potential for landslides induced by irrigation canals; 2) potential loss of investment due to canal-induced landslides; 3) potential loss of investment due to natural landslides and gully erosion; 4) cost per hectare without landslide and erosion control; 5) cost per hectare with landslides and erosion control including watershed management in the areas influencing the canals; and 6) the ratio of benefits from irrigation to benefits from alternative land use.

The objectives of applying risk engineering at the project level are: 1) selection of the most appropriate canal alignment based on hazard and risk assessment; 2) design of canal and canal structures on the basis of risks to mitigate the residual hazards; and 3) construction of the irrigation network to minimize environmental degradation.

The application of risk engineering requires careful field investigation along potential canal alignments and at the location of each structure. The "state of nature" is assessed and a description and a rating of the potential hazard are given for each location along the way. The methodology for recording field information in tables to allow comparison and ranking of risk for each potential alignment is given in ICIMOD (1991a).

Table 4.2 illustrates a format used in this process. The criteria and relative importance of each must be established at the policy level by agreeing on the appropriate weight for each. The

Table 4.2. Form for compiling weighted rankings for selecting among site/alignment alternatives.

Criteria to be evaluated	**Relative importance (%) (a)**	**Alternative A**		**Alternative B**	
		Point (b)	**Value (axb)**	**Point (c)**	**Value (axc)**
Initial cost of the project Maintenance cost of the project	10 5				
Public support and participation Size of command area	10 5				
Local employment generation Period of construction	5 5				
Technology adopted Hazards and risks involved	10 15				
Economic return Environmental impact	20 10				
Other considerations	5				
Total rating	100				
Rank					

design team then assesses each criterion for each alternative and assigns a value for each. The value is in a range of 0-100; 100 points when there is no problem for that particular criterion and zero if there is a serious problem. The rating for each alternative is established by multiplying the relative importance factor times the points for each criterion and totaling the column for each alternative. The alternative with the highest point total by this process is ranked highest.

Risk engineering as a resource-optimization approach can be used at all levels of the project cycle. It allows comparison among alternatives and design options within an alternative, using information about hazards, standards and cost in terms of risks. Rating and prediction though is based on subjective judgement. Experience is important and can be improved continuously from feedback obtained from the applications made.

Irrigation canals in the hilly areas face the risks of hazards created by natural forces. Construction and maintenance costs, as well as benefits are affected by risks. The uncertainty introduced by the risks affects the economic viabilities of the alternatives. Risk assessments should be incorporated into the economic analysis in order to realistically account for costs and benefits.

Application of risk engineering alone, however, is not sufficient to solve risk-related problems. Public awareness and determination to save the environment through the enforcement of environmental codes and proper management of the resources are equally important.

TYPES OF STRUCTURES USED IN MOUNTAIN IRRIGATION SYSTEMS

In the following chapters, a series of design examples are used to illustrate design options that engineers and farmers have selected in mountain irrigation systems under a variety of circumstances. This is not to imply that the designs illustrated are the only or even the best solutions. They are included to provide a range of ideas that might stimulate innovation by design engineers. Several examples where designs failed are included since analysis of failure provides insights not available in successful examples.

The examples are grouped by functional task—water acquisition, conveyance, distribution, and sprinkler systems. As an exercise to explore the range of structures typically designed in hilly and mountainous environments, the participants at the Kathmandu Workshop prepared a list based on their own experiences. The list as presented below has been organized to follow the water from the source to its disposal. The examples in the following chapters are organized roughly along this sequence but there are numerous gaps.

Table 4.3. Structures important in hilly and mountainous environments.

1. WATER ACQUISITION

- 1.1. Gravity diversion
    - 1.1.1. *Temporary*
        - ■ Brushwood with boulders
        - ■ Gabion
        - ■ Boulder-filled
    - 1.1.2. *Permanent*
        - ■ Masonry weir
        - ■ Bottom Intake with trashrack (Tyrolean weir)
        - ■ Side Intake
- 1.2. Intake discharge regulation
    - 1.2.1. Fixed orifice
    - 1.2.2. Gate
    - 1.2.3. Weir
    - 1.2.4. Siphon
- 1.3. Sediment removal and exclusion
- 1.4. Control device
- 1.5. Lift-pump house, pumps, pipes, distribution from lift system, settling device before pumping.
- 1.6. Groundwater/bed flow

(Continued)

Table 4.3. (Continued).

2. WATER STORAGE
    - 2.1. *Before diversion*
        - 2.1.1. Large/small dam within stream reservoir, water harvesting
    - 2.2. *After diversion*
        - 2.2.1. Tanks, ponds, reservoirs fed by canal

3. CONVEYANCE
    - 3.1. Canal cross section
    - 3.2. Canal lining
    - 3.3. Canal slope
    - 3.4. Canal supports
    - 3.5. Energy dissipators
        - 3.5.1. Drop structures
        - 3.5.2. Chutes
    - 3.6. Escape structures (for limiting water discharge, not sediment)
        - 3.6.1. Designed breach
        - 3.6.2. Siphon
        - 3.6.3. Gate
        - 3.6.4. Weir
    - 3.7. Cross drains
        - 3.7.1. Level crossing
        - 3.7.2. Superpassage
        - 3.7.3. Under passage
        - 3.7.4. Inverted siphon
        - 3.7.5. Aqueduct
            - ■ Masonry arch
            - ■ Suspended pipe/flume
            - ■ Beam-support truss, RCC, wooden
    - 3.8. Tunnels
    - 3.9. Crossings on unstable slopes
        - 3.9.1. Pipe
        - 3.9.2. Tunnel
        - 3.9.3. Covered canal
    - 3.10. Slope stabilization
        - 3.10.1. Retaining walls (Upslope)
        - 3.10.2. Bioengineering
        - 3.10.3. Catchdrain
    - 3.11. Drainage
        - 3.11.1. To natural (storm) drain
        - 3.11.2. To irrigation system

4. DISTRIBUTION
    - 4.1. Open channel system
        - 4.1.1. Check structures
        - 4.1.2. Outlets
            - ■ Siphons
            - ■ Nongated
            - ■ Gated
                - □ On/off
                - □ Adjustable
            - ■ Proportional dividers
                - □ Fixed
                - □ Adjustable
        - 4.1.3. Field channels
    - 4.2. Pressure pipe system
        - 4.2.1. Pressure regulator

5. FIELD IRRIGATION AND DRAINAGE
    - 5.1. Surface (gravity) structures
    - 5.2. Drip
    - 5.3. Sprinklers
    - 5.4. Drainage