Designing Irrigation Structures for Mountainous Environments

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A Handbook of Experience

Edited by Robert Yoder

INTERNATIONAL IRRIGATION MANAGEMENT INSTITUTE

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Cover photograph (courtesy AKRSP) shows a completed channel in a rocky area of the Hunza Valley in Pakistan.

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The International Irrigation Management Institute (IIMI) is an autonomous, nonprofit international research and training institute supported by the Consultative Group on International Agricultural Research (CGIAR). The CGIAR is an informal association of public- and private-sector donors that supports a worldwide network of 18 international agricultural research centers, including IIMI, conducting global research on agriculture, forestry and fisheries. The CGIAR is sponsored by the Food and Agriculture Organization of the United Nations (FAO), the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Programme (UNDP) and comprises more than 45 donor countries, international and regional organizations, and private foundations.

IIMI's mission is to foster the development, dissemination and adoption of lasting improvements in the performance of irrigated agriculture in developing countries. With its headquarters in Colombo, Sri Lanka, IIMI conducts a worldwide program to generate knowledge to improve irrigation management and policymaking, strengthen national research capacity, and support the introduction of improved policies and management approaches.

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Foreword

Irrigation facilities in mountainous places are very different from those which we find in flat alluvial plains. That is the essential reason why this handbook is being produced. Mountain irrigation systems face quite different kinds of risk, operate on quite different scales, and use quite different resources, from those that we can regard as standard in the plains. Remote and independent-minded communities in the mountains have evolved, sometimes over centuries, ingenious and diverse ways of responding to the stresses that are peculiar to their environment. These stresses include high variability of physical conditions, deficiencies of raw materials, constrained logistics, and the need to sustain social cohesion and to avoid various sorts of physical catastrophes.

Mountain irrigation is a tiny sector in comparison with the great irrigated expanses that are possible in the alluvial plains. It has therefore not received prominent attention in the irrigation literature. The training of young irrigation engineers tends to be based upon certain standard models of irrigation, which are those found in the plains. If subsequently assigned to work in the mountains, such an engineer may try to implement these standard approaches in circumstances where they will not succeed. If the engineer recognizes this danger and tries to guard against it by looking for a textbook that is devoted specifically to mountain irrigation practices, another sort of difficulty appears, because such texts are scarce.

The present volume is not a textbook or a manual of design. It is, however, a step in that direction. It is an attempt to consolidate a large body of existing experience of mountain irrigation, and to make it available to irrigation practitioners. Some of the experience comes from designing new irrigation structures for mountainous sites, and some of it comes from examining and analyzing traditional structures which mountain communities have evolved for themselves.

In 1991, the International Irrigation Management Institute invited Dr. Robert Yoder to develop this handbook of experience. The Ford Foundation generously agreed to provide most of the necessary funds. Dr. Yoder had been Head of IIMI's Field Operations in Nepal for the preceding five years, and has a deep personal acquaintance with the small mountain irrigation facilities of this country.

In order to collate a diverse, global range of experience, Dr. Yoder sought case histories of irrigation structures from practitioners in mountainous environments in many countries. Most of those who submitted such cases were brought to a workshop in January 1992 at Kathmandu, Nepal, where the examples were all discussed, and various general issues about the factors that determine mountain irrigation structural design were analyzed in depth.

This volume is the result. Most of it is the work of the individuals who submitted their case examples and supporting illustrations, and to them special thanks are due. Dr. Yoder's personal energy and enthusiasm for the project ensured its range and authority, and he has put in a great deal of additional work after the workshop, to harmonize the materials offered and to add from his own fund of general experience.

Many others have helped. The international Centre for Integrated Mountain Development (ICIMOD) hosted and cosponsored the workshop at their headquarters in Kathmandu. The Nepal office of the International Labour Organisation (ILO) provided a supplementary grant which helped to meet the local expenses.

Farmers of the Baguwa village, Sindhupalchok District welcomed the workshop participants to their irrigation system after the workshop, and showed their structures and their organizational processes. Other mountain communities, who have participated in the design of some of the structures described in this book, also deserve our thanks.

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CHAPTER 1

Overview

People have inhabited hilly regions and mountainous terrain from the earliest periods of civilization. Defense against invasion, escape from disease and oppressive heat in the lowlands, and the never-ceasing search for new opportunities were all reasons for settlement in rugged areas. The often harsh conditions forced the adaptation of agriculture to local conditions. In arid regions, irrigation was necessary for establishing cultivation. In the humid tropics, irrigation emerged as a means of stabilizing and intensifying food production.

Irrigation in the Swiss Alps and Bali of Indonesia are two well-known examples where hydraulic infrastructure, developed many centuries ago, is still in use. The 2,200-year old Dujiangyan Irrigation System in western Sichuan Province of China diverts water from a mountain river. Lessons from structures associated with this diversion, i.e., *macha* (wood tripod cofferdam), *zhulong* (rock sausages [gabions]), and *shigeng* (stone ridge), are used to teach the value of using local materials and the value of good maintenance and management. Irrigation in these communities has survived many changes in government. To a large extent, they have not been disrupted by invasion and colonization. The carefully crafted institutions governing them remain unbroken. Evidence of sophisticated hydraulic structures of past civilizations are still visible in the Andes and other locations but much of the irrigation presently in use in mountainous areas has been developed in the past two centuries.

National efforts to increase food production in the nineteenth and twentieth centuries first focused on areas with high potential, where water resources could be delivered to large expanses of land. These undertakings required vast resources and new technology. The civil engineering discipline progressed rapidly under the challenge of constructing these large canal systems.

Formation of agricultural and irrigation services in easily accessible areas of the plains is well advanced in many countries. Development efforts are now being made in long-neglected isolated valleys. Roads and infrastructure to support development in remote mountainous areas are slowly being put into place. Governmental agencies and nongovernmental organizations are providing assistance for building new and improving existing irrigation systems located in mountain valleys, on river terraces, and on hill slopes.

SPECIAL FEATURES OF MOUNTAIN IRRIGATION

It is observed in a number of countries that design factors related to topography distinguish irrigation systems built in the mountains from those in the plains. It is assumed that this is true for most mountainous and hilly regions. Because of the topography, systems tend to be small and access to them is difficult. The topography has a predominant influence on both the design approach and the design product, i.e., the way the design is done and the outcome of the design.

The design constraints for systems built in mountainous areas are different from those for large, accessible systems in the plains. Typically, sufficient hydraulic head is available and losses through structures can be tolerated. Steeper gradients in canals are possible, allowing a smaller cross section. Bed load and silt can often be removed hydraulically. However, access to the site may limit the type of equipment and material that can be used for construction and the operation of remote structures. Because of the remoteness, it may also be difficult to get skilled craftsmen to work at the site. The cost of collecting adequate design

data by traditional engineering methods may be a serious limitation to reliable design.

Local people, especially where irrigation already exists, have an intimate knowledge of local conditions. They can provide valuable information about the hydrology of the watershed, rainfall patterns, and the stability of slopes. Farmers with irrigation experience have developed a wealth of knowledge about irrigation requirements for local soils and crops. They often have practical design experience. The goal should be to have these farmers work in partnership with the technical staff as a part of the design team.

Technical staff from outside the community are seldom available to operate and maintain irrigation structures. In line with the recent emphasis in a number of countries on turning over management of systems to farmers, structures selected must be compatible with the skills and resources that will be available for operation and maintenance.

While improved watershed management is a long-term goal for reducing erosion and flood damage, floods and landslides are assumed to be natural occurrences that will continue. Resulting high bed load moved by floods complicates reliable system operation. Either the capacity to mobilize labor and materials for emergency maintenance resulting from floods and landslides should be improved or the need for maintenance should be reduced. As forest products become less accessible because of depletion and protection, other materials need to be substituted to meet maintenance needs.

THE NEED FOR A HANDBOOK OF DESIGN

When irrigation agencies undertake development in mountain areas, the arduous task of investigating and designing structures in remote locations typically falls on junior technical staff. Small systems are considered to be less complex but recently graduated engineers have had little preparation for design conditions in mountainous environments. The design examples that they diligently worked through during their training were typically taken from large irrigation systems with little resemblance to the situation they now face in the field. Coward et al. (1988) describe the results as follows:

> A frequent criticism of the technical designs that agencies have produced for small systems is that they failed to "fit" the local situation. The facilities didn't work as intended, they quickly fell into disrepair or they proved costly to operate and maintain. A typical outcome was that farmers did not make use of structures that were installed or significantly altered them—placing variable gates in fixed positions, creating turnouts in new locations or modifying the rules of water turns. When assisting existing systems, a common disappointment has been that agency projected expansions in area served have not been achieved. Poor fit has meant facilities, layouts and technical rules that were inappropriate for the physical setting. In addition, designs often have been ineffective because of their unsuitability for operation and maintenance by either the agency or the local group.... agency design procedures now too frequently result in agency-essential technology when locally manageable facilities would be better.

Irrigation developers and, especially, engineers with long experience in designing and constructing irrigation systems in mountainous terrain, have learned to change design norms to fit local conditions. Those with successful field experience are eventually promoted to administrative roles and, unfortunately, much of their rich design experience is lost. New staff must learn from their own mistakes that textbook solutions are not always appropriate in the hills. The purpose of a "handbook of experience" is to provide technical staff with a range of practical designs that have been tried.

Though designs that have failed provide perhaps the most important lessons they often do not find their way into design manuals. The fact that a design may be successful under certain conditions and fail under others underlines the importance of understanding the design environment. Examples given in this handbook, in most cases, give some detail of the environment and operating conditions in describing the design of structures.

THE KATHMANDU WORKSHOP

The basis of the handbook is material, especially case studies, which were presented and discussed at a workshop, sponsored by the International Irrigation Management Institute (IIMI) with funds provided by the Ford Foundation, and conducted during 13-17 January 1992 at the International Centre for Integrated Mountain Development (ICIMOD), in Kathmandu, Nepal. The Nepal office of the International Labour Organisation provided a supplementary grant which helped to meet local expenses. This workshop was attended by 34 full participants, coming from Bangladesh, Bhutan, China, Ethiopia, India, Indonesia, Nepal, Pakistan, Peru, the Philippines, the Netherlands, the United Kingdom and the United States. They represented a tremendous range of experience of mountainous environmental conditions across the world.

In the months before the workshop, the participants had prepared and submitted examples of designs of irrigation structures existing in the mountains. These case studies, and further commentaries on them developed out of the discussion that occurred during the workshop, are the major components of this handbook.

PURPOSE, SCOPE AND ARRANGEMENT OF THE HANDBOOK

The handbook does not focus on theoretical hydraulic and structural design detail but rather the design principles appropriate for irrigation in mountain settings. It is based upon a series of design examples prepared by irrigation practitioners from many countries. The examples are of design situations typically found in mountain systems and they present practical design solutions. Where information is available, evaluation of their success is also included. The objective is to present a range of possible design options with adequate description of the environmental context to enable the users to determine the conditions under which a particular type of structure would be appropriate.

While the handbook gives a representative sample of experience from many areas of the world, it is far from complete. Systematic field research comparing a large number of structures designed for a similar task (e.g., river diversion, crossdrain, etc.) should be undertaken and the results included. This would allow comparison of site conditions, design parameters, costs, management considerations, and maintenance requirements. Such additions would be a major step in developing the handbook into a complete practical design manual.

Environmental factors and some observed irrigation practices in mountain irrigation systems are discussed in Chapter 2. Much of this information was generated by working groups at the Kathmandu Workshop. This material is placed at the beginning of the handbook to stress the importance of understanding each design example in the context of its environment. Chapter 3 examines the design process and argues for placing importance on the sustainability of the design.

Chapter 4 uses some general presentations and discussions made at the Kathmandu Workshop, to illustrate aspects of the specific and different philosophy of design, including questions of selection among alternatives, which are characteristically appropriate to the conditions we encounter in mountain sites. This chapter also presents a list, compiled by the Workshop's participants, categorizing the kinds of structures that occur in mountain irrigation systems.

The chapters 5 through 7 present the examples contributed by engineers and irrigation practitioners. The examples are divided roughly into chapters representing the tasks of water acquisition, conveyance, and distribution. Chapter 8 presents several examples of the emerging technology for using sprinkler and drip irrigation in hilly and mountainous environments.