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Contour Trenching as a Strategy in Watershed Rehabilitation: Application to Nepalese Condition

Kumar P. Upadhyay
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CONTOUR TRENCHING AS A STRATEGY IN WATERSHED REHABILITATION:
APPLICATION TO NEPALESE CONDITION

by

Kumar P. Upadhyay

A report submitted in partial fulfillment of the requirements for the degree of
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in
Watershed Science
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1977
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Kumar P. Upadhyay
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ABSTRACT

CONTOUR TRENCHING AS A STRATEGY IN WATERSHED REHABILITATION: APPLICATION TO NEPALESE CONDITION

by

Kumar Prashad Upadhyay

Utah State University, 1977

Major Professor: Richard H. Hawkins
Department: Forestry and Outdoor Recreation

The disastrous soil erosion problems and the uncontrolled movement of water in Nepal's mountains caused by human and livestock activities call for the identification of simple, cheap, and effective rehabilitation techniques. This report analyzes contour trenching as rehabilitation techniques in the United States and examines the applicability and transferability of the techniques to the Nepalese conditions.

The details of contour trench systems as applied by the U. S. Forest Service have been analyzed by reviewing available research papers, handbooks, official records, personal communication, and actual field visits. The results and observations have been delineated for the physical and cultural aspects of the Nepalese watershed system.

Contour trench systems in the United States are designed to hold overland runoff resulting from a high-intensity, short duration rainfall events. The idea is to store overland flow on site and allow it to
percolate slowly into the soil. Trenches are an interim measure and are no substitute for rehabilitation measures designed to reduce runoff and erosion for a prolonged period of time. Quantitative evaluation of trenching effects are lacking. The findings of the few quantitative studies report the combined effects of trenching, grazing and fire control. There are examples of tremendous success and disastrous failures. Contour trenches are delicate structures. Evaluation by experienced personnel reveals that contour trenching has a definite role in the rehabilitation of impaired watersheds if the plan is carried out systematically and precisely.

Contour trenches have questionable benefits in areas where large volume, long duration and possibly high intensity rains occur (such as the monsoon areas). Thus, this control method has its limited role in the overall strategy of rehabilitation planning in Nepal. The primary limitation as seen from the analysis is the huge amount of long duration rainfall and direct runoff produced. However, there is some potential for application of contour trenching in the semi-arid parts of Nepal where frequent floodings are caused by short duration, high intensity rainfall. Watershed rehabilitation techniques developed in U. S. can be applied in Nepal in certain cases. However, site specific research support is essential in designing control structures. Nepal needs to develop research projects to identify and apply alternative rehabilitation techniques which can handle large volume of uncontrolled water over the impaired watershed.
CHAPTER I
INTRODUCTION

The kingdom of Nepal, until 1951, was under a direct feudal regime which was consistently opposed to its exposure to the outside world. This isolation of a century prevented the people from receiving the benefit of modern technology and science. There was no communication and exchange of knowledge with the outside world. This caused obstruction in the growth of knowledge for a wise use of limited resources. Only recently has Nepal been exposed to the needs and aspirations of modern times.

With growth and urbanization, the need to improve the quality of environment in Nepal is obvious. At present, Nepal is facing interrelated and contrasting problems. On the one hand, techniques to exploit hitherto undeveloped natural resources have to be developed in the shortest time, while on the other hand, advancement in the field of repairing extensive damage to the environment due to over utilization is urgently needed.

His Majesty's Government of Nepal has initiated a number of far-reaching policies, plans and programs which provide immediate as well as long lasting effects upon the quality of natural environment in Nepal. In this context, foreign agencies are keen to cooperate with Nepal. Different training programs have been developed to fill the gaps in current knowledge and technology between Nepal and the
developed world. This report attempts to fill the gap in the field of watershed rehabilitation strategy in the national perspective with contour trench system as a specific example.

Statement of the Problem

The highly populated Mid-Himalayan mountains and valleys of Nepal are in a process of desertification because of the intensive use and abuse of the land. Torrential floods, mass movement, and mudflows are common and are increasing every year. Slopes are devoid of vegetation. Fire, uncontrolled grazing, indiscriminate liquidation of forests, and cultivation of steep slopes have aggravated the situation towards an unpredictable disaster which may cause loss of life and properties for the mountain dwellers as well as valley farmers.

Realizing this alarming situation, His Majesty's Government of Nepal has recently established a Directorate of Soil and Water Conservation to formulate a direction in resource conservation programs. Within three years, this new department has been able to generate increasing awareness of the need for land rehabilitation among the people within the government agencies, and with foreign agencies who are willing to help Nepal.

In the past, no conservation measures had been taken. Now, attempts are being made to rehabilitate the exposed watersheds. This new conservation movement is gaining its popularity within and outside Nepal. Financing watershed rehabilitation projects does not seem to be a handicap for a few years. Large numbers of unemployed laborers in the countryside, coupled with a recession, has made it compulsory
to generate some productive land use projects in the unproductive, mountainous regions of Nepal. But the leading technicians in this field are in a dilemma on how to handle a substantial portion of the taxpayer's money, international loans and cooperation from other countries because of lack of past experience, technical knowhow, research results and simple guides to the technicalities of the rehabilitation.

There has been a tremendous wastage of limited resources, skilled manpower, and time in most of the developing countries by trying to transfer the prototype of research and technology from developed nation to developing nations, especially in the field of agriculture and natural resources. The primary reasons attributable for failures are the absence of prior analysis of transferability of the technology, and the lack of the understanding of the socio-economic structure.

The great experience and research of a developed nation is not a curse but a boon for today's third world if the transferability of the developed technology is intensively analyzed and then improvised to suit the local conditions of the country in question. The United States, a leader of the world in the conservation movement, has done much work in watershed rehabilitation in the past. This paper aims towards attaining a small goal of reviewing the past work in the United States and their application in Nepalese condition. However, the multiple strategy of watershed rehabilitation involves a network of techniques. A tremendous amount of work is required to cover all the aspects of rehabilitation. This paper covers only one aspect of the whole network which is contour trenching.
Objectives

Contour trenching has been done in different parts of the United States involving a number of techniques. A few studies and publications dealing with the designs, layout, construction and performance have been published. The review and analysis of these publications provide an opportunity to get exposed in this field and an opportunity to visualize contour trenching as a strategy in watershed rehabilitation of Nepal.

Thus, this paper attempts to fulfill the following objectives:

1. Analyze contour trenching as a strategy in watershed rehabilitation in the United States.

2. Examine the applicability and transferability of the techniques to the Nepalese conditions.

3. Formulate a structure to prepare a handbook of contour trenching suitable for the Nepalese condition.

Limitations

The status of data governing the hydrologic behavior of a watershed is very poor in Nepal. There are very few hydrometeorological stations in the country, and they represent the regional precipitation behavior. Discharge records are primarily maintained for large rivers. Studies and research in small watersheds has not yet been started. Information on infiltration, antecedent moisture, physical and mechanical properties of soils, topographic contour maps, and vegetation maps are very scanty. Hence the findings and recommendations in this paper
are based upon projections and extrapolations of existing data base. Efforts have been made to rectify the deviation from the general situation in Nepal by comparing the projected data base with the actual data base of the nearby Experimental stations in India.

Contour trench systems have been applied primarily in western United States. Extensive field trips in the state of Colorado, Utah, Idaho, Oregon, California and Arizona have helped in communicating the personal feeling of the leading watershed scientists of western United States. Little or no analytical quantitative data have been maintained or collected over the years to assess the effects of contour trenching. Today mechanical treatments such as contour trench systems are little used by the U. S. Forest Service. Old records of design, cost, and project evaluation are very hard to find. Therefore the review of contour trench system as presented here are primarily based upon published research notes, research papers, personal contact and personal communications.
Development of the United States for more than three centuries has been advanced by the prodigious utilization of her natural resources, especially soil, water, timber, forage, oil and minerals. The world audience has been curious to watch and to understand the conceptual philosophy of the people of the United States for governing land and natural resources. Present understanding of the laws of nature and to live with them has been established in different stages. Initially, the philosophy of use and exploitation of natural resources was the unrestrained free enterprise system for the best of the people for the contemporary generation. As the time passed by, the profound impact of man's activity resulted in the impoverishment of productivity, impairment of hydrologic processes, aggravating of the flood peaks and the increasing menace of sedimentation. However, during the different stages of development, enlightened individuals have contributed decent ideas to create and maintain conditions under which man and nature can exist in productive harmony. A historical background of the changing strategies in watershed rehabilitation will be an interesting aspect to observe.
Reclamation

The earliest settlers arriving in North American continent found a land richly endowed by nature and virtually unexploited by man (Bennett, 1939). In all but a few scattered barren areas dense stands of perennial plants sheltered the ground from the hazardous elements, and enriched it with their decaying material. Soil was building up but the scientific use of the natural resources for the good of mankind was still unknown.

Into this virgin land, enthusiastic colonists occupied the continent, first on the fertile plains east of the Mississippi River and then slowly moved westward. The occupation of the continent was accomplished not through steady planned infiltration of population into undeveloped regions, but through a rapid advance, usually unorganized and unsupervised, over a wide front by farmers, stockmen, miners, trappers, loggers, explorers and adventurers. The philosophy of plenty and a myth of inexhaustibility prevailed for many years. The concept of environmental limitations had not yet been accepted as either an ideal or as public policy.

Early French settlers arriving in North America in the flood plains of the Mississippi valley were the first to encounter the damage caused by the disturbance of natural cycles. The idea of reclaiming and protecting the plains from floods started cropping up; they started building up dikes around 1717. At first, each landowner operated independently of his neighbors in his effort. However, the situation worsened year by year, and later citizens joined forces and operated
on a community basis. Eventually all the settlers who lived on the flood plains were required to help with levee construction. The unplanned cultural development in the flood plains triggered the flood damages. Agencies involved in navigation started showing concern and in 1824 the Corps of Engineers of the U. S. Army began working on navigation improvement. Congress showed interest in flood control for the first time in 1850 by authorizing a survey of the Mississippi River with the view of protecting adjacent lands from floods. Beginning in 1879, Congress appropriated funds over a period of years for the construction of levees along the Mississippi River. Appropriation was also made for the repair of old levees along the river. In 1893 Congress started showing interest in reclamation beyond the Mississippi River by establishing the California Debris Commission. This Commission was authorized to prepare plans for the control of mining debris clogging the Sacramento and San Joaquin Rivers. The next step was the creation of the Board of Engineers for Rivers and Harbors in 1908. This board promoted navigation improvements when first established and helped in regulating commerce between states as provided in the constitution. As federal interest in flood control became active as a result of action by congress, the board was assigned flood control responsibility. Flood control plans were developed later and a flood control program was started in these rivers in 1917. The history of Forest Service begins from the Creative Act of 1891, Organic Act of 1897, Transfer Act of 1905 and the Week's forest purchase act of 1911. These acts promoted some concern for employment of upper watershed rehabilitation by creating reservations and establishing
national forests. Provision for acquisition of land by transfer or purchase were also made. However, the objectives were heavily oriented towards regulating the flow of navigable streams in the Eastern United States. In 1917 Congress enacted legislation---the Flood Control Act---recognizing the need for a broader consideration of river basin problems. In addition to authorizing works on the Mississippi and Sacramento Rivers, this act provided that federal laws relating to rivers and harbors be applied as far as possible to flood control. The Rivers and Harbors Act of 1920 provided for local participation. It authorized the Chief of Army Engineers to determine both the local and general benefits of a proposal, and to recommend that local cooperation be required as a result of local benefit. During the 1920's disastrous floods along different river valleys as well as in mountainous country occurred frequently. It aroused great concern among the local people, state and federal government. In 1928, large scale flood control activity was launched by the federal government. Local support was required by the 1928 Act to contribute one-third of the construction cost to provide rights of way and to maintain and to operate the works on the rivers (Stallings, 1957, and U. S. Department of Agriculture, 1974). In 1938 a new concept of integrated rehabilitation in the upper watershed with the protection of the flood plains was initiated.
Rehabilitation

In 1938 the Federal participation in flood control was established on a nationwide basis. The 1938 Flood Control Act authorized the Secretary of Agriculture to initiate programs for runoff control and erosion prevention. In 1944 Congress authorized specific rehabilitation projects which provided for improvements of the upper watershed. In 1954 Congress recognized the great importance of upstream watershed protection by enacting the Protection and Flood Prevention Act (PL 566). This act provided a broad program of federal technical and financial assistance to local watershed groups that were willing to assume responsibility for initiating, carrying out and sharing the cost of watershed protection that would help conserve water for agriculture uses and supplement any needed downstream flood control measures (U. S. Department of Agriculture, 1974).

Congress, in making appropriations for the Department of Agriculture for the fiscal year ending June 1954, appropriated $5,000,000 for "Watershed Protection." This appropriation was designed to meet the expenses of large scale rehabilitation and protection of watersheds, including, but not limited to, engineering operations, methods of cultivation, revegetation and change in use of land. This appropriation provided funds for a cooperative program with local organizations for 60 watersheds, for the purpose of demonstrating the practicability of conserving soil and water resources and alleviating flood damages, siltation of reservoirs, impairment of river channels, and related problems. These pilot watershed projects were to be completed in an
average of five years. This was a local-state-federal cost-sharing partnership in the protection and improvement of soil and water. The watershed protection demonstration projects varied in size from 12 square miles to as much as 390 square miles. Large scale rehabilitation works were launched in different areas of the country under a variety of physical, vegetation, climatic and economic conditions. Tremendous achievements resulted in different watersheds of the country in reducing the loss of the nation's water and soil resources. Ample evidence was documented to the effect or proper use of watershed lands on run-off, sediment production, groundwater supply, and other hydrologic processes. Achievements and shortcomings were analyzed, drawbacks were uncovered and growing recognition of the close relationship of land, water, and vegetation was realized (Stallings, 1957).

On the other hand, wide gaps in correlating the planning with inter-disciplinary agencies was felt. Widely used watershed management techniques suffered from serious setbacks. For example, management efforts were concentrated over individual farms, ranches and forest units without regard to watershed boundaries and could not encompass the intended goal of integrated watershed management. Similarly, river-valley development projects did not recognize the incidental changes of runoff, sediment production and cumulative aggravation of the aquatic environment resulting from the development efforts. This caused tremendous concern over the prevailing approach. Conflicting demands of different regions created a confusing atmosphere in the history of watershed rehabilitation. For example, an effective contour-trenched slope looked aesthetically ugly. Resource exploitation pro-
grams such as logging roads, chaining, ripping, and other productive land development programs also became part of the controversy. Furthermore, arbitrary selection of demonstration projects without prior analysis of the cause and source of erosion failed to fulfill intended objectives in many cases. Thus, the geographically scattered, arbitrarily chosen and individually planned demonstration watersheds approved by Congress, offered a new generation of concepts, exposed missing links in the planning process, and generated a more refined direction of watershed rehabilitation.

Prevention--A New Direction

A new direction of watershed rehabilitation techniques followed in accordance with the well known axiom "an ounce of prevention is worth a pound of cure." It was felt that preventing damage to the basic soil resources was by far more desirable for an economic and a conservation standpoint than to repair damages allowed to occur by isolated and single use planning. In the past, single use planning resulted in the omission of interrelationships of the different components of natural resources values. It caused conflicts and prevented effective and orderly development. Consequently, it was realized that single use planning cannot provide all the answers to all
environmental questions. It was also realized that the conflicts created and the interaction involved can be prevented or minimized by carrying out impact analysis with the help of interdisciplinary teams. Recognizing the sharp increase in public interest in the environment and the conservation of natural resources, the Forest Service inaugurated a policy to allow the public a greater voice in the planning and management of natural resources, at the national, regional, and local levels (U. S. Department of Agriculture, 1976).

The multiple use-sustained act of 1960, National Environmental Policy Act of 1969 and Environmental Quality Improvement Act of 1970 are landmarks of this new direction. These three acts together require that most public lands be managed to produce all tangible and intangible natural resources at the highest net benefit without degrading the environment (Reid, 1973). National Environmental Policy Act of 1969 requires all agencies of the Federal Government to:

1. Use a systematic interdisciplinary approach in planning and decision making which may have an impact on man's environment.

2. Identify and develop methods and procedures for environmental assessment in consultation with the council of Environmental Quality.

3. Include in reports on proposed federal action, significantly affecting the environment, detailed statements of environmental impact, adverse impact that cannot be avoided, alternatives to the action, relationship between short term uses and long term productivity, irreversible or irretrievable commitments of resources, and details of consultations with others.

Thus, this multidimensional analysis approach in natural resources, planning and development has provided a new approach to decision making that accounts for the major alternatives and shows the interaction between elements. This approach has two primary factors. First, it provides a system for identifying inputs needed for assessment; and, second, it highlights those areas where knowledge is lacking (Welch and Lewis, 1975).

This new approach to natural resources management is also not free from confusion and contradiction. Commoner and Ehrlich (1972) have termed this approach as "adversary science." In fact, some of the more publicized cases of purported environmental impacts analyses could almost be considered "advocacy science" in that lack of data and differences in analytical approach have lead investigators to conflicting conclusions. Yet the conclusions reached have been cited and used to support opposing courses of action for minimizing environmental damage. The National Environmental Protection Act of 1969 stands among those rare legislative acts that have produced change and controversy across a broad spectrum of American life. The Act touched off an avalanche of paper work that some claim will simultaneously alter the process of public decision making and bring the government machinery to a grinding halt. The almost unprecedented level of controversy created by the Act, and by subsequent judicial interpretations of it, produced 27 Court of Appeals decisions, 79 District Court decisions, and 4 discussions in Supreme Court dissents in the Act's first 30 months (Warner and Bromley, 1974).
However, the proponents of NEPA are very optimistic with this new direction. According to them, it is much easier to talk about something than to put it in writing. Now for the first time, certain projects have to be evaluated in writing, then the evaluation must be circulated for review, and lastly, a final statement prepared describing how potential points of environmental impact will be handled. They believe that public interest in the environment and the conservation of natural resources provides a sound base in the planning and management of natural resources.

As the environmental assessment and the impact statement have become central cores of resource planning and management, administrators responsible for managing wild land resources are faced with a dilemma: on one hand they receive constant pressure from various interest groups to release the resources for production and yet, on the other hand, they are receiving constant threat from the large body of environmental lobbyists, local people, and press about the serious consequences that can result from the intensive resource use. There are a variety of environmental responses to consider when contemplating any environmental disturbances. It is presently impossible from the available research support to accurately predict the onsite effects and offsite effects of these responses. This has posed a crucial problem to the land manager because he is unable to define limitations to use, if and how management practices might be applied, and possible trade-offs in the various uses and values, even though he is required to do so for environmental analysis reports. During the public hearings of a proposed management plan of a particular watershed, the Forest Service is
encountering different questions, serious doubts are raised about the proposed strategy, from the people as well as from the industrialist. This has created a frustrating situation among land managers and has lead them to believe that NEPA has given the "public" (unknown people) too great an influence in decision making. But it should not be forgotten that a system works only when there is check and balance between resource managers and users. So public involvement must be a part in the decision making process. Communication between the users and managers provides a good opportunity to refine the management practice. There is a general consensus among the land managers that writing environmental impact statements is an art rather than a science. It is correct that natural resources planning is currently an inexact process. However, with the help of modern science and technology such as system analysis, photogrammetry, electronic and other tools, many unanswered and difficult questions can be answered in the future.

In Nepal, public involvement in natural resources planning has not been fully recognized. In the past, local people used to protect, if not scientifically manage, the wild land resources around their community. As the restriction and regulation from the government was applied without due participation of the local community, they lost interest in protecting the resources. This caused tremendous damage in the total environment of Nepal. Thus from the experience of the United States, Nepal can learn primarily two basic approaches in
developing future wild land management strategy. First, public involve-
ment at local levels must be a part of the decision making process.
Secondly, maximum emphasis must be given to prevent damages from the
future disturbances of the environment rather than repairing damages
from the past misuse.

Water resources use is a topic of controversy and will be a major
controversy in the future. So some of the prevailing concepts of
watershed management are presented in the following chapter.
CHAPTER III
NEPALESE WATERSHED SYSTEMS AND THEIR SIMILARITY
WITH UNITED STATES WATERSHEDS

The area of the conterminous United States is so large that it sounds ridiculous to compare the physical features or hydrometeorological characteristics with a small country like Nepal. However, the functioning mechanisms which influence the same type of input (precipitation) and produces the same type of output (runoff and sediments) will have many similarities under a broad perspective. They may have a wide range of differences in terms of local environment.

Many important relationships, in a watershed system, are direct, rather obvious and widely understood. Others, many of which are complex in character, are more indirect and cannot be easily comprehended. The focus of this chapter is on the analysis of broader perspectives rather than analysis of specific environments. It should enable one to derive some wide range of strategy in terms of watershed rehabilitation planning in Nepal. The gross features of Nepalese watersheds are discussed first, and then a comparison is made with conditions in the United States.

Land Use

Nepal, a nation of 54,000 square miles is divided into three roughly parallel strips, each running generally east and west (Figure 1).
Figure 1. Map of Nepal showing political boundaries and main rivers.
The Terai region, the southernmost flat region about 15 miles wide, covers about 17 percent of the total land area. It is an extension of the Gangetic plain of North India, flat open country blends into the forested hills. Elevation ranges from 300 feet to 3,000 feet. It is noted for its heavy jungles and big game including tiger, rhinocerous, elephant, wild boar and crocodile. The central region, sometimes called the "hill area," is about 60 miles wide, ranges from about 3,000 feet to 12,000 feet above sea level, and covers 68 percent of the land area. It includes the valley of Kathmandu (capital of Nepal) at about 4,500 feet, with encircling hills up to 9,000 feet. The northern region consists of the high mountains, 12,000 to 29,000 feet, forming the majestic panorama of the perpetually snow-covered Himalaya range. The region is about 25 miles wide, and accounts for about 15 percent of the total land area.

On the basis of climatic and vegetational variations, Nepal can be broadly classified into seven divisions (Stainten, 1972). Dobremez (1972), on the other hand, has divided Nepal into five zones with subdivisions. For the sake of convenience and also on the basis of distinct climatic variations, it is thought appropriate to divide Nepal broadly into three vegetational zones (Malla and Sakya, 1968):

1. Tropical and subtropical zone.
2. Temperate zone.
3. Subalpine and Alpine zone.
Major Land Use

Table 1 shows that 33.61 percent of the total area of the country is not usable for productive purposes. This area includes barren and perpetual snow covered mountains. The total area of the used lands including forest, cultivated area, range lands, water bodies, and settlements and roads amounts to 66.39 percent.

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<td>18,500</td>
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<tr>
<td>2. Agriculture</td>
<td>8,900</td>
<td>16.49</td>
</tr>
<tr>
<td>3. Pasture and meadows</td>
<td>6,600</td>
<td>12.66</td>
</tr>
<tr>
<td>4. Water bodies</td>
<td>1,500</td>
<td>2.83</td>
</tr>
<tr>
<td>5. Settlement and roads</td>
<td>116</td>
<td>0.21</td>
</tr>
<tr>
<td>6. Barren</td>
<td>10,010</td>
<td>18.64</td>
</tr>
<tr>
<td>7. Area under perpetual snow</td>
<td>8,174</td>
<td>14.97</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>54,000</strong></td>
<td><strong>100.00</strong></td>
</tr>
</tbody>
</table>


The quality of much statistical data, especially regional data, is quite poor. Different statistical reports use different regional divisions. However, an effort is being made to present the status of different categories of land uses.
Forest

At present, forestry is the most important land use in terms of the coverage of the usable lands. The total forest cover of the country (excluding the northern mountain strip) as given by 1964 national forest survey report was 24,718 square miles. Using satellite photographs and delineating over the 1964 map, His Majesty's Government of Nepal, (1974), has reported that the present area under forest is estimated to be 18,500 square miles, which amounts to 34.19 percent of the country. The extent of forest cover in different regions is given in Table 2. The vegetation types in different zones are outlined in Table 3.

Table 2. Regional distribution of forest cover

<table>
<thead>
<tr>
<th>Region</th>
<th>Forest area (square miles)</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mountains and mountain valley (upper)</td>
<td>16,500</td>
<td>89.2</td>
</tr>
<tr>
<td>2. Mountains and mountain valleys (lower)</td>
<td>1,800</td>
<td>9.7</td>
</tr>
<tr>
<td>3. Plains</td>
<td>200</td>
<td>1.1</td>
</tr>
<tr>
<td>Total</td>
<td>18,500</td>
<td>100.00</td>
</tr>
</tbody>
</table>


A combination of factors prevailing in the country has caused progressive disturbances on the wild land ecosystems. The development of forestry and maintaining its ecological equilibrium has been a great challenge. Some of the major problems associated with indiscriminate destruction of rich forests of Nepal are highlighted below.
Table 3. Vegetation type in different climatic zones in Nepal

<table>
<thead>
<tr>
<th>Zone</th>
<th>Altitude</th>
<th>Vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropical and</td>
<td>300 - 1,000 ft</td>
<td><em>Shorea robusta</em>, <em>Adina cordifolia</em>, <em>Dillenia pentagyna</em>, <em>Terminalia spp.</em>, <em>Albizia spp.</em>, <em>Salmalia malabarica</em>, <em>Semicarpus anaraldium</em>, <em>Mallotus philippinensis</em>, <em>Acacia catechu</em>, <em>Dalbergia sisso</em>, <em>D. latifolia</em>, <em>Pinus roxburghii</em>, <em>Schima spp.</em>, <em>Castanopxis spp.</em></td>
</tr>
<tr>
<td>Sub-tropical</td>
<td>1,000 - 4,500 ft</td>
<td></td>
</tr>
</tbody>
</table>

Source: Compiled from vegetation and medicinal plants of Nepal, Malla and Sakya (1968).

Forest encroachment. In Nepal, clearing of the national forest land for cultivation without legal permission from the government has been defined as forest encroachment. This is one of the acute problems Nepal is confronted with at the present. It is more serious in the Terai plains. There are many reasons associated with this situation: mass migration of people from the mountains and hills to low lands,
inefficiency in protecting national forests from the encroachers, exploitation of the landless people by the landlords; inefficient distribution of land cleared for resettlement, and, to some extent eradication of malaria, can be attributed as the primary reasons for this situation. The expanding population in hills has forced people to utilize steeper slopes for the only source of living. The first area to be converted are the marginal pasture lands and community forests which in no case can support cultivation.

The holder's permit system. Under this permit system villagers are entitled to procure dead, dying, and fallen trees worth more than $100 with the payment of only $3. But the people, under this pretext of concession, misuse the permit and in most cases destroy the green standing trees to get easy money.

Forest fire. Usually during March and April, practically all forests in the plain land and adjoining hills are deliberately burned to provide a fresh stock of grass. Negligence on the part of smokers and travellers, also sometimes results in devastating forest fires. The frequent occurrence of forest fires has adversely affected the regeneration of valuable timber species, has limited the growth of stock and caused immense destruction of wildlife.

Grazing. Heavy uncontrolled grazing through the forest lands of Nepal has created a semi desert type of vegetation in certain concentrated areas of mid-Himalayan slopes. Most of the forest is devoid of underground cover. Regeneration of the native climax species is absent in many places. Lopping, browsing, and trampling are causing a xeric type of vegetation.
Shifting cultivation. This is invariably practiced in hills and mountains by the local tribes. After cultivating steep slopes for a number of years, the land can no longer support any crop. Then, they clear another forested area and cultivate as long as that area can support the crop. In this way, they are continuously shifting from one place to another, bringing about an imbalance in the whole ecosystem of the region.

Fodder and fuel wood collection. The cattle in the hills are mainly supported by the fodder from the forest. Lopping of branches and twigs of trees like oak has practically taken out the upper canopy. The organic layer of the forest floor or the humus are taken out for fertilizing cultivated lands.

Pasture and meadows

It is estimated that about 6,800 square miles occupy permanent meadows and pastures. It accounts for 12.7 percent of the total land area (H.M.G. of Nepal, 1974). In the hills, however, the pastures are generally nothing more than loitering places for the animals from mid-morning to late afternoon.

Forage supplied by pastures, forests, crop residues and fodder trees is always in short supply. Natural grazing lands exist in the hills and alpine areas, but the sward conditions are poor. Under the same basic environmental factors that govern the composition of grass community, different types of ranges are distributed in Nepal. Intensive use of rangelands and the heterogenic impact by the growing population have created a different succession in time and place. Often, the grasslands are overrun with weeds and brush.
Serious soil erosion due to overstocking and overgrazing has scarred the hillsides with gullies. Pastures are commonly used by farmers of a particular village, even though the grazing lands have now been nationalized. There is no restriction on the kinds and numbers of animals or on grazing time. During the rainy season the grasslands become green but no flush of excess herbage occurs because of the excess stocking rate. Herbage quality is slightly increased, in crude protein and reduced in crude fibre content, but it is still insufficient to satisfy the needs of the grazing animals.

Burning of grasslands is frequently practiced during the dry season in an effort to stimulate renewed herbage growth. In some instances fresh growth is regenerated but at the cost of the meagre root reserves. These fires frequently escape into the forests and cause further damage to an already limited vegetative cover.

Alpine pastures, above 9,840 feet elevation, are in less serious condition because of the rotation system of yak and sheep grazing, that is upward movement during the warmer season and then downward grazing during the colder season (Sharma, 1973). Even here, however, the grasslands are becoming less productive each year because of the closing of the Tibetan border to the semi-nomadic herds.

In addition to the crop residues as supplemental feedstuffs, a limited quantity of hay is sometimes preserved, taken from natural grasses and weeds growing in wastelands.

Fodder trees are an important source of supplemental feed during the dry season. They occur naturally in the forests and are considered a supplemental source of communal herbage. Many species, however, are
established by farmers along field boundaries and around house sites as private properties. This source of feed is becoming scarce in the forests. It is frequently reported that one human porter load of such fodder now requires a full 8 hour day or longer as compared to 3 or 4 hours a decade ago.

The lack of restriction on grazing is the principle factor in degradation of Nepal's natural pasture and fodder resources. Land under cultivation are continually encroaching on the grasslands, placing heavy pressure on grazing lands and forests.

Agriculture

Agriculture is the second important productive land use in terms of area. On the basis of conservative estimates the cultivated area seems to be 8,900 square miles or 16.49 percent of the total area. The area under cultivation in different geographical regions is shown in Table 4.

Agricultural land use features and problems in Nepal have their own regional characteristics. Some of the points outlined below are for the broad geographical regions, such as the mountains, the hills, and the Terai.

Mountains. The mountain land, including the Himalayan temperate highlands and Trans-Himalayan Tibetan valleys, have been marginal for human occupancy owing to its harsh environmental factors. Population is sparse and there is very little land under agricultural use. There are no conflicting demands on the land.

The hills. Lying between Mahabharat lekh on the south and the Himalayas on the north is the broad hill complex with varying degrees of topographical changes. The central hill region is extensively cultivated and has been the traditional zone of Nepalese settlements.
<table>
<thead>
<tr>
<th>Region</th>
<th>Population</th>
<th>1971 Total land area (1000 acres)</th>
<th>Area under cultivation 1971 (1000 acres)</th>
<th>Cultivated area as % of total cul. area (%)</th>
<th>Population as % of total (%)</th>
<th>Population density Per mile of cultivated area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern Hills</td>
<td>2,036,240</td>
<td>6,362</td>
<td>418.3</td>
<td>8.5</td>
<td>17.6</td>
<td>204</td>
</tr>
<tr>
<td>Western Hills</td>
<td>2,296,941</td>
<td>8,322</td>
<td>444.3</td>
<td>9.1</td>
<td>19.9</td>
<td>176</td>
</tr>
<tr>
<td>Far West Hills</td>
<td>1,834,128</td>
<td>10,368</td>
<td>392.6</td>
<td>8.0</td>
<td>15.9</td>
<td>113.2</td>
</tr>
<tr>
<td>Kathmandu Valley</td>
<td>618,911</td>
<td>188</td>
<td>118.1</td>
<td>2.4</td>
<td>5.4</td>
<td>2107</td>
</tr>
<tr>
<td>Hills Region</td>
<td>6,786,220</td>
<td>25,240</td>
<td>1,373.3</td>
<td>28.1</td>
<td>58.7</td>
<td>172</td>
</tr>
<tr>
<td>E. Inner Terai</td>
<td>260,031</td>
<td>1,250</td>
<td>254.5</td>
<td>5.2</td>
<td>2.3</td>
<td>133</td>
</tr>
<tr>
<td>Cent. Inner Terai</td>
<td>347,410</td>
<td>1,159</td>
<td>178.0</td>
<td>3.6</td>
<td>3.0</td>
<td>191</td>
</tr>
<tr>
<td>W. Inner Terai</td>
<td>167,820</td>
<td>551</td>
<td>136</td>
<td>2.8</td>
<td>1.5</td>
<td>195</td>
</tr>
<tr>
<td>Inner Terai</td>
<td>775,261</td>
<td>2,960</td>
<td>568.5</td>
<td>11.6</td>
<td>8.0</td>
<td>168</td>
</tr>
<tr>
<td>Eastern Terai</td>
<td>2,974,150</td>
<td>3,617</td>
<td>2,055.1</td>
<td>42.0</td>
<td>25.7</td>
<td>526</td>
</tr>
<tr>
<td>Mid-West Terai</td>
<td>595,110</td>
<td>1,317</td>
<td>486.8</td>
<td>9.9</td>
<td>5.1</td>
<td>289</td>
</tr>
<tr>
<td>Far West Terai</td>
<td>425,242</td>
<td>1,972</td>
<td>409.4</td>
<td>8.4</td>
<td>3.7</td>
<td>137</td>
</tr>
<tr>
<td>Terai Region</td>
<td>3,994,502</td>
<td>6,906</td>
<td>2,951.3</td>
<td>60.3</td>
<td>33.3</td>
<td>357</td>
</tr>
<tr>
<td>NEPAL</td>
<td>11,555,983</td>
<td>35,106</td>
<td>4,893.1</td>
<td>100.0</td>
<td>100.1</td>
<td>210</td>
</tr>
</tbody>
</table>

The most obvious situation of land use in the hills is the scarcity of usable lands and deterioration of land resources.

There is considerable population pressure in the hills. Here 59 percent of the country's population live on 30 percent of the country's cultivated land. This gives a population density of 5 persons per cultivated acre; the average area of cultivation per family is about 1 acre. The main crops grown during the monsoon season are maize and rice; and, where conditions permit, winter crops of wheat, millet, and potatoes. Yields are rather low; and, apart from one or two special agricultural projects, the number of extension workers serving hill farmers is negligible.

There are extremely limited areas within the hills where land can be found with slopes of less than 30 percent and they are normally much steeper. In the context of normally accepted systems of land classification the entire region would be classified as non-arable. However, here and in other parts of the world where farming is not highly mechanized, such slopes are cultivated. Some are cultivated to a very high standard which will sustain yields indefinitely; but, in other cases, deterioration and degradation has occurred.

The Terai. The Terai, a flat strip of land lying in the southern part of the country, is predominantly in agriculture. The position of agriculture in the Tarai is not encouraging. With rapid population increases, production levels of agricultural lands are dwindling at an increasing rate. Cultivation has been extended to the Bhabar area and to the river banks. This has led to frequent flooding. But it should be noted that the Terai Plain contains only about 38 percent of the total population in
about 60 percent of the agricultural output. Over 90 percent of the country's agricultural comes from the Terai. The potential for any expansion of agricultural land lies only in the Terai. The excessive concentration of development efforts including transportation in the Terai during the last two decades has created conflicting demands on the land.

The River System

The river systems of Nepal can be classified by their runoff characteristics and topography into three types:

The Four Main Rivers System

The Sarda, Karnali, Narayani, and Sapta Kosi Rivers cover the northern two thirds of the country and extend from high Himalayas in the north to alluvial plain land in the south through the mountain valleys of Mahabharat range. The catchment area of the Narayani and the Sapta Kosi include about 27 percent in Tibet, but due to its location in an arid zone, only around 10 percent of the surface runoff available annually in Nepal enters from Tibet.

A good part of the catchment area in these river systems are situated above tree lines and is occupied by huge glacier areas. The snowpack around these areas provides good temporary storage of precipitation for a considerable period of time. Because the mountain ranges of Nepal ranges generally run from northwest to southeast, the general direction of the main tributaries of these rivers are cutting the mountain ranges at about right angles.

In these river basins, two types of erosion are predominant: gully erosion and mass wasting.
Eroded gullies of every possible size up to several hundred feet wide and more than one thousand feet deep exist. Torrents with steep slopes and weak geology are loaded with high flood runoff. The excessive energy, thus created, scours the bed continuously. The slopes resistance of the torrent banks are reduced to a great extent. This has greatly contributed to the number of gully systems over the last twenty years.

Mass failure due to water saturation of steep slopes or lubrication under unstable geological conditions is very common. In most cases, the water required for saturation and the lubrication is brought to the site by artificial irrigation and increased infiltration caused by ponding in the paddy terraces over the steep slopes. Because the angle of repose under water saturation can be very small compared with the hill slopes and lubrication causes deep penetration of water into the rock layers, the soil mass as well as huge boulders slips down progressively. This type of erosion is very common and extremely effective in discharging gigantic mud flows into the valleys.

In Nepal rapid mass failures seem to be closely associated in peoples' mind with deforestation and general agricultural activities, but observation in the field and on aerial photographs do not seem to bear this out. Areas having the most numerous and most spectacular land slides (apart from those associated with roads) were observed to be under forest cover and appeared to be more closely associated with structure and land form rather than land use (Hunting Technical Services Limited, 1975).
**Inner Valleys River System**

These river systems originate in Mahabharat Range in the north and flow through different valleys and gorges, and reach to the Gangetic plain, penetrating the Siwalik Range. Conditions over the northern slopes of this river system have the same situation as described in the previous section. Because of the favorable climate, the valleys and southern slopes are the traditional location of Nepalese civilization and subjected to severe man-made erosion. A good part of the area in this river system consists of rather incoherent formation of ancient sand and gravel deposits which are easily erodable. Valleys formed in these hills have a very flat gradient (1-2 percent) and to cover the height difference of around 1000 feet the rivers meander greatly. The side slopes are steep, nearly vertical; and, since they are useless to man, they are still covered by small trees and bushes. However, due to steep slopes, poor vegetation and unstable soils, slope failures are common and more sand and gravel into the river bed is common. Thus, each individual river contributes large erosion debris to the main river system which otherwise would carry reasonable silt loads. The erosion in this river system is accelerated by a combination of factors such as landform, slope, soils, adverse human practices and heavy population density. The most obvious situation around the region is the scarcity of usable land and growing deterioration of land resources. All possible types of erosion and mass wastage are conspicuous.
Outer Terai River Systems

The outer Terai river system drains from either the south face of Mahabharat Range or the south face of Siwalik Range. They discharge right into the Gangetic Plain down to the Indian border. The importance of the study and management of these rivers lies in the fact that they carry huge amounts of erosion debris when they enter the plains. When these rivers enter the Gangetic Plains, the carrying capacity for bedload drops almost to zero resulting in the deposition of the bedload there. Frequent flooding and changes in the river courses are therefore quite common. These rivers are much more sensitive to flooding because of the fact that the watershed areas are smaller and time lag for discharge is shorter. Hence storage capacity of these watershed systems is very low. The resulting erosion debris cannot be reduced in size during transport which causes big boulders and rocks to choke the whole river bed. While the other river systems discussed above show a twelve fold increase in flow between March and August, these river systems show a 150 fold increase between low and high flows.

Hydrology and Floods

Surface water is a resource which varies in time and in quantity. This is especially true in Nepal, where the southwest monsoon of about 4 months duration is followed by 8 months of drought. River discharges vary widely each year; they are very high during monsoons and low in the dry season. Although much of the data are questionable, efforts are being made to obtain a general picture of hydrometeorology and flooding behavior of Nepalese river systems.
Meteorology

The climate of Nepal can be distinctly delineated over the altitudinal range of Nepal. The Trans-Himalayan highlands above 13,000 feet have short and cool summers with summer night temperatures of freezing. This zone has occasional storms and comparatively mild climate for some protected high valleys. The mild climate in the zone between 6,500-13,000 feet consists of short summers, maximum temperatures of 77°F, minimum temperatures of -36°F, and rainfall as often as snow. The subtropical climate in the zone between 3,000-6,500 feet consists of warm summers with temperatures up to 80°F, cool winters at average temperature of 50°F, and monsoon rainfalls. A humid tropical climate occurs north of the Siwalik hills which is still part of the Terai region.

The monsoon with heavy rainfall occurs from July to September. It comes from the south-east and passes to the west. Winter rains are brought by south-west winds and contribute more rain to western Nepal. But the summer rains are much heavier. Ninety percent of the total rainfall in Nepal is due to the monsoon. The country's average annual precipitation is about 61 inches with a dry and wet regional variation from 10 inches to 135 inches respectively. The climatic data in one cross section of Nepal are given in Figures 2 and 3.

Hydrology

Nepal is very rich in its water resources. Its numerous river systems constitute one of the nation's greatest assets, and their development and conservation are essential to the future development of the country. About 72 percent of the total rainfall in Nepal
Figure 2. Vertical distribution of temperature in Central Nepal.

Source: H.M.G Dept. of Irrigation, Hydrology and Meteorology (Nepal, 1973)
Figure 3. Rainfall distribution in Central Nepal.
contributes to river flows, and about 10 percent to the ground water recharge (Dixon, 1975). The total annual runoff from the territory of Nepal is 124 million acre feet; the average annual discharge rate of the major rivers is 171,000 cubic feet per second. As 90.4 percent of the precipitation is concentrated in the wet season, the river runoff is also highly concentrated during that season. The monthly river runoff from Nepal is summarized in Table 5. This table shows that 79 percent of the annual runoff of the ten major rivers in Nepal occurs in six months from June to November, and 21 percent in the remaining six months. The monthly outflow declines to its minimum of 37,964 cubic feet per second in February and reaches its maximum of 545,696 cubic feet per second in August.

Floods

The mountainous terrain of northern and central Nepal combines with the southwestern monsoon to produce disastrous floods annually. Major rivers such as the Sapta Kosi will have a twelve fold increase in flow between March and August while a minor river such as Banaganga shows 152 fold increase between low and high flow. Snowmelt runoff floods are observed during mid-April, but they are not devastating. Most of the rivers are subjected to land slides which frequently block narrow gorges temporarily, and then upon collapse release the water quickly causing floods. The frequency of large floods is showing an increasing trend, especially in highly populated, small watersheds. However, a few years observation are not sufficient to substantiate this trend. Aerial photographs taken at different intervals provides
Table 5. Monthly average discharge from major rivers in Nepal.

<table>
<thead>
<tr>
<th>River</th>
<th>Station</th>
<th>Drainage Area M$^2$</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Monthly Average</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karnaali</td>
<td>Chisapani</td>
<td>16,525</td>
<td>12,571</td>
<td>11,300</td>
<td>11,688</td>
<td>14,478</td>
<td>19,775</td>
<td>42,693</td>
<td>42,975</td>
<td>99,759</td>
<td>155,483</td>
<td>100,385</td>
<td>36,372</td>
<td>200,234</td>
<td>14,690</td>
<td>44,932</td>
</tr>
<tr>
<td>Bubhi</td>
<td>Bangadaha</td>
<td>1,158</td>
<td>1,510</td>
<td>484</td>
<td>417</td>
<td>314</td>
<td>254</td>
<td>604</td>
<td>6,744</td>
<td>3,672</td>
<td>5,226</td>
<td>1,787</td>
<td>823</td>
<td>692</td>
<td>1,794</td>
<td>21,327</td>
</tr>
<tr>
<td>Bangana</td>
<td>Bangerhia</td>
<td>134</td>
<td>28</td>
<td>21</td>
<td>35</td>
<td>18</td>
<td>11</td>
<td>733</td>
<td>1,041</td>
<td>2,691</td>
<td>2,231</td>
<td>74</td>
<td>39</td>
<td>32</td>
<td>380</td>
<td>5,934</td>
</tr>
<tr>
<td>Western Rapti</td>
<td>Jalkuudi</td>
<td>1,988</td>
<td>874</td>
<td>752</td>
<td>678</td>
<td>459</td>
<td>314</td>
<td>3,393</td>
<td>7,274</td>
<td>10,841</td>
<td>8,051</td>
<td>7,179</td>
<td>2,691</td>
<td>1,056</td>
<td>7,233</td>
<td>35,210</td>
</tr>
<tr>
<td>Timau Khola</td>
<td>Butuwal</td>
<td>214</td>
<td>159</td>
<td>102</td>
<td>85</td>
<td>71</td>
<td>85</td>
<td>1 1</td>
<td>4,626</td>
<td>1,218</td>
<td>642</td>
<td>290</td>
<td>194</td>
<td>757</td>
<td>9,199</td>
<td></td>
</tr>
<tr>
<td>Eastern Rapti</td>
<td>Rapti</td>
<td>601</td>
<td>816</td>
<td>678</td>
<td>586</td>
<td>537</td>
<td>540</td>
<td>1,427</td>
<td>7,239</td>
<td>13,313</td>
<td>9,322</td>
<td>3,111</td>
<td>1,606</td>
<td>1,009</td>
<td>3,349</td>
<td>17,286</td>
</tr>
<tr>
<td>Gandaki</td>
<td>Nova yangath</td>
<td>12,008</td>
<td>12,254</td>
<td>11,265</td>
<td>10,028</td>
<td>14,125</td>
<td>6,886</td>
<td>50,286</td>
<td>128,821</td>
<td>167,736</td>
<td>116,321</td>
<td>52,853</td>
<td>33,017</td>
<td>22,423</td>
<td>32,156</td>
<td>626,727</td>
</tr>
<tr>
<td>Bagmati</td>
<td>Karmaiya</td>
<td>1,050</td>
<td>533</td>
<td>410</td>
<td>505</td>
<td>629</td>
<td>699</td>
<td>4,626</td>
<td>19,775</td>
<td>19,739</td>
<td>11,583</td>
<td>2,669</td>
<td>1,450</td>
<td>720</td>
<td>5,276</td>
<td>63,318</td>
</tr>
<tr>
<td>Saptakoshi</td>
<td>Saukbabi</td>
<td>22,934</td>
<td>14,407</td>
<td>12,642</td>
<td>30,475</td>
<td>15,113</td>
<td>23,836</td>
<td>68,073</td>
<td>121,033</td>
<td>162,016</td>
<td>134,189</td>
<td>59,835</td>
<td>30,629</td>
<td>19,614</td>
<td>57,661</td>
<td>691,022</td>
</tr>
<tr>
<td>Kukkai Mal</td>
<td>Chopt</td>
<td>444</td>
<td>417</td>
<td>310</td>
<td>251</td>
<td>212</td>
<td>975</td>
<td>763</td>
<td>5,156</td>
<td>5,579</td>
<td>3,531</td>
<td>1,371</td>
<td>773</td>
<td>522</td>
<td>1,447</td>
<td>19,780</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>57,056</td>
<td>42,569</td>
<td>37,964</td>
<td>54,748</td>
<td>45,956</td>
<td>53,375</td>
<td>172,619</td>
<td>398,573</td>
<td>545,696</td>
<td>392,057</td>
<td>161,563</td>
<td>50,952</td>
<td>60,352</td>
<td>171,455</td>
<td>2,057,356</td>
</tr>
</tbody>
</table>

a better exposure of the fact that river beds are widening at faster rates within the last few decades. After crossing varied mountainous terrain, most of the river suddenly meets the flat Terai lands where their carrying capacity decreases causing deposition. This is causing the rise of the river bed and frequent changes in the river coarse. Devastating floods in fertile valleys and plains are increasing. There are some recent instances that the Government of India is building East West dams to protect their flood plains just south of the Indo-Nepal border. This has resulted in flooding and water logging of fertile lands in Nepal's flood plain.

Soils, Geology, and Bedload

It is beyond the scope of this paper to give a detailed description of soils and geology and only a very generalized one is given here from the point of view of hydrology and bedload.

Soils

A country wide soil survey has not yet been completed. Soil surveys in the forested areas of the Terai land is nearly completed. However, soil survey information for all land uses are available for one cross section of Nepal which can be represented grossly. Soils of the Great Himalayas The area of the great Himalayas includes the highest mountains, with many areas covered by perpetual snow. Cryumbrepts of sandy loam and loam textures cover some of the lower ranges while Cryopsaments of sandy texture occur in narrow valleys (United Nations Development Program, 1975).
Soils of the river valleys

The soils in these areas are predominantly Rhodustalfs and Dystrochrepts, with a complex of Eutrocrepts, Haplaquepts and Udorthents probably covering less than 30 percent of the area. The most extensive soils, Rhodustalfs, are well drained, strongly to moderately acid clay loams, silty clay loams, and clays extending to a depth of more than 150 cm. They have a massive structure.

Soils of the tectonic valleys

The soils of the tectonic valleys are developed on both subrecent lacustrine sediments and recent alluvial deposits. They occupy a complex landscape of erosion terraces, flood plains and alluvial fans. The unit comprises imperfectly drained Haplaquepts with a complex of Haplaquents, Psammaquents and Dystromchrepts covering less than 30 percent of the land. Textures vary widely, from clay to sandy loams.

Soils of the mountainous lands

The most extensive soils of the mountainous lands are Haplumbrepts and Dystrochrepts, developed mainly on igneous and metamorphic rocks, chiefly granite and gneiss. The dominant textures are sandy loams, loams, and silt loams. Soil depth varies from 20 inches to very deep. These soils are well drained to moderately drained and slightly acidic.

Soils of the hilly lands

The soils of the hilly lands are dominantly Dystrochrepts and Hapludalfs. On steep, dissected lands, the soils are usually eroded and stony. Textures are mostly loams, silt loams and silty clay loams. Depth varies from place to place.
Soils of the inner Terai valleys

The soils of the inner Terai valleys are developed on recent and subrecent alluvial sediments. They consist predominantly of the association of Udorthents and Haplaquents. Textures are sandy loams, loams, or silty loams. In most of the area the soil depth is deep, well drained and slightly acidic.

Soils of the Terai Plain

The soils of the Terai Plain are also developed on recent and subrecent alluvial sediments covering a broad, nearly level to gently undulating plain in the south of Siwaliks. The great groups consist of Haplaquents, Haplaquepts, Eutrocrepts, and Haplaudolts. Textures are mostly sandy loams, loams, silty clays, silty clay loams, and some calcareous and noncalcareous sediments of sand and silt.

Geology

Detailed geomorphological and structural analysis of Nepal has not been completed yet. To analyze the prospects and problems of watershed management, a section of the central region of Nepal is discussed here.

Landforms and geomorphology

The geomorphology of the area is complex and difficult to trace, owing to the tectonic movements which took place during the orogenesis of the Himalayas. Few studies have been made and very little has been published. From the available information, the following divisions and interpretations have been made.

Terai Plain. The Terai plain represents the northern part of the Indogangetic Depression, filled up by alluvial detritus derived from the Himalayas. Most sediments are sandy and silty, with thick gravelly
layers in the northern part. This plain slopes gradually towards the south. Three broad landforms can be recognized: the upper piedmont plain, the lower piedmont plain, and the flood plain. The flood plain is exposed to river erosion.

**Inner Terai valleys.** The inner Terai valleys represent a tectonic depression, probably of a synclinorium type, enclosed between northwest-southwest ridges of the Churia Range. These depressions have been filled with alluvial detritus, deposited mainly by rivers originated from Mahbarat Range. Sediments are sandy and silty, sometimes with thick gravelly layers at shallow depths.

The valleys consist of a series of subrecent terraces and recent flood plains, with numerous alluvial fans occurring at the foot of the bordering hills. The terraces are broadly dissected by drainage ways, and have three levels. The flood plains are composed of an intricate network of abandoned levees, alluvial flats, cutoff meanders and sand banks. Overall the topography is nearly level to gently undulating, but the terrace levels sometime differ by more than 16 feet in elevation.

**Lower Himalayas.** The Churia Range corresponds to the outermost range of the Himalayas. Land generally rises rather gently from the Terai plain up to about 1300 feet, and then rises abruptly in steep, almost perpendicular scarpments up to 3,000 feet. This range consists of a succession of narrow parallel northwest-southwest ridges composed of interbedded sedimentary rocks and unconsolidated alluvial detritus, mainly conglomerates, sandstones, siltstones, and clays.
The hilly and mountainous land includes an intricate system of moderately steep to very steep hill and mountain ranges with deeply incised rivers between the great Himalayas and Churia Range. Elevations range from about 3,000 to more than 11,000 feet above sea level. Dominant slopes vary from 30 to over 100 percent.

These ranges mainly represent a complex pattern of anticlinal, synclinal and homoclinal ridges with two major thrust zones: the main boundary fault in the south and the main central fault in the north. Numerous rock outcrops occur in the mountainous areas as abrupt scarps, irregular ridges and mountain peaks.

The tectonic valleys are presumably of a synclinorium type and have been filled by alluvial detritus derived from the bordering hills and mountains, mainly under lacustrine conditions. Sediments are fine to coarse grained and include gravels.

The continuous erosion of the lacustrine sediments by the network of rivers, together with the deposition of alluvial and colluvial materials at the margins of the valley has had a pronounced effect on the physiography of the area. The valleys are characterized by an intricate pattern of erosion terraces with well defined levels, numerous alluvial fans at the margins and flood plains along major river courses.

Great Himalayas. The Great Himalaya includes the highest chain of mountains in the world with many areas covered by perpetual snow. Topography is very steep, with slopes over 100 percent in many places. Elevation ranges from 13,000 feet to the peak of Mount Everest (29,000 feet). Most of the original topography has been modified by glacial erosion and deposition. Serrate ridges, glacial cirques, glacial troughs, hanging valleys, moraines and glacial lakes are common.
Stratigraphy

On the basis of recent studies, a tentative stratigraphic column can be summarized as follows: (Sharma, 1973):

Table 6. Geologic stratigraphy in Nepal.

<table>
<thead>
<tr>
<th>Lithological groups</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alluvium</td>
<td>Holocene-Pleistocene</td>
</tr>
<tr>
<td>Siwaliks</td>
<td>Pliestocene-Miocene</td>
</tr>
<tr>
<td>Phulchoki</td>
<td>Silurion</td>
</tr>
<tr>
<td>Mahabharat</td>
<td>Cambrian-Precambrian</td>
</tr>
<tr>
<td>Himalayan gneiss</td>
<td>Precambrian</td>
</tr>
<tr>
<td>Granitic intrusion</td>
<td>Eocene</td>
</tr>
</tbody>
</table>


Most of the hilly and mountainous areas are occupied by metamorphic and sedimentary rocks of the proterozoic and Paleozoic eras. There are also significant areas covered by intrusion of granite rock. The outer hills and plains are composed of tertiary and recent alluvial deposits respectively.

Bedload

The heavy river flows during monsoons results in erosion and damage to heavily terraced hillsides, newly-built roads, newly-cleared agriculture areas, and structures and channels in irrigation networks. Again, as discussed previously, the rock formations and dipping and striking of Nepal's rocks are favorable to excessive
erosion rates. Large amounts of sediment and boulders of different sizes are often carried. For example, it has been estimated that the total silt volume removed by the Karnali river amounts to $2648 \times 10^6$ cubic feet annually or equivalent to 0.07 inches of top soil being removed from the catchment area. In total, Nepal may be losing as much as $8475 \times 10^6$ cubic feet of soil annually (His Majesty's Government of Nepal and Nippon Koei Ltd., 1970).

**Socio-Economic Infrastructure**

Increasing population, the lack of transport and communication, small land holding, and a stagnation in agricultural output combine to render difficult the economic and social betterment of Nepal. Socio-economic restraints in improving the overall standard of living are complex and numerous. Present status of different components of these restraints related to land and water developments are discussed here.

The population of Nepal, according to the 1971 census was 11.6 million. Since 1930, the country's population has been growing at the rate of about 1.4 percent per year during the period of 1951 to 1961 and 2.1 percent per year during 1961-1971. As a result of accelerated population growth, the population density is now estimated to be 210 per square mile compared to 170 in 1961 (International Bank for Reconstruction and Development, 1974).

**Migration**

The migration of population has been a complicated problem in Nepal. Three types of migration may be distinguished from the point of view of its duration and location: (1) seasonal, (2) recurrent, and
(3) permanent (Rana and Thapa, 1974). These have resulted from the following factors:

1. Economic conditions in the Hills steadily deteriorated as population pressure on available agricultural resources increased;

2. Environmental stresses were accentuated and became no longer tolerable as increasing population continuously put pressure upon the environment, upsetting its balance;

3. There were employment opportunities elsewhere; and

4. The opening up of the Terai due to the malaria eradication attracted land hungry hillmen to the opportunity for better farming.

The government sponsored resettlement programs for the rehabilitation of landless farmers from the hills encouraged further migration out of the hills into the Terai.

**Employment**

Of the total population of Nepal, 92 percent depend on agriculture for a living; in the Hill area the corresponding proportion is 94 percent. About 42 percent of the total population are estimated to be economically active.
Irrigation

No firm estimates of the area brought under irrigation in Nepal are available. Prior to 1955, there were about 37,000 acres under irrigation. By the end of 1968-1969, it has been estimated that 290,342 acres of lands are under irrigation systems (Pradhan, 1976). These areas are located mainly in the Terai and in Kathmandu valley.

Irrigation in the Hills remains at the traditional level with individual farmer-built schemes consisting of temporary and crude diversions through dug-out channels without any technical planning or drainage arrangements. Springs, where available, provide for occasional irrigation of slopes. These irrigation works serve only small and individual holdings. No reliable estimates is available of the total area under irrigation in the hills.

Irrigation canals in the hills are subjected to large scale erosion and land slide damages. Faulty designs, weak geological structures, steep torrents crossing the canals, and barren slopes above the canal contour are causing development of gullies, land slides and other forms of mass wastage.

Hydropower

Nepal, although a small country, is one of the few in the world with a very high but still undeveloped hydroelectric potential. Estimates of this potential are as high as 83,000 megawatts, which is comparable to combined installed hydroelectric capacity of Canada, the U.S.A. and Mexico (Dixon, 1975). Despite its enormous hydroelectric
potential, Nepal's per capita power production and consumption are among the lowest in the world. Forty percent of the existing power plants consist of steam and diesel units, which are dependent upon coal and diesel fuel imported from India. The total installed capacity of all existing plants is about 33,600 kilowatts (Shrestha, 1976). High siltation rates, variable flow, lack of seismic information are a few challenges to the development of hydropower in Nepal.

**Livestock and Fodder**

Nepal ranks among the highest in the world in regard to livestock population density and the contribution of the livestock sector to total Gross National Product was about 1.3 billion rupees or 15 percent in 1969-70. Most of Nepal's livestock population consists of cows and buffaloes which together are estimated to amount to 9.7 million head while sheep and goats account for another 4.3 million. The 1961-62 livestock census showed that density of animal population per farm varied from 1.4 head in Kathmandu valley to about 17.5 head in the inner Terai. In the hill districts, each household normally keeps one buffalo, one cow, and one or two sheep or goats while in the mountain districts the number varies from 5 to 15 animals. For most farm households, animals are not only the source of proteins but also an integral part of their production system. They are kept to produce manure to fertilize land, and to provide fuel, for plowing and for transportation. Most of the meat produced in Nepal, therefore, originates from buffaloes (41 percent) and poultry (38 percent), pigs and goats contribute about 5-7 percent each of the country's total meat production (His Majesty's Government of Nepal, 1975).
Forest Products

Commercial extraction of forest products in recent years has been confined mainly to areas earmarked for settlement. The development of the forests in Nepal are still in the rudimentary stage and utilization is very poor. Of the fifty to sixty sawmills in Nepal, only about half are operating. Fuel-wood accounts for 90 percent of the trees cut annually, and the balance of timber cut goes for housing, furniture and export. There are no paper and pulp mills. Fuel-wood is becoming so scarce that the villagers often spend entire days getting a head load of fuel wood.

Lack of accessibility and transportation is still the major constraint for the general development of Nepal. An East-West highway linking the eastern Terai plains with western Terai, is nearly completed. North-south roads connecting each region to the east-west highway are either completed, under construction, or planned.

Comparison of Watershed Conditions in Nepal and the United States

On a broad perspective, the following similarities can be noted between the United States watersheds and Nepalese watersheds:

1. Geomorphological setting of mountainous United States and Nepal are mainly formed from post glaciation processes.

2. From the stability point of view, the following types of watersheds are common to both the U. S. and Nepal:

   a. Mantle soils fully stabilized with vegetation.
b. Slopes have never been covered with soil-mantle due to constant gravity movement, and
c. Mantle-soils have been so disturbed by impairment of vegetation that erosion of soil has been much accelerated.

4. South facing slopes above 8,000 feet are natural grasslands.
5. There is snow at least for 8 months of the year above 8,000-10,000 feet.
6. Soils on the slopes are heterogeneous.
7. Variable rainfall because of orographic conditions.
8. High intensity storms.
9. Similar river systems with high bedloads.
10. Runoff conditions under natural conditions are similar.

The following dissimilarities can be noted in Nepalese watersheds compared to the United States watersheds:

1. Human and livestock population density is very high.
2. Agriculture practices are very primitive
3. Ninety percent of the rain occurs during the month of July-September (monsoon season).
4. The intensity of rainfall is very high (maximum 100 year-1 hour storm is 4.5 inches in Florida compared to 8 inches in Pokhara, Nepal.
5. Vegetation below 8,000 feet is tropical and subtropical.
6. Water management is very poor and drought periods are uncontrolled.
7. Mechanized equipment cannot be used in watershed rehabilitation.
8. Land ownership pattern in Nepal is in small units.
9. Land use is broken. In one small watershed agricultural land, forest land, range land, and settlements are mixed.
CHAPTER IV
PRINCIPLE OF WATERSHED REHABILITATION

A watershed is generally considered to be the geographic area of overland drainage which contributes waters to the flow of a particular stream at a chosen point. It is a "water collection" and "water handling unit," a topographic entity which is usually surrounded by other entities of the same nature (Hudson and Stall, 1951).

Watershed management is the management of the natural resources of a drainage basin primarily for the production and protection of water supplies and water-based resources, including the control of erosion and floods, and the protection of aesthetic values associated with water. Every watershed is the product of many natural processes, including rock weathering, soil formation, erosion, and biotic succession, all of which have been operating under the impact of climate over the ages. Because of local differences in the climate, the resistance of rock to weathering, and other features such as the aspect, length and steepness of slopes, differences have developed in the character of the plant cover and soil mantle and in runoff and in the sediment load of the streams. In some drainage basins, streams fluctuate but little either seasonally or annually, and carry negligible quantities of sediment. Others are frequently in violent flood stages and are generally muddy. Most streams exhibit runoff and sediment characteristics between these extremes. Where such variations are manifestations of different degrees of control established by nature, there is
little that watershed rehabilitation can do toward their control.

It is quite well established, however, that many of the floods and much of the sediment loads carried by streams are not normal proportions, but have been magnified by impairment of the plant cover and soil mantle on the watershed slopes and in the valley bottoms. Watershed rehabilitation techniques can reduce such discharges and sedimentation rates, but only to the extent they have been increased by watershed deterioration above the normal (Bailey, 1941). However, results of watershed rehabilitation will not prevent all floods nor will they keep all sediment out of streams. Some degree of soil loss from slopes is normal, being rapid in some places and very slow in others.

The environment of large areas of damaged watersheds throughout the world is very inhospitable. Most of the developing countries are aware of this precarious situation. They are trying to develop watershed rehabilitation strategy suitable for their conditions. However, several points of misunderstanding are currently prevalent in the national land and water programs in developing nations. The principle relations between land and water has not been fully recognized. In this chapter, efforts are being made to analyze some controversy about watershed rehabilitation in Nepal's context.

Protection Versus Production

During the past several years public recognition of the intimate relationship of land and water has increased rapidly. It is unfortunate that in this logical succession, programs and plans are often con-
fused. Many people, including professionals in various land using agencies, have thought that watershed rehabilitation should not exclude production activities. This is not quite right. Watershed rehabilitation only serves as a sound base from where the production could be performed effectively. It is not a panacea for all the ills of agriculture, forestry and range use. It cannot substitute for good crop varieties, pest control and profitable marketing. Use and treatment of watershed lands could substantially modify runoff characteristics, sediment loads, groundwater supply, and other hydrologic factors. These in turn could modify both planning requirements and design of major downstream works for river regulation. Conversely, downstream river works for flood control, irrigation and drainage can materially increase the net area and yield of agriculture land (Brown, 1951).

Others have thought that watershed rehabilitation is needed only when the lands are severely damaged. Not many people are aware of the seriousness of sheet erosion which causes rapid deterioration in the productivity of the land. Countries like Iran, Egypt, and other middle east countries are prepared for a large scale rehabilitation program. Some watershed scientists have expressed concern about the feasibility of rehabilitating these watersheds. In most of these areas the extent of soil damage is very high. Rehabilitation techniques can be effective only if some soils are still present, so that vegetation development can be achieved. Nepal has a very limited land area. Erosion hazards are very high. The faster rates of soil erosion in Nepalese watershed can be reduced and the declining productivity of marginal mountainous land can be improved, if rehabilitation techniques
are applied now.

An adequate job of watershed rehabilitation will accomplish the maximum reduction in erosion rates (and sedimentation production) and the maximum increase in infiltration consistent with the proper use of land. The greatest benefits from watershed rehabilitation are the conservation and improvement of water and the resulting increase in the productivity, but its benefits do not stop there. The increased infiltration on a watershed may result in substantial reductions in flood peaks and resulting flood water damages. The decreased sediment production rates may cause major reductions in sedimentation damage in alluvial lands, reservoirs, stream channels, harbors and waterways, drainage and irrigation systems, and other improvements. In many cases the construction of reservoirs for municipal or industrial water supply, irrigation or flood control may not be economically feasible until sedimentation rates have been reduced by watershed protection (Matson, 1952).

Generally speaking, applying rehabilitation techniques on watershed lands may temporarily result in a loss of on-site benefits but it will provide off-site benefits. So there is always some trade-off involved while trying to manage and use the natural resources. The natural resources and environmental condition of a country could thus be improved if a national program and policy embraces these types of trade-offs. The investments for watershed rehabilitation should not, therefore, be considered only from a production point of view.
Rehabilitation Versus Continuing Land Use

Erosion rates increase, in general, with the increase of slope gradients. Except for cultivation on absolutely flat lands, cultivation on any slopes will induce varying degrees of erosion.

In Nepal, more than 80 percent of mountainous land areas under agriculture, forestry, or range use need some type of rehabilitation measures. In many cases, there is need for change in land use from cultivation to pasture. However, there is an acute shortage of agricultural land in Nepal. At present, a change in land use from an intensive one to a less intensive one, or putting land entirely out of production, is not feasible. But long term alternatives must be explored for a sound multiple use resource management. Many have suggested that small farmers should be moved from the marginal steep slopes to the low land forests of Nepal. If one looks this idea over superficially, it does not sound bad, if it is socially, economically, and technically practicable to undertake such a vast resettlement program. But the allocation of low land areas in forest and range use is not feasible from the supply and demand point of view. The increasing human and cattle population in low lands are already in short supply of forest and range produces. Similarly, any rehabilitation measures (such as contour trenches) which may reduce or stop the continuation of land use for a long period of time may not be feasible in Nepal.
Land Treatment Versus Mechanical Treatment

Watershed rehabilitation mainly consists of land treatment and mechanical treatment. Sometimes the distinction between land treatment and mechanical treatment is difficult to define. In a broad sense, land treatment is defined as the retardation of runoff by the improvement of existing vegetative cover, the establishment of trees or other vegetative cover on denuded areas, and the protection of forest and grasslands from fire. The objective is to increase amount of surface storage, rate of infiltration, and the capacity of the soil to store water. Mechanical treatment is defined as the retardation of runoff by obstructing the channel, breaking the slope length, and ponding the water. These are the supplemental devices or structures like contour trenches, terraces, diversion ditches, check-dams, small detention dams, and debris basins.

Many watershed managers believe that coordinated land treatment efforts alone would suffice for restoration of watersheds. Large amounts of public funds have been spent on these measures; the evaluation of the effectiveness of these treatments are rather meager or never put to the test in terms of quantitative figures. The general feeling is that these measures are best applied where slopes are gentle, rainfall is not intense, watersheds are not impaired heavily, and where semi-permanent and permanent vegetative cover can be established. It is false economy to undertake ineffective rehabilitation measures simply because they are cheap. In most developing countries there is a tendency to adopt less effective and less permanent cheaper measures in harsher topography and climatic conditions. They are not maintained
and supervised well. The achievements are judged by the extent of the area covered rather than quality and effectiveness of the measures adopted. As a result, many rehabilitation efforts can not provide lasting benefits.

On the contrary, mechanical treatments are comparatively expensive. These are generally built in adverse conditions. They are necessary for controlling the overfall at the head of large gullies, to drop discharge from vegetated waterways into a drainage ditch, or to hold water where it falls to help establishment of vegetation. Mechanical treatment structures are more susceptible to damage if they are not properly designed and not maintained regularly. The two primary causes of failure are: insufficient flow or storage capacity, and insufficient provision for energy dissipation. However, where topographic and other conditions are suitable and the extent of soil damage is high, mechanical protection is the only effective and economical method available for watershed rehabilitation.

In summary, the choice of treatment is dictated by the specific watershed conditions. The combination of land treatment and mechanical treatment can be adopted by careful planning and design.
CHAPTER V
CONTOUR TRENCHING AS A STRATEGY IN WATERSHED REHABILITATION IN THE U.S.

Earlier in this century, the deteriorated condition of numerous high, mountain watersheds in the Western United States resulted in large mudrock flows that flooded valuable low lands, claimed several lives, and caused considerable property damage (Berrick, 1962). These floods followed high intensity summer rain storms on the badly denuded areas. Overgrazing and burning of the protective vegetation were considered to be the primary causes of the deterioration (Cannon, 1931).

In 1930 a Flood Control Commission was appointed to determine the cause of unprecedented floods in Utah. To restore the watersheds, a rehabilitation program was recommended on the same year. In 1933 the Intermountain Forest and Range Experiment Station, U. S. Forest Service, was given the responsibility of devising the most efficient and effective methods for the control of floods and erosion originating on forest and rangeland (Copeland, 1960). Contour trenching, one of the numerous practices recommended, was widely used, and by 1969 approximately 30,000 acres had been contour trenched in the States of Utah, Idaho, Montana, California, and Wyoming. However, the practice was not of a proved effectiveness for controlling runoff from high intensity summer storm.

A contour trench is essentially a small reservoir with no spillway. The plan is to store all runoff, and then have the runoff
evaporate or infiltrate before next event. Proponents of contour trenching systems have contended that:

1. Trenches absorb all the water thereby preventing floods and improve soil moisture conditions which stimulates plant growth.

2. They check erosion losses, thus improving soil stability which is necessary for plant growth.

The theoretical reasons for these contentions will be analyzed in this section, whereas the effectiveness and the application of trenching will be discussed in Chapter VII. A definition sketch showing different terms used in this section is presented in Figure 4.

Effects of Contour Trenching on Runoff and Peak Flow

Runoff on sloping land must flow to lower lands in a controlled manner which will not result in gully formation and will not hinder the growth of vegetation. Undisturbed forest and range sites, in addition to producing living things and developing a soil mantle, performs the function of receiving the precipitation and disposing of the resulting runoff safely. In any event a considerable amount of energy are dissipated as flow proceeds downwards. Fifty cubic feet per second flowing 100 feet down a 5 percent slope, releases energy at the rate in excess of 0.28 horsepower (Schwab, et al., 1966). If this energy acts upon watershed whose hydrologic functions and the stability of soil are impaired, a considerable amount of soil particles will be detached and transported by water. When a series of contour trenches are spaced sufficiently close to hold a predetermined
Figure 4. Definition sketch of a contour trench designed to hold 75 percent of a 2" rain allowing 0.2" free board in a 50 percent slope.
amount of surface runoff for a particular storm size and return period, the ill effects of energy caused by excessive runoff will be absent and balance can be restored close to natural condition.

How properly designed contour trenches can reduce surface runoff can be visualized from the runoff model developed by USDA Soil Conservation Service. The runoff model used is, in an elementary form:

\[ Q = \frac{(P-I_a)^2}{(P-I_a+S)} \]  

(1)

for all \( P > I_a \), where,

- \( P \) = storm rainfall in inches,
- \( I_a \) = the initial abstraction or rainfall before runoff is initiated (inches).
- \( S \) = storage index in inches.
- \( Q \) = the direct storm runoff in inches.

The three parameter equation is simplified by a relationship between \( I_a \) and \( S \):

\[ I_a = 0.2S \]  

(2)

Making the substitution of (2) and (1) and simplifying yields:

\[ Q = \frac{(P-0.2S)^2}{(P+0.8S)} \]  

(3)

Thus, runoff (Q) is taken as a function on the parameter \( S \), which is related to another parameter called Curve Number (CN):

\[ CN = \frac{1000}{(10+S)} \]

Or \( S = \frac{1000}{CN} - 10 \)  

(4)

Appropriate values of CN must be selected to apply the technique. The choice depends upon soil type, vegetative type, cover density, and antecedent soil moisture.
Contour trenches increase the $S$ factor in the equation $CN = 1000/(10+S)$, initially by storing excess rainfall and gradually restoring the watershed condition close to natural in the long run. Thus the objective of applying contour trenches from the runoff point of view is to increase the storage capacity of the watershed artificially, until the site can handle the precipitation naturally.

Peak flow from a watershed is equally important in watershed management. Contour trenches affect peak rates of direct runoff due to the fact that (a) they reduce volume of direct runoff, and (b) they change the watershed lag time. The reduction in the volume of direct runoff during individual storms may be caused by increasing the infiltration rate, or by increasing surface storage or both. Trenches increase surface storage and to some extent increase infiltration rates. The unit hydrograph principle states that, with other things constant, the peak rate of flow varies directly with volume of flow. Thus, a 30 percent reduction in volume gives a 30 percent reduction in peak flow rates (U. S. Department of Agriculture, 1972).

The degree of effectiveness of contour trenches generally depends upon the quantity that can be installed. Contour trenches, however, can be made to have a small or large effect by changing the dimensions of the trench. Thus, theoretically, peak flows over an impaired watershed can be regulated by the construction of contour trenches.

Contour trenches can produce a lag effect. Lag, as used here, means the delay between the production of direct runoff on upland areas and its appearance at a given cross section in a stream channel. Trenches produce lag effects by increasing infiltration and by increas-
ing infiltration and by increasing opportunities for surface detention storage.

Contour Trenching and Infiltration

Trenches collect and impound surface runoff. The rates at which ponded water infiltrates is an important facet of hydrology.

Infiltration is the process by which water passes through the soil-air interface. Percolation refers to its advance through the soil. Water infiltrates into an unsaturated soil in response to capillary and gravity potential. If water is ponded on the surface, the pressure head is an additional potential causing infiltration. The capillary potential predominates initially when soils are dry. As water percolates deeper and soil water content increases, the capillary potential becomes progressively less important; and, when saturation is approached, gravitational forces predominate. The maximum rate at which water can enter a soil is termed infiltration capacity. The rate at which water is actually entering the soil at any time is the infiltration rate. The major factors which effect infiltration are:

(a). Antecedent moisture content of the soil.
(b). Soil texture and structure.
(c). Cover density.
(d). Biological activity and organic matter.
(e). Depth and type of mulches.
(f). Surface soil wetability.
(g). Rates of rainfall.
(h). Soil frost and ice (concrete and granular).
(i). Soil porosity.

(j). Entrapped air in underlying soil.

Contour trench trap, pond, and dispose of water initially through high infiltration rates and then as the pressure head decreases, the water slowly soaks into the soil. Part of the ponded water is evaporated.

Widely differing combinations of the above factors conceivably will have contrasting effects on water disposal in an area with contour trenches. Physical and chemical properties of the soil are altered under contour trenching treatments. Bulk densities are reduced by mechanical disturbances but with time tend to recompact to their original pretreatment levels. As bulk densities are reduced and infiltration is increased, more water is leached through the profile causing downward movement of salts (Sodeik, et al., 1974). As more water moves into the soil, plant growth is increased, resulting in an increase in soil organic matter and residue on top of the soil. This favors improved infiltration. However, there is the possibility that contour trenches in fine textured soil may result in decrease in infiltration rates because fine soil particles silt in and plug the capillary pore spaces (Neff, 1973).

The hydrologic influence of a contour trench cannot be easily generalized. There is the possibility of wide variation in infiltration rates in the bottoms of contour trenches. Depending upon the soil type and other microclimatic factors, infiltration rates can vary considerably on what appears to be a uniform soil type. Due to the high infiltration capacity of decomposed granites, contour trench construction should have less influence on water yields in granitic soils than
in finer textured soils. But as more water moves through the coarse-textured soil, plant growth is increased and soil structure improves. Fine textured soils cause water to pond in the trenches for a considerable time, thus permitting it to evaporate or to be consumed by vegetation on site. The timing of water yields may also be effected. The slow percolation of water from the bottom of trenches in fine textured materials may serve to delay stream flow and lower the peak runoff. On the other hand, contour trenches in decomposed granitic soils probably would not alter the timing of water yields appreciably (DeByle, 1970b).

**Contour Trenching and Erosion**

There are two types of erosion: geologic and accelerated. Geological erosion includes soil-forming as well as soil eroding processes which maintain the soil in a favorable balance, suitable for most plants. Accelerated erosion includes the deterioration and loss of soil as a result of man's activities. Though both types of erosion are recognized, only accelerated erosion is considered a problem in conservation activities.

Accelerated erosion is soil loss in excess of geological erosion. It is normally associated with changes in natural cover or soil conditions and is caused primarily by water and wind. The forces involved in accelerated erosion are:

1. Attacking forces which remove and transport the soil particles.
2. Resisting forces which retard the erosion.

The major variables affecting soil erosion are climate, soil,
vegetation, and topography. Of these, vegetation and, to some extent soil, may be controlled by proper management. The climatic factor and the topographic factor, except the slope length, are beyond the power of man to control.

Before planning any watershed treatment, it is always desirable to predict soil losses for a given set of conditions, in order to determine the adequacy of conservation measures.

Contour trenches as a strategy in reducing erosion can be visualized by analyzing the different components of the Universal Soil Loss Equation which was developed for agricultural land, east of the Rocky Mountains, in the United States (Wischmeier and Smith, 1958b). The basic equation is:

\[ A = RKLSCP \]

where,

- \( A \) = the average soil loss per acre per year,
- \( R \) = the rainfall factor,
- \( K \) = the soil erodibility factor,
- \( L \) = slope length factor,
- \( S \) = slope gradient factor,
- \( C \) = cropping management factor

and \( P \) = the erosion control practice factor.

Each of these factors consists of an equation, expressed as a nomograph, or tabulated values. Soil loss is calculated as the product of six factors.

Contour trenching has no impact on the rainfall factor in the equation. The rainfall factor is a product of the kinetic energy of
the storm and maximum 30 minute intensity. The soil erodibility factor (K) has been found to vary with basic soil textural properties, organic matter, structure, and permeability. The variables which define K are very hard to control. However, land surface modification such as contour trenches may cause increases in organic matter contents due to subsequent forage production, and improved soil structure. These changes in soil physical parameters modify the value of K with a resultant decrease in A. The topographic factor adjusts the soil loss from the standard length of 72.6 ft and 9 percent slope. These factors can be calculated from the equation:

\[ L = \left( \frac{\lambda}{72.6} \right)^m \]

and

\[ S = \frac{(0.43+0.30s+0.043s^2)}{6.613} \times \left( \frac{10000}{1000+s^2} \right) \]

where \( \lambda \) = slopes length in feet and

\[ m = 0.3 \text{ for slopes from 0 percent to 5 percent} \]
\[ = 0.5 \text{ for slopes from 5 percent to 10 percent} \]
\[ = 0.6 \text{ for slopes greater than 10 percent} \]

Contour trenching will not effect the gradient of natural slopes. But slope length is changed according to the spacing between the trenches. Each trench divides the slope into different slope lengths. Trenches perform two purposes: first, they trap the silt from between the trenches, and second, they reduce the energy of the flowing water by ponding the surface runoff.

The cover and management factor, C, for wildland conditions, depends upon three factors (Wischmeier, 1975):
Type I - canopy cover.

Type II - mulch or close growing vegetation in direct contact with soil surface.

Type III - tillage and residue.

Contour trenching could have some influence on all the above factors.

$P$, the conservation practice factor, which is the ratio of the soil loss for a given practice to that for up and down the slope farming. This factor would be greatly influenced by contour trenching. All kinds of conservation practices reduce the value of $P$ substantially. Contour trenches trap the silt, reduce the velocity of flow and break up the slope length. Thus the average annual sediment yield for the field is highly reduced by contour trenching.

**Contour Trenching and Soil Moisture**

The water in soil is dynamic. It is constantly moving from one place to another in response to capillary, gravity, and osmotic forces. Water, as an input to the surface of the land, may infiltrate into a soil at one rate in one place and a greatly different rate in another place. In order to evaluate completely the soil water system, one must know the energy of water, the amount of water in the soil, and how these conditions change in space and time. This requires a complete understanding of water movement and flow in soils. Such complete evaluation of soil moisture conditions are not easily made and is out of the scope of most projects.
Any land surface modification affects the hydrologic cycle of a watershed in many ways. Factors such as soil moisture conditions are significantly altered around trenched areas. In general, the land surface can be divided into four facets: trench cut bank, trench bottom, trench fill, and between the trenches. These areas will have differential infiltration rates because of differences in permeability, slope, undulation, compaction, and plant cover. As a result of soil water movement, there are likely to be differences in the amount and energy conditions of water in contiguous volumes of soil. In addition, plants remove water at different rates from adjacent soil areas because of differences in density of crop cover and because of differences in the rates with which water can move in the soil.

Fill materials consist of surface soils. Thus the water holding capacity of soil should be greatest in the trench fill. Trench construction apparently alters the soil water condition in trench bottoms. Construction displaces 3 to 4 ft of surface material. Consequently trench bottoms may have a lower water holding capacity. The improvement of moisture conditions between the trenches depends upon the spacing between the trenches and texture and structure of the soil. Trenches receive some moisture from cut slopes due to seepage.

In general, soil moisture recharge can be expected from contour trenches from at least three sources: (1) Rainfall and snowmelt runoff retention, (2) improved infiltration, and (3) snow trapping. Retention of water that would normally be lost as runoff is probably the major benefit of contour trenching.
Contour Trenching, Snow Distribution and Snow Melt Runoff

Contour trenches affect snow accumulation which in turn influences soil water, vegetation and ultimately stream flow. Most snow management research has been directed towards the relationship between vegetative cover and snow deposition. In alpine areas snow accumulates to great depths only in places that are protected from wind (Martinelli, 1965). Snow accumulates in most of the depressions before the end of the winter. Once full, these areas are aerodynamically smooth and trap little additional snow. There is no shortage of drifting snow in alpine regions. Therefore, snow accumulation could be greatly increased if trapping efficiency were improved. If snow depths could be increased in areas where it is normally 10 to 15 feet deep, the amount of snow available for summer stream flow would be increased substantially. The hypothesis of increased yield from this form of snowpack management is based on the assumption that significant evaporative losses occur during prolonged transport of snow by wind, and these losses can be reduced by retaining the snow where it falls (Tabler, 1968). The effects of curvature, shading, and exposure on snow accumulation and melt can be substantial (Anderson, 1963). As vegetation responds to an improved mesic soil water regime, more crop residue is usually available to trap and hold snow. Thus, contour trenching might influence snow accumulation and melt around the vicinity of the trench, since the fill side of the trench provides the mechanical barrier and shading effects which extend above the natural slope profile.
Contour trenching may affect vegetative production in at least four ways: (1) improved soil water regime; (2) improved soil properties; (3) improved species composition; and (4) improved soil fertility. Trenches constructed on steep eroded areas may greatly improve conditions necessary for plant growth (Bailey and Croft, 1937). However, responses of species, either exotic or indigenous, seeded or natural, cannot be expected to be homogeneous. Mechanical disturbance of native sod temporarily increases soil fertility as disturbed soil and organic matter weather and decompose. Changes in species composition may result from invasion or reinvasion of the disturbed area (Wight, 1975). Species composition is also changed when treated areas are seeded to native or introduced species. When species composition is changed, root systems are also changed considerably.
CHAPTER VI
DESIGN, LAYOUT, AND CONSTRUCTION OF CONTOUR TRENCHES

A contour trench system was applied effectively by the Civilian Conservation Corps on the Davis County Experimental Watershed in Utah. The trench system was located on steep mountain watersheds at elevations of 7,000 to 10,000 feet. Slopes varied from 20 to 60 percent (Bailey and Croft, 1937). Since its inception nearly 45 years ago, the criteria guiding the application of contour trench systems have been greatly improved upon. However, records and documents are very scanty. The criteria presented below are based upon available published reports and personal communication with different scientist involved in contour trenching projects.

Design Sequence

Because of the highly varied conditions of soil and slope that are encountered on mountainous watersheds, no one type of trench has been found suitable to meet all conditions, although the design is fundamentally the same for each trench. Different trench specifications, as applied by the U. S. Forest Service, are summarized in Table 7. The cross sectional views of these trenches are presented in Figures 5, 6, 7 and 8. For a detailed explanation of the trenching criteria and trench construction, the reader is referred to the following references: Bailey and Croft (1937), and U. S. Department of Agriculture (1959). Also a
Table 7. Summary of contour trenches specification as applied by the U. S. Forest Service.

<table>
<thead>
<tr>
<th>Trench type</th>
<th>Proposed by</th>
<th>Slope limitations</th>
<th>Minimum soil depth</th>
<th>Cut slope</th>
<th>Fill slope</th>
<th>Design depth (ft)</th>
<th>Free board (ft)</th>
<th>Provision for settling</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard trench</td>
<td>Bailey and Croft, 1937</td>
<td>40 %</td>
<td>12-18&quot;</td>
<td>1:2:1</td>
<td>1:4:1</td>
<td>0:21</td>
<td>No</td>
<td>2 to 10 times</td>
<td>Spacing is as shown in Figure 5. 200 equalizers per mile. The height of the equalizer is .3 foot below the filled dike. Width is .7 foot.</td>
</tr>
<tr>
<td>Substandard trench</td>
<td>Bailey and Croft, 1937</td>
<td>65 %</td>
<td>12-18&quot;</td>
<td>1:1</td>
<td>1:4:1</td>
<td>.21</td>
<td>x</td>
<td></td>
<td>Spacing as shown in Figure 6. 200 equalizers per mile. The height of the equalizer is .3 foot below the filled dike. Width is .7 foot.</td>
</tr>
<tr>
<td>Semi-standard trench</td>
<td>Bailey and Croft, 1937</td>
<td>50 %</td>
<td>12-18&quot;</td>
<td>1:1</td>
<td>1:4:1</td>
<td>.21</td>
<td>x</td>
<td></td>
<td>Spacing as shown in Figure 7. 20 equalizers per mile. The height of the equalizer is .3 foot below the filled dike. Width is .7 foot.</td>
</tr>
<tr>
<td>Super standard trench</td>
<td>Bailey and Croft, 1937</td>
<td>30 %</td>
<td>12-18&quot;</td>
<td>1:2:1</td>
<td>1:4:1</td>
<td>2 to 10 times</td>
<td></td>
<td></td>
<td>Spacing depends upon the contributing area above the trench.</td>
</tr>
<tr>
<td>Outside trench</td>
<td>Forest Service Land Treatment Handbook</td>
<td>30 %</td>
<td>13-18&quot;</td>
<td>2:1:1</td>
<td>1:1 ins. variable</td>
<td>x</td>
<td>x</td>
<td></td>
<td>Spacing is variable. Equalizers are provided 40 ft apart. Figure 8.</td>
</tr>
<tr>
<td>Inside trench</td>
<td>Forest Service Land Treatment Handbook</td>
<td>30 %</td>
<td>12-18&quot;</td>
<td>1:2:1</td>
<td>2:1:1 ins. variable</td>
<td>x</td>
<td>x</td>
<td></td>
<td>Spacing is variable. Equalizers are provided 40 ft apart. Figure 8.</td>
</tr>
<tr>
<td>Type I</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type II</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A - STANDARD TRENCH

INTERVAL TABLE

<table>
<thead>
<tr>
<th>Percent</th>
<th>Trench</th>
<th>Horizontal Interval</th>
<th>Vertical Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>9.5 Ft</td>
<td>25.0 Ft</td>
<td>5.0 Ft</td>
</tr>
<tr>
<td>30</td>
<td>12.0 Ft</td>
<td>&quot;</td>
<td>7.5 Ft</td>
</tr>
<tr>
<td>40</td>
<td>16.5 Ft</td>
<td>&quot;</td>
<td>10.0 Ft</td>
</tr>
<tr>
<td>45</td>
<td>23.0 Ft</td>
<td>30.0 Ft</td>
<td>13.5 Ft</td>
</tr>
</tbody>
</table>

Designed to hold 75% of a 2" rain allowing 0.2' freeboard

Figure 5. Trench specifications for various slopes: Standard Trench.
### 8-SUB-STANDARD TRENCH INTERVAL TABLE

<table>
<thead>
<tr>
<th>Percent Slope</th>
<th>Trench Width</th>
<th>Horizontal Internal</th>
<th>Vertical Internal</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>11.5 Ft</td>
<td>25.0 Ft</td>
<td>12.5 Ft</td>
</tr>
<tr>
<td>60</td>
<td>16.5 Ft</td>
<td>=</td>
<td>15.0 Ft</td>
</tr>
<tr>
<td>65</td>
<td>23.0 Ft</td>
<td>30.0 Ft</td>
<td>19.5 Ft</td>
</tr>
</tbody>
</table>

Figure 6. Trench specification for various slopes. Redrawn from Bailey and Croft (1937).
### Semi Standard Trench Interval Table

<table>
<thead>
<tr>
<th>Percent</th>
<th>Trench Width</th>
<th>Horizontal Interval</th>
<th>Vertical Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>7.0 ft</td>
<td>12.0 ft</td>
<td>6.0 ft</td>
</tr>
<tr>
<td>60</td>
<td>9.5 ft</td>
<td>12.0 ft</td>
<td>7.2 ft</td>
</tr>
<tr>
<td>65</td>
<td>12.0 ft</td>
<td>16.0 ft</td>
<td>10.4 ft</td>
</tr>
</tbody>
</table>

Figure 7. Trench specifications for various slopes. Redrawn from Bailey and Croft (1937).
Figure 8. Trench specification for different types of V-shaped trenches. Redrawn from Forest Service Land Treatment Measures Handbook (1959).
more recent description of the U. S. Forest Service's criteria for trench design and application are given by Noble (1963) and Megahan (1966). The names of the trenches, as summarized in Table 7, do not have any real connotation. A classification, such as standard trench, semistandard trench, substandard trench and superstandard trench, are primarily based upon their capacity and the maximum slopes on which they can be built. Similarly, the outside trench gets its name from the fact that storage is provided on the downhill or the outside part of the excavation, where water is held by the dike formed of the excavated material. The inside trench gets its name from the fact that the trench is made on the inside of the excavated section. A type one inside trench can be constructed only on slopes of less than 30 percent. They are constructed on relatively gentle slopes where the tractor blade can be tilted opposite to the slope of the land so as to cut a V shaped trench. Type two inside trenches are constructed on slopes 30 to 70 percent. The first operation consists of making a level base or road on which the tractor operates and then building a trench on the inside of the road.

The design suggested by Bailey and Croft (1937) is site specific. The free board of 0.2 foot provided initially will be lost after settlement. The hydrologic design procedures are obscure. For example, a 25 year, 1 hour storm is used but the reason is not explained. It has been assumed that 75 percent of the precipitation will appear as surface runoff. Site specific spacing for different slopes have been recommended (Figures 5, 6, and 7). How these spacings are derived is not explained.

The Forest Service, Land Treatment Measures Handbook (U. S. Department of Agriculture, 1959) has also recommended a 25 year, 1 hour design
storm. The following relationship between expected rainfall, the spacing and the capacity of contour trenches has been recommended:

\[
\text{(Rainfall in inches) times (estimated runoff) times (interval between trench in feet) divided by 12 equals trench capacity in cubic feet needed per lineal foot of trench.}
\]

The Forest Service, Land Treatment Measures Handbook (U. S. Department of Agriculture, 1959) has not resolved different problems that develop during hydrologic design. For example, no explanation is given about the procedure of estimating runoff in percent, provision for settling, and free board. Megahan (1966) has suggested an increase in estimated runoff by 100 percent to take care of all the unknowns such as settling, slumping, faulty construction, site not representative of runoff curve numbers, etc.

Thus, the available information reveals that the hydrologic design of contour trench systems is still crude and is based upon rules of thumb. Contour trenching design techniques used in the past cannot be regarded as a sound engineering practice. In some cases they are overdesigned, resulting in higher costs and in other cases they have failed because of lack of understanding of the unknowns involved in the design procedures.

**Surveying and Planning**

The following surveying and planning procedures are outlined by Bailey and Croft (1937) and Forest Service, Land Treatment Measures Handbook (U. S. Department of Agriculture, 1959). Whenever aerial photographs or large scale maps are available, they should be used for the initial planning. A large scale sketch map of the work unit should be
prepared by field survey. Because of the large amount of information required, the map should be drawn to a scale of not less than 1/4 inch per 100 feet. As far as possible the following information should be delineated on this map: (1) the work unit drainage boundary, (2) the area on which no treatment is needed and the area needing treatment, (3) conspicuous physical features such as rock outcrops, cliffs, talus, and snow bank areas which may have an accelerating or retarding influence on surface runoff, (4) the location of gullies and treatment needed, and (5) the type of trench to be constructed in each areas.

Plan layout should be as simple as possible for interpretation. Flags should be placed on the work unit to indicate the boundaries of the area and the gully section to be trenched. Assessment of the service roads needed, the kind of equipment to be used, the personnel requirements and estimated time necessary to complete the job should be done and a copy of this information should be attached with the map.

The application of the control plan depends upon the personal skill of the planner and the equipment available. Since the inception of contour trenching, the type of equipment used has changed. Progressively, contour trenches are built with great economy by using tractors of the largest sizes (U. S. Department of Agriculture, 1959).

**Construction Sequence**

There are four major steps in the construction of contour trenches (Bailey and Croft, 1937, and U. S. Department of Agriculture, 1959). They are: (1) layout, (2) roughing out, (3) finishing, and (4) inspection.
Layout

The first trench should start on the area farthest from the base of operation to prevent damage due to trampling by machine and man.

Grade lines should be determined and marked by stakes which are 2 feet above the ground level at every 15-foot interval. After the first trench is staked on grade, the process is repeated for succeeding trenches.

Roughing out

Method I. This method is used on relatively gentle slopes where the bulldozer blade can be tilted into the slope so as to cut a V-shaped trench. They should later be finished to the nearest design dimension.

Method II. This method is used for slopes 30 to 70 percent. The first operation consists of making a level base or road on which the tractor operates and the trenches are built on the inside of the road.

Method III. This method is used to build outside type trenches. The bulldozer blade is tilted to 10 to 15 degrees steeper than the slope being trenched.

Finishing

Finishing operation involves: (1) checking of the final grade, (2) the finishing of the trench to standard dimension, and (3) placing of the equalizer along the axis of the trench. Depth and shapes should be maintained precisely. Templets should be used for fast measurement of the finished trench. When finished, equalizers are placed in the trench at an interval depending on the type of trench and their top should be at least 0.3 foot below the top of the trench dike.
Inspection

Thorough inspection of every point along the axis of the trench is essential. One weak point in the trench may cause devastating results. The engineering technician should visit every trench and make sure that it is built to required specifications.

Revegetation

One of the objectives of a contour trench system is to stimulate plant growth by checking surface soil movements and thus provide a more stable seed bed. Revegetation may develop naturally under the improved microenvironment or more seeding may be needed to restore the barren land with desirable plant cover. The research results in the Intermountain Region indicate that seeding is generally necessary on depleted areas. However, seeding of productive grasses may not be a success in areas where erosion of the soil may have progressed to such degree that humic content must be built up through the subclimax plant stages before reseeding will be effective. In many cases, protection from grazing will be necessary to stimulate the growth of native subclimax vegetation (Bailey and Croft, 1937).

Maintenance

After the initial construction, subsequent maintenance is essential. In no case should it be assumed that the construction is perfect. There will always be unforeseen human errors during the construction of structures. For example, the fill material or fill slope will not be compact enough to resist settlement. Failures due to excessive settlement might therefore be anticipated and timely maintenance of these failures saves money and time.
CHAPTER VII
SUMMARY OF RESULTS AS EXPERIENCED IN U.S.A.

While the principle of terracing as a soil conservation measure is very old and extensively used, the use of contour trenching on forest and range lands for controlling soil erosion and floods is new and its application is limited. Only a few qualitative and quantitative evaluations have been made to determine the effectiveness of contour trenching.

Perhaps the most exhaustive and the best instrumented studies of contour trenching to control flooding were conducted in Davis County Experimental Watershed, Utah, where intensive systems of trenches were constructed in the early 1930's. The study of the flood control by contour trenches goes back to 1936 (Bailey and Croft, 1937). The study shows that during a rainfall of 1.14 inches on July 10, 1936, a rainfall rate of 5.04 inches per hour for a five minute period was registered. This storm produced no floods from the treated watershed, but the same storm caused mudrock flows in four other drainages within the area that had not been treated. Again, on the evening of August 19, 1945, when 1.09 inches of rain fell, rainfall rates at several recording gages exceeded 6.00 inches per hour for a 5 minute period, and at one station a rainfall rate of 6.80 inches per hour was registered. The runoff produced by this storm was disposed of safely from the contour trenched area safely.

Bailey and Copeland (1960) compared stream flow records from a trenched and untrenched watershed in Utah. The trenches, installed in
1935, were spaced 25 feet apart. Each had a capacity of 1.5 area inches of water. A gradual decrease of 2.7 inches (23 percent) in average annual stream flow from the trenched watershed developed over a 22 year period. The decreased yield was observed mostly during the high flow months, March, April, and May. Discharge reduction in all low flow months was negligible. However, this decline cannot be attributed only to contour trenching, because the area was also protected from grazing animals.

Doty's (1971) study of contour trenching effects on stream flow from a Utah watershed represents a single major effort for providing quantitative information on the effect of large contour trenches on water yield. His results are based upon the outcome of the research conducted on two Utah watersheds, Halfway Creek and Miller Creek. Contour trenching was evaluated in terms of:

(1) Total annual stream flow.

(2) Spring stream flow (total flow peak volume, and recession flows).

(3) Low stream flow (July through February) with respect to total volume of stream flow.

The upper 15 percent of Halfway Creek was treated with contour trenches in 1964 and Miller Creek was selected as the control watershed. Twelve years of records before trenching and six years of records after trenching were analyzed. The regression analysis comparing annual streamflow from Halfway Creek drainage with that from Miller Creek drainage prior to trenching revealed a high degree of correlation ($r^2 = 0.878$) between the annual stream flows from the Halfway Creek drainage and that from the Miller Creek drainage.
A covariance analysis \( r^2 = 0.46 \) compared the regression obtained before trenching with that after trenching. The analysis indicated that contour trenching had no statistically significant effect on annual flow. A covariance analysis comparing low flow periods (July through September) revealed that low flow runoff decreased slightly after trenching. But this decrease was not statistically significant. Analysis of 12 years of snowmelt generated daily stream flow data of Miller Creek and Halfway Creek prior to trenching revealed that 86 percent of the variance of Halfway Creek stream flow was explained by Miller Creek. After trenching, all peaks were lower than predicted by the regression line. Doty (1971) analyzed the percentage of total annual runoff from summer storms in Halfway Creek and Whipple Creek. The percentage did not represent a significant portion of the total annual flow. He tried to analyze the effect of trenching in controlling runoff caused by summer storms. But his analyses are based on two irrelevant storms and does not bear any significant conclusions.

DeByle (1970) studied the effects of contour trenching on the east slopes of the Sierra Nevada mountains. He concluded that approximately 110 lineal miles of contour trenches in a 16 square miles of watershed may have reduced flood peak during a flood period about 60 acre-feet.

Contour furrows differ from contour trenches as being smaller in size. Hydrologic responses due to land surface modification by contour trenches and contour furrows is believed to be very similar. A number of qualitative and quantitative studies have been done regarding the effectiveness of contour furrowing. Results observed from contour furrowing in different parts of the U. S. can be compared.
Contour furrowing of native grasslands in central Nebraska reduced storm runoff by 84 to 94 percent and protected lower lying lands from the effects of siltation and runoff (Wasser et al., 1957). In a similar Nebraska study, contour furrowing of a range in very poor conditions, where grazing was uncontrolled, reduced runoff and conserved an average of 1.2 inches of additional moisture (Dragoun et al., 1968).

Branson et al., (1966) compared the effects of contour furrowing, pitting, and ripping on rangelands from Montana to New Mexico. These treatments added to soil moisture and forage production by increasing infiltration and delaying runoff. The study areas receive low annual precipitation, most of which occurs during summer rainstorms. Thomas (1975) found that contour furrows constructed with a Holt trencher on shallow soils derived from shale near Cisco, Utah, were effective in holding runoff and sediment on site. However, if the micro climatic conditions are harsh, continuance of these types of treatments cannot be recommended on sites similar to Cisco (Wein and West, 1971, 1973).

Six years of soil water measurements on and adjacent to a contour trenched area revealed that some redistribution of soil water occurred following trenching (Doty, 1972). No perceptible change of soil water condition was observed between the trenches. Construction of the trenches apparently altered soil water conditions in trench bottoms. Trench bottoms have a lower water holding capacity because of soil disturbances. However, shading effects, less wind, more snow, later snow melt and less evaporation causes more soil water in trench bottom. In addition, seepage from the cut slope also contributes soil water to trench bottom. The cut bank shows some increase in evaporation. Seasonal evaporation from the fill slope increased with time as...
vegetation occupied the site more completely.

Because natural barriers contribute significantly to snow accumulation in the subalpine zone, the effect that contour trenches might have on snow pack accumulation was examined by Doty (1970). It was believed that trenched areas on windswept slopes may induce additional snow accumulation; although snow accumulation increased slightly, water yields during snowmelt were not affected. Increased snow accumulation probably affected revegetation. The absence of normal frost conditions on trench bottoms led to premature seed germination which is very harmful for vegetation growth. The exposed fill slopes became a harsh environment on which to maintain vegetation. Redistribution of snow across the area produced a dry site on the exposed fill slope and excessive moisture in the trench bottoms. Vegetation that existed prior to trenching remained unchanged in the area between the trenches. Re-vegetation in the trench and cut slope was lacking. Development of vegetation on the fill slope over 6 years of study was encouraging.

DeByle (1970) studied infiltration rate for water ponded in the bottoms of contour trenches constructed in the Sierra Nevada Range. Sixty-four infiltration tests, using a double ring infiltrometer, were made. The average rate of infiltration in coarse textured soils derived from granite was 19.5 inches/hr, more than six times the 3 inches/hr rate measured in fine textured soils derived from andesite. These widely differing rates should be considered when contour trenches are installed.

In southeastern Montana, contour furrowing increased infiltration rates from less than 0.2 inches/hr to 0.8 inches/hr or more up to 7 years after treatment (Soiseth et al., 1974). After that, the infiltra-
tion rate tended to decrease because of increasing bulk density and deposition of fine silt particles from between the trenches and ridge of the fill.

During an extensive field tour in the Intermountain Region and California, I visited four areas where contour trenches failed. In two projects documents and records explaining the reason of failures were not available. However, the following comments are based upon available information and personal communication with available field staff:

Farmington, Utah

Three small tributaries of Farmington Creek (Halfway, Whipple and Corduroy) in Farmington Canyon, Utah, had been contour trenched and reseeded toward the end of Civilian Conservation Corps program in 1937 and 1938 (Rosa, 1954). The trenches constructed here were fewer and smaller than those installed on the nearby experimental areas in Parrish, Barnard, Davis, Ford, and Steed Canyons. These lower standards of construction were used on the assumption that natural vegetation would be sufficiently rapid for achieving effective control on untrenched areas. A rain of 1.0 inch with intensities ranging up to nearly 8.50 inches per hour for the maximum 5 minute period caused mud-rock floods from these small tributaries. After the flood, the ruins revealed numerous weaknesses in the design of the control work. There was not adequate provision for handling drainage from the work access road. The accumulated runoff from the road drainage ripped out the large section of trenches which ran straight downhill, causing successive lower trenches to collapse. This caused rapid concentration of runoff in the head water channel. Failure of reseeding and natural re-
vegetation on both trenched and untrenched areas produced enough run-off to cause additional trench failure and thus to augment the flow in the natural channel. It was also evident that a considerable volume of trench capacity had been lost prior to the storm due to erosion from intertrench areas where plant cover had failed to develop as expected.

San Dimas, California

Large contour trenches were installed to provide storage for about 3 inches of rainfall on the San Dimas Experimental Forest, in Southern California following an intense wild fire. During the storm of November 30, 1961, rainfall exceeded the capacity of these trenches for the first time (Krammes and Rice, 1963). Individual trenches overtopped and water rolled down slope to the trenches below. A chain reaction of failures usually followed, producing high peak flows and sedimentation. At present mass movements are conspicuous. Several gully systems have developed. The average slope of the watershed is 68 percent which is nearly the angle of repose for unconsolidated material. The soils are generally granitic and very erodible. This site clearly indicates that contour trenching may not be a satisfactory structure for flood control measures for steep slopes with highly erodible soils. Slope stability seems to be the major cause of failure. The capacity of the trench was also too small to accommodate the runoff from the intense storm.

Boise, Idaho

Contour trenches were installed for rehabilitating a burned area in the Boise National Forest. The area is called Poverty Burn. Soils are derived from granitic parent materials and slopes vary from 40 to
60 percent. Soil depth varies from two feet on the upper slopes, two to three feet in the middle slopes, and 10 feet on the lower slopes. The bedrock is fractured. Immediately after the installation of contour trenches, a high intensity summer storm hit the area. The trenches had the sufficient capacity to hold the runoff. But the impounded water percolated inside and lubricated the fractured bedrock. A number of land slides occurred. The drainage system was diffused. When the area received another storm, the drainage system could not hold the water and disastrous erosion and floods occurred. This area is a very good example of limitations of contour trenches in areas susceptible to landslides.

Boise, Idaho

In the Rattle Creek drainage of Boise National Forest about two square miles of heavily grazed mountain slopes were contour trenched and seeded around 1960. The head water drainage is very rocky and steep. The soil is granitic and very erodible. In 1961, a heavy summer storm overtopped a series of contour trenches and developed a network of gullies. From the ruins left now, it was observed that the uppermost trench could not accomodate all the runoff generated over the uppermost rocky steep slopes. When the first trench collapsed, the lower trench could not handle the excess runoff and was overtopped. In areas where the trenches are intact, vegetative growth is very poor, in spite of seeding. The trenches are fully silted up. The whole project is a complete failure. This area clearly indicates that, contour trenching may not be effective in granitic soils subjected to overgrazing. In addition to that if trenches having sufficient capacity cannot be
installed just below the rocky steep slopes, the whole idea of trenching should be dropped.

Watershed managers experienced in the application of contour trenching have some observations and some reservations about the effectiveness of the contour trenching. A summary of these opinions serves to conclude the experience with this practice in the United States:

1. "Contour trenching has proved to be a more effective land surface modification in controlling flooding, and sedimentation occurring from badly deteriorated mountain watersheds occasioned by high intensity summer rainfall. But the application of this method is not a panacea for all flood-source areas (Noble, 1963)."

2. "Trenches are especially valuable in situations where surface flow and erosion are preventing revegetation of the area. Also they are particularly helpful when they break up impermeable layers at or near the soil surface. Finally, trenches are beneficial where they increase infiltration as a result of their increased surface detention. There are numerous limitations on applicability of contour trenches. In addition, there is always the risk of failure and resulting greater damage to the area than if it were left untreated. Furthermore, contour trenches need close and continuing maintenance. In practically all cases, physical conditions limit the effectiveness of contour trenches to a relatively short period (Meiman and Schmidt, 1963)."

3. "A more thorough understanding of trenching effects is necessary to adequately determine what changes, if any, in water yield or water quality occur when a watershed is trenched (Doty, 1971)."

4. "Experience has clearly demonstrated that even such small structures as contour trenches will be successful in checking runoff from torrential rainstorms and melted snow water uniformly on steep slopes, only when constructed on a precision basis (Bailey and Croft, 1937)."

5. "Successful control of erosion and floods requires an accurate problem analysis. It is essential, first, to know the relation of the current flood and erosion phenomena to the geologic norm and, secondly, to determine the relative importance of each of the many factors
that contribute to the problem (Bailey, 1941)."

6. "Past research has shown that land surface modification treatments can effectively reduce runoff and erosion and increase soil water and subsequent forage production on arid and semiarid range lands. The treatments are currently not being used to their full potential as watershed management tools because of several factors:

a. High treatment cost compared to product values.

b. Need for specialized equipment - treatments that can be applied by individual ranchers and farmers have been the most popular.

c. Landowner's unfavorable attitude toward the rough microtopography associated with the treatments.

d. Professional resource manager's unfavorable attitude towards perturbation of native ecosystems. Research should be continued on the development and evaluation of land surface modifications treatments with emphasis on reducing application costs and increasing treatment longevity (Wight, 1975)."

7. "Contour trenches were intended originally to control the overland flow caused by intense summer rains falling on a dry mantle and, when adequately designed and properly installed, they serve this purpose admirably. They will not prevent floods caused by long lasting, low intensity rains falling on a frozen or a saturated mantle. However, regardless of conditions, streamflow will be affected if runoff water is held in the trenches for several hours (DeByle, 1970)."

8. "Trenches are an interim measure to hold water from overland flow onsite. They are not a substitute for rehabilitation measures designed to reduce runoff and erosion between trenches. Intertrench rehabilitation must be done or the trenching project will fail after a few years. Rehabilitation means maintaining a successful vegetation cover in subsequent years. This requires no grazing during the time when vegetation is becoming established and carefully regulated grazing thereafter (complete elimination of grazing may be advisable) (Megahan, 1977)."
The above discussion indicates that contour trenching provides the most benefits for high intensity, short duration rainstorms that cause runoff on areas of depleted vegetative cover. The surface runoff, in this case, results when rainfall exceeds infiltration rates. The trenches allow the water to slowly infiltrate into the soil, rather than run overland causing erosion. For this to occur, there must be ordered flow. In addition to ponding of the overland flow, contour trenches must also intercept shallow subsurface flow. Thus, in some situations, where soils are deep and infiltration is high, they will not solve the purpose of reducing floods. Contour trenches have questionable benefits in areas where large volumes, long duration, and possibly high intensity rain occur (such as monsoon areas). In such cases, trenches may have a detrimental effect rather than a beneficial effect. In this type of climatic event, in addition to large volumes of overland flow, subsurface flows will continuously contribute large volumes of water to the trench system. If the interception rate of subsurface flow in trenches exceeds the infiltration rate of the impounded overland flow, overtopping of the trenches is unavoidable. It will cause chain reaction to successive trenches down the slope, resulting in a failure. Other factors can be important too, such as mass erosion hazards increase greatly as the zone of soil saturation approaches the surface. These observations point up the need for greater care in designing contour trenches. Limitations on the applicability of contour trenches and some recommendations are discussed in detail in Chapter VIII.
CHAPTER VIII
APPLICABILITY OF TECHNIQUES TO NEPALESE CONDITIONS

The details of the contour trench system reveal that several relationships may exist between contour trenching and runoff, peak flow, infiltration, snow distribution, snowmelt runoff, vegetation, and soil moisture. However, quantitative evaluations of trenching effects are lacking and the entire idea cannot be accepted straightforwardly. Conclusions derived from a few studies are based upon the trenching of only a partial area of the watershed. Again the findings report the combined effects of trenching, grazing and fire control. On the other hand, the researchers whose findings do not conclude any significant effectiveness of contour trenches do not refute the whole idea of contour trenching. There are number of examples, especially the Davis Couty Experimental Watershed in Utah, and the Cottonwood Creek Watershed near Boise, Idaho where tremendous successes have been achieved. The opinion of experienced watershed managers in the 1930's and 1940's reveals that contour trenching has a definite role in the rehabilitation of an impaired watershed, if the plan is carried out systematically and precisely. So, a contour trenching system may be applied in Nepalese conditions if the limitations are systematically analyzed. Therefore some fundamental criteria which govern the applicability of contour trenching systems are discussed in the context of Nepalese watersheds.
Applicability

Origin and Causes of Flood

The study of flooding behavior of the Mahabharat and Siwalik River system in Nepal indicates that since 1955 frequency of flooding is increasing. This increasing flood menace is directly related to population growth, increased farming, and other developments. This is substantiated by the fact that eastern Nepal is observing a greater infrequency of flooding, than is western Nepal, where growth is less. Overgrazing, overcutting, and the conversion of the range and forest land to agricultural land is common and increasing at a precarious rate. Settlements, power lines, irrigation canals, reservoirs and roads are being damaged with increasing rate. During the land use survey of the eastern Nepal, I studied increasing flood damage over time by digging soil profiles in the flood plain and stream deltas. The kind and character of material deposited in these areas provided a clear picture of the recent deposits. The soil profile consisted of alternating layers of fine silt and gravel, cobbles, rocks, timbers and twigs. While interviewing local citizens, who were mostly senior citizens, it revealed that once a beautiful settlement in the flood plains is now under sand and gravel. From this study it can be confirmed that in most of the mid-Himalayan and outer Himalayan watersheds there exist a recent radical departure from the flow characteristics of the drainage.

The study was continued to investigate the source areas responsible for the floods. Flood source areas can be defined as those areas where floods are triggered almost exclusively by impeded infiltration and the
resultant overland flow. Flood source areas had the following specific earmarks: (1) numerous fresh discontinuous shallow gullies tending to form a continuous gully system, (2) absence of organic soil, (3) absence of plant cover, (4) development of erosion pavement such as gravel pebbles, and rocks over the surface. These areas were located in open grass and shrub type areas easily accessible to livestock on denuded slopes after excessive exploitation of vegetation, abandoned agricultural terraces, on areas where topography favored the congregation of livestock, and on areas of weak geological formations.

The situation discussed above is very close to that of the Davis County Experimental Watershed during the 1930's. So contour trench systems may help in rehabilitating these watersheds to reduce increasing flood damage in Nepal.

Rainfall and Design Storm Analysis

Rainfall records in Nepal are very short and the quality is poor. However, the records of a few stations have been used to project the rainfall depth for different design storms. Comparison of these extrapolated figures with that of records published in nearby experimental stations of India reveals that the projected figures are very close. In general Nepal can expect rainfall intensities as shown in Table 8.

For calculating the expected runoff from these storms, the physical characteristics of three typical watersheds of Nepal are used and curve number for each of these watersheds have been estimated by using Soil Conservation Service, Hydrology Handbook (U. S. Department of Agriculture, 1972). The physical features and hydrologic conditions of
Table 8. Maximum rainfall storms that can be expected in Nepal.

<table>
<thead>
<tr>
<th>Frequency (years)</th>
<th>Maximum depth of rainfall (inches)</th>
<th>1 hour</th>
<th>6 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>3.14</td>
<td>5.90</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>3.93</td>
<td>7.87</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>4.72</td>
<td>9.84</td>
<td></td>
</tr>
</tbody>
</table>


these watersheds are given in Appendix A. Estimated curve numbers for these watersheds are 74, 79, and 86.

Q has been calculated by using the runoff model developed by Soil Conservation Service (U. S. Department of Agriculture, 1972).

\[ Q = \frac{(P-0.2S)^2}{(P+0.8S)} \]

where \( S = \frac{1000}{CN} - 10 \).

It should be noted that this equation can be avoided if the fraction of rainfall that appears as runoff can be directly studied in the field. In general the Curve Number method is more sensitive to the selection of an accurate curve number than to equally accurate design rainfall. That is, a given relative error in the selected curve number will cause more error in the calculated runoff Q than on equally poor estimate of the input rainfall (Hawkins, 1975).
I have prepared Table 9 to analyze the trench capacity and spacing required to accommodate the expected runoff volume for comparison and discussion. Almost all the spacing equations recommended in the Forest Service Handbook (U. S. Department of Agriculture, 1959) and other research papers are not dimensionally homogeneous. The following equation has been used to calculate the spacings in Table 9:

\[
A (\text{feet}^2) = \frac{P \text{ (inches} \times C \text{ (fraction)} \times L \text{ (feet)}}{12 \text{ inch/foot}}
\]

Again,

\[
A (\text{feet}^2) = Q \text{ (feet)} \times L \text{ (feet)}
\]

where,

- \( P \) = precipitation in inches
- \( C \) = fraction of precipitation that appears as runoff
- \( L \) = spacing in feet
- \( A \) = area of the trench in square feet
- \( Q \) = expected runoff in feet

Now, the spacing can be expressed as:

\[
L \text{ (ft)} = \frac{A \text{ (ft}^2\text{)}}{Q\text{(ft)}}
\]

For the present discussion, area of the trench is fixed and spacing distances have been calculated. However, this equation can be easily used to find the capacity of the trench when the site conditions dictate that the trench be spaced at a fixed interval.

A 100 percent safety factor over the calculated direct runoff from the above relation is recommended by Megahan (1966). Questions may
Table 9. Spacing and trench capacity required for different design storms in Nepalese conditions.

<table>
<thead>
<tr>
<th>Design storm</th>
<th>Curve</th>
<th>Safety factor</th>
<th>P (%)</th>
<th>Q (ft²)</th>
<th>L (ft)</th>
<th>Area of the trench (ft²)</th>
<th>A (ft²)</th>
<th>Risk of failure for design life of 10 years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P</td>
<td>Q</td>
<td></td>
<td></td>
<td></td>
<td>2 ft²</td>
<td>4 ft²</td>
<td>6 ft²</td>
</tr>
<tr>
<td>30 yr-6 hr</td>
<td>9.84</td>
<td>74</td>
<td>6.16</td>
<td>13.20</td>
<td>1.81</td>
<td>3.62</td>
<td>5.43</td>
<td>7.24</td>
</tr>
<tr>
<td></td>
<td>79</td>
<td>7.23</td>
<td>16.47</td>
<td></td>
<td>1.65</td>
<td>3.30</td>
<td>5.13</td>
<td>6.83</td>
</tr>
<tr>
<td></td>
<td>86</td>
<td>8.12</td>
<td>16.24</td>
<td></td>
<td>1.47</td>
<td>2.94</td>
<td>4.61</td>
<td>5.88</td>
</tr>
<tr>
<td>25 yr-6 hr</td>
<td>7.87</td>
<td>74</td>
<td>4.81</td>
<td>9.62</td>
<td>2.49</td>
<td>4.98</td>
<td>7.47</td>
<td>9.96</td>
</tr>
<tr>
<td></td>
<td>79</td>
<td>5.38</td>
<td>10.77</td>
<td></td>
<td>2.23</td>
<td>4.46</td>
<td>6.69</td>
<td>8.92</td>
</tr>
<tr>
<td></td>
<td>86</td>
<td>6.20</td>
<td>12.40</td>
<td></td>
<td>1.93</td>
<td>3.86</td>
<td>5.80</td>
<td>7.72</td>
</tr>
<tr>
<td>10 yr-6 hr</td>
<td>5.90</td>
<td>74</td>
<td>3.10</td>
<td>6.20</td>
<td>3.87</td>
<td>7.76</td>
<td>11.61</td>
<td>15.68</td>
</tr>
<tr>
<td></td>
<td>79</td>
<td>3.59</td>
<td>7.18</td>
<td></td>
<td>3.34</td>
<td>6.08</td>
<td>10.02</td>
<td>13.37</td>
</tr>
<tr>
<td></td>
<td>86</td>
<td>4.31</td>
<td>8.62</td>
<td></td>
<td>2.78</td>
<td>5.36</td>
<td>8.34</td>
<td>11.12</td>
</tr>
<tr>
<td>50 yr-1 hr</td>
<td>4.72</td>
<td>74</td>
<td>2.14</td>
<td>4.28</td>
<td>5.60</td>
<td>11.21</td>
<td>16.80</td>
<td>20.30</td>
</tr>
<tr>
<td></td>
<td>79</td>
<td>2.56</td>
<td>5.12</td>
<td></td>
<td>4.68</td>
<td>9.36</td>
<td>14.04</td>
<td>18.72</td>
</tr>
<tr>
<td></td>
<td>86</td>
<td>3.20</td>
<td>6.40</td>
<td></td>
<td>3.74</td>
<td>7.48</td>
<td>11.12</td>
<td>14.96</td>
</tr>
<tr>
<td>25 yr-1 hr</td>
<td>3.93</td>
<td>74</td>
<td>1.34</td>
<td>3.09</td>
<td>7.76</td>
<td>15.32</td>
<td>21.28</td>
<td>31.04</td>
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<td>6.97</td>
<td>13.95</td>
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<td></td>
<td>86</td>
<td>2.48</td>
<td>4.06</td>
<td></td>
<td>4.83</td>
<td>9.06</td>
<td>14.69</td>
<td>19.92</td>
</tr>
<tr>
<td>10 yr-1 hr</td>
<td>3.14</td>
<td>74</td>
<td>1.00</td>
<td>2.00</td>
<td>12.00</td>
<td>24.00</td>
<td>36.00</td>
<td>48.19</td>
</tr>
<tr>
<td></td>
<td>79</td>
<td>1.29</td>
<td>2.58</td>
<td></td>
<td>9.30</td>
<td>16.60</td>
<td>27.80</td>
<td>37.72</td>
</tr>
<tr>
<td></td>
<td>86</td>
<td>1.78</td>
<td>3.56</td>
<td></td>
<td>6.74</td>
<td>11.48</td>
<td>20.22</td>
<td>26.98</td>
</tr>
</tbody>
</table>

*A 100 percent safety factor over the calculated direct runoff is used as recommended by Nepahani (1986)*
arise that a safety factor of 100 percent may result in large over-
design runoff volume resulting in oversized trenches and closer spacing.
A 100 percent safety factor is justified by the fact that structures
designed under Nepalese conditions involves many unknowns. The unknowns
are: (1) site not representative of curve number, (2) settling char-
acteristics of soils, (3) poor precipitation records, (4) knowledge of
other soil characteristics is limiting, (5) infiltration capacity,
and (6) antecedent moisture conditions. The elimination of these un-
knowns dictates the need for intensive field studies. Even if a 100
percent safety factor is not used, a provision of 0.2 ft freeboard and
15-25 percent of the effective height as settling height results in
nearly the same trench specification.

Table 9 shows that the volume of direct runoff stored, for a
larger storm is so high that any attempt to design a trench system will
be in vain. For example, if we use 25 year, 6 hour design storms to
provide design criteria for contour trenches in a watershed of relatively
good condition (curve number of 74) and with a workable spacing of 15
feet, the area of the trench required to accommodate the direct runoff
will be 12 sq. ft. Construction of such a supersized trench with a
spacing of 15 feet involves much work. Again, they are not feasible
for slopes greater than 30 percent because trench width will be so wide
that trenches may overlap. The 10 year, 1 hour design storm is out of
question because the risk of failure for a design life of 10 years is
70 percent (Table 10).

From Table 9, contour trenches of reasonable spacing and with
reasonable capacity are possible only if 25 year, 1 hour design storm
is used. The validity of using this design storm from the frequency
Table 10. Design (flood or storm) recurrence intervals (years) needed to provide a given project life with a given chance of failure** (Schmidt, 1977).

<table>
<thead>
<tr>
<th>Design life in years</th>
<th>Percent chance of failure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td>3</td>
<td>59</td>
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<td>4</td>
<td>79</td>
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<td>5</td>
<td>98</td>
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<td>*</td>
</tr>
<tr>
<td>7</td>
<td>*</td>
</tr>
<tr>
<td>8</td>
<td>*</td>
</tr>
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<td>*</td>
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<tr>
<td>19</td>
<td>*</td>
</tr>
<tr>
<td>20</td>
<td>*</td>
</tr>
</tbody>
</table>

*More than 99

Example: If a culvert through a road is to last for 20 years with a 30 percent chance of failure, the culvert should be designed for the 57 year flood recurrence event.

**Based on the formula \( J = 1 - (1 - 1/T)^N \), where \( N = \) Design Life, \( T = \) Flood Recurrence Interval, \( J = \) Chance of failure.
point of view will be discussed later in this Chapter. The use of this design storm is limited for the following combinations of conditions (Table 9).

a. (1) the watershed produces less than 0.4P as surface runoff (Curve Number of 74),
(2) a trench area of 4 ft$^2$ or more is installed, and
(3) a spacing of not more than 15 ft is used.

b. (1) the watershed produces less than .44P as surface runoff (Curve Number of 79),
(2) a trench area of 6 ft$^2$ or more is installed, and
(3) a spacing of not more than 20 ft is used.

c. (1) the watershed produces less than 0.63P as surface runoff (Curve Number of 79),
(2) a trench area of 8 ft$^2$ or more is installed, and
(3) a spacing of not more than 20 ft is used.

For detailed combination of trench size and spacing refer to Table 9.

These limitations may be satisfied if the validity of using a 25 year, 1 hour storm is sound. In the Intermountain Region a 25 year, 1 hour design storm is used (Bailey and Croft, 1937). However, there is no reasonable explanation for using it. In engineering designs, frequency and design storms are dictated by size of the structure, design life, capital cost, and the risk that can be tolerated. The acceptable design storm for any structure is that point where risk and the capital cost are the lowest. There is little flexibility in reducing the design life and size of the contour trenches. Design life is dictated by the
capability of the site to establish the vegetation. The vegetative re-establishment period should be at least 10 years on a deteriorated site. This may be the reason of using 25 year, 1 hour design storms in the Intermountain Region. There are other valid reasons too. Most of the flash flood damages are caused by floods of short duration-high intensity rainfall storms. Contour trench systems are basically designed to hold runoff from these high intensity storms. This condition exists only in the northwestern part of Nepal. Studies have shown that more than 50 percent of the total storm rainfall depth occurs in 25 percent of the storm period; usually more than half of the total depth of rain is delivered as burst rainfall. Rainfall burst occurs most frequently in the first quarter of the storm period (Farmer and Fletcher, 1971).

The applicability of contour trench systems to Nepalese conditions is not encouraging. However, there is some room for limited application if other factors are satisfactory.

Site Adaptability

Nepalese watersheds are in various stages of erosion. There are some sites where erosion is advanced. Topsoils are gone. soil depth is shallow, mass movement is conspicuous, and slopes are steep with dense rock outcrops. Hill slopes are generally parallel to bedrock slopes. When large volumes of rain are dumped in paddy terraces, they saturate the soil mantle and ultimately lubricate the bedrocks. This has lead to soil creep and landslides on many hill terraces. The study of aerial photographs has revealed that even the densely forested hill slopes are susceptible to landslide damages. In
these conditions the application of contour trenches is limited, if not impossible. On the other hand, there are sites where all other factors except the vegetation potential are favorable. Because of excessive grazing, revegetation by simple control measures only is not possible. In such areas contour trenching may be considered.

Revegetation Potential

Because of the humid climate and large amount of precipitation, the revegetation potential of Nepalese watersheds is favorable. However, because of a moisture deficit during early part of the growing season and excessive runoff in the later part of the growing season, revegetation potential is minimal on eroded areas. This is especially true in areas where the moisture holding capacity has been radically changed due to excessive abuse of the slopes. If contour trench systems are adopted, the cumulative effect of grazing control, fire control, and trenching systems may provide better opportunities for revegetation.

The discussion on the applicability of contour trench systems in Nepal reveals its limited role in the overall strategy of rehabilitation planning. The primary limitation is the huge amount of long duration rainfall and direct runoff produced. Large capacity trenches at close spacing would be required to handle the runoff. This is feasible only when slopes are gentle and the soil is deep. The wildlands in Nepal are mostly located on steep slopes (>40 percent). Application of large capacity contour trenches on steep slopes is subject to high risk of failure. Damage due to failure of contour trenching results in a great damage downstream. No treatment is far better than the failure of contour trenching. Even if different evidence indicates the suitability of contour trenching, the whole idea may be restricted by a
single limitation. A summary of limitations are outlined in the following section. If these limitations are rectified by careful observation and analysis, applicability of a contour trench system can be included in the overall rehabilitation planning.

**Summary of Limitations**

1. When assessment of the flood causes, flood sources, expected runoff, and expenditure cannot be properly estimated, the application of contour trenches is very risky.

2. Contour trenching precludes continuous land use. Countries like Nepal cannot afford a moratorium in range use for a prolonged period. Contour trenches obstruct the free movement of cattle in range land. If good vegetation control already exists or can be obtained relatively fast by proper management of grazing, fire control and other simple improvement techniques, contour trenches should not be installed.

3. If multiple use considerations create a undesirable impact after slope is trenched, contour trenching should not be done.

4. Contour trenches do not achieve the intended purpose on soils with a shallow "effective depth" either because of shallow development or presence of impermeable layer which would not be modified by the trench.

5. Slopes having very coarse textured soils containing little clay or organic binding material should not be trenched. They are very susceptible to washout. Such soils generally have high infiltration and percolation rates and thus trenches will not intercept any water.

6. Contour trenching in extremely fine textured soils which are highly impermeable and subject to extreme shrinking and swelling should
not be done. Such soils are susceptible to mass failures.

7. Highly dispersed soils and soils containing an excess of soluble salts should be avoided.

8. Soils with a stone content high enough to interfere with contouring operations should not be trenched. These soils would also have a low water holding capacity.

9. Mass stability of soil is another factor determining the applicability of trenching system. Areas with a history of mass soil movement or slumping should be avoided.

10. Areas where runoff is from the steep slopes, rock outcroppings or otherwise untreated slopes should not be trenched. There is a possibility that runoff from the upper slope will exceed the capacity of the trench.

11. Very steep topography, where safety factors are critical and operations are very expensive, should not be trenched. Contour trenches in such sites may overlap.

12. One of the fundamental limitations of the contour trench system in Nepalese conditions is the tremendous amount of precipitation. Contour trenching in such extremely wet areas which produce large quantities of surface runoff is very hard to justify. Big trenches with close spacing will be required to accommodate the flood runoff. Soil depth and slope steepness precludes the adaptability of supersized contour trenches.

13. The size, shape, and capacity of the trenches are dictated not only by the expected runoff but also by the type of the equipment that is available for operation. If tractors are used, it is very hard, if
not impossible, to trench a slope greater than 65 percent. At the most the capacity of the trench should not exceed 24 cubic feet per lineal foot of the trench. In Nepal where heavy equipment is not presently available, and all operations must be done by human labor or animal-drawn ploughs, the maximum capacity that can be installed cannot be more than 10 cubic feet per lineal foot of trench. However, a maximum of 75 percent slope may be trenched.

14. The effectiveness of contour trenches in preventing flood from the melting of very deep snow or prolonged rainfall has not been demonstrated. In Davis County Experimental Watershed in Utah, trenching has been effective in controlling floods which result from short duration high-intensity events. Accordingly, their use for this purpose under prolonged rainfall is not recommended although they may have limited use in special situations.

15. Areas subjected to seepage as well as live water sources should be avoided. Contour trenches which are primarily designed for collecting and disposing of runoff from rainstorms will not function properly if continually saturated from live water sources.

16. This system does not recognize the diversion of water from one trench to another trench, nor should water from a trench be diverted to a natural channel.

Summary of Recommendations

Contour trenching requires understanding of potential runoff, recognition of site adaptability, and careful construction. Failure to recognize any one of these factors can cause disastrous results. Contour
trenching under Nepalese conditions appears to have limited application, though there may be 100 square miles of wildlands which may need treatment by contour trenches. However, this conclusion is based upon generalization of physical data for whole of Nepal. At present, site specific data support is a limiting factor. In the future, as supporting facts and figures become available, site specific analyses can be made. The following recommendations are made for the future site specific study of the applicability of a contour trench system in Nepal.

Feasibility Analysis

Feasibility of contour trenching is determined by digging out the history of runoff from a flooding stream in question. Whether or not flooding is a natural and common occurrence in the area should be determined by using professional ingenuity. If floods and mud-rock flows have been frequent during the period since settlement, this fact may be ascertained from inhabitants of the area, and their testimony may be checked by a study of local conditions. For example, undisturbed homes, farmlands, power and irrigation developments located along stream channels reflect watershed stability. On the other hand, recent damages of these developments by floods may indicate watershed problems. Historical records may be projected back into the immediate geological past by studying the kind and character of material deposited in flood plains and stream deltas. If the study of the deposition together with the facts gathered from the local inhabitants indicates floods as a common phenomena and have always occurred, effectiveness of contour trenching is doubtful. However, if the data reflects the departure from the normal flooding behavior in the recent past, then the application of contour trench systems may be feasible.
Economic Justification

Trenches are expensive and should be considered only as a last resort treatment on flood source areas. The potential benefits should be weighed against the costs along with a variety of other rehabilitation measures, such as contour furrowing, simple revegetation, etc. Only after careful evaluation should contour trenches be used.

Determination of the Flood Causes

If the feasibility study is convincing, determination of flood causes is very important. The study of the existing condition of the watershed may well reflect the flood causes. Numerous shallow gullies, soils devoid of organic materials, exposed bedrocks, overgrazed slopes and erosion pavement show unmistakable evidence of flood source areas.

Understanding of the Potential Runoff

Precipitation is the driving force which plays a major role in the damage of an impaired watershed. The detailed analysis of rainfall, as well as snow, is a prerequisite for the design and construction of any control structure. Present knowledge of precipitation patterns in Nepal is very limited. Only daily precipitation records for a period of 10 years are available for few stations located in urban and suburban areas. Not a single station is truly representative of the problem areas. The extrapolation of this information in designing a structure in mountainous wildland conditions is very risky. The resolution of daily data to hourly or 6 hour storms involves another risk. Normally, a 25 year design storm is recommended in designing contour trenches. Extrapolation from 10 years of records to 25 years involves equally threatening risk. Though authentic information is lacking, the climato-
logical data reveal that only 10 percent of the precipitation comes in the form of snow. The information on snowmelt runoff is meager. The analysis and extrapolation of the available data reveals that 50 percent of the rain for a 6 hour storm occurs during the first hour. The duration of the design storm should be based upon soil, vegetation topology, and storm patterns. Durations of 6 hours or 1 hour are commonly used. Devastating damage in a impaired watershed is caused by infrequent storms of unusually high intensity and short duration. So further study of the storm patterns is essential to decide the design duration of rainfall.

The widely accepted method of calculating direct runoff is the method described in SCS Handbook (U. S. Department of Agriculture, 1972). Representative values of the curve number are very hard to determine by using this method. The cumulative hydrologic effects of antecedent moisture, soil type, cover density as well as storm intensity minimizes the reliability of calculated curve numbers. This may inflate or underestimate the expected runoff. Therefore, the following recommendations are made for the future watershed rehabilitation in general:

1. For finding reliable curve numbers, gaged watersheds, where values of precipitation and discharge for different storms, are available should be used. Any set of measured values of P and Q will define a Curve Number.

2. In ungaged watersheds actual field plots to determine the direct runoff under different storm patterns should be established. Though infiltration studies in a small plot may not be the true
representative of the area, the infiltration data from different cover types and soil types is recommended. This study when delineated over the adjectoral description of the SCS Handbook will help in estimating appropriate Curve Numbers. In essence, the design of contour trench systems needs expected runoff as a fraction of the precipitation. Any method which results in reliable runoff volumes will minimize the risk.

Local Experimental Plots

If the site limitations do not preclude the application, a study of region-wide site adaptability of contour trenches are recommended before the large scale application of contour trenching in Nepal. This will provide an opportunity to explore the feasibility of labor intensive applicability, problems of training local workers, and the thorough understanding of the hydrologic effects.

Design, Field Layout, and Construction

If it is determined that contour trenches can be adopted with labor intensive construction, the design, field layout, and actual installation may proceed. Some aspects of design, field layout, and construction have already been discussed. The basic principles of design and field layout remain the same whether it is labor intensive or mechanized. The only difference lies in the actual construction sequence. Labor intensive programs need more careful planning, proper supervision well-organized crews, and rigid inspection. Training of crew leaders and crews prior to field construction is recommended. For a detailed explanation of trenching criteria and trench construction, as applied by the U. S. Forest Service, the work of Bailey and Croft (1937), Noble (1963), and U. S. Department of Agriculture (1959) should be
consulted.

Advantage of Labor Intensive Program

Experience in the construction of hill irrigation developments in Nepal reveals that human labor can carry out the trenching job very neatly and effectively. The large numbers of unemployed laborers in rural areas can be employed. The cost of importing heavy equipment is saved. Generally, smaller contour trenches at more frequent intervals result in better vegetative recovery, less hazards, better maintenance, less disturbance, and reduced cost as compared to larger trenches (Meiman and Schmidt, 1963). Maintenance during the storm is possible by human labor in case of a few failures. The best advantage in employing local laborers is to provide conservation education by working in the field.

Revegetation

Native vegetation are recommended for seeding and reseeding of the trenched area. However, exotic grasses and other forage species which have already been tested for site adaptability can be used.

Design Example Under Nepalese Conditions

An example of contour trench design for typical Nepalese conditions follows:

Given: A herbaceous-grass type watershed having slope of 50 percent is to be contour trenched. The 25-year, 1 hour design storm for the area is 3.93 inches. The runoff curve number for the area is 74. A trapezoidal trench having a cross-sectional area of 4 square feet can
be installed effectively by human labor.

Find: Design a contour trench system for this area with a detailed specification of the trench.

Solution: For the given storm, using the relations

\[ S = \frac{1000}{CN} - 10, \text{ and } Q = \frac{(P-0.2S)^2}{(P+0.8S)}: \]

Direct runoff = 1.55 inches

Adding 100 percent safety factor,

\[ Q = 3.1 \text{ inches.} \]

Now, spacing = \[ \frac{\text{Area of the trench (ft}^2\text{)}}{\text{Direct runoff (ft)}} \]

\[ = \frac{4 \text{ ft}^2}{3.1 \text{ in/12(in/ft)}} = 15.5 \text{ ft} = 15 \text{ ft (say)}. \]

Specifications

![Figure 9. Geometry of a trapezoidal trench having an area of 4 square feet.](image)

- Cut slope = \( Z_1:1 = 1:1 \).
- Fill slope = \( Z_2:2 = 1.5:1 \).
- Bottom width = \( b = 1 \text{ foot} \).
Let \( h \) be the height from the bottom to the ridge.

Area of the trench = \( \frac{1}{2}h^2(z_1+z_2)+bh = \frac{1}{2}h^2(1+1.5)+1xh \)

or \( h^2+0.8h - 3.2 = 0 \)

\[
\text{or } h = \frac{-0.8 \pm \sqrt{0.8^2 - 4 \times 1 \times (-3.2)}}{2 \times 1}
\]

or \( h = 1.44 \text{ ft} \)

Top width = \( z_1h+z_2h+b = 4.6 \text{ ft} \).

Ridge width = 1 ft.

Maximum cut depth = 1.7 ft. (Figure 10)

Top width of the equalizers = 0.8 ft.

Height from trench bottom to the top of the equalizer = 1.14 ft.

Distance between the equalizer = 40 ft.

Cross section and plan view are presented in Figure 10

Rough cost estimate for 100 sq. miles of area is presented in Appendix B.
Figure 10. Cross section and plan view of a contour trench having an area of 4 square feet.
CHAPTER IX
RESEARCH NEEDED

Watershed rehabilitation techniques developed in one part of the world can be applied in another part. However, in the absence of fundamental site specific research, the performance may be poor and frustrating. In recent years, it has been increasingly evident that watershed rehabilitation needs site specific research support. Four categories of basic research support must be emphasized. They are:

1. Fundamental studies of the various parts of the hydrologic cycle.

2. Development of more efficient ways of measuring hydrologic phenomena.

3. Inventories to define better the characteristics and problems of natural resource management.

4. Development of analytical methods to permit more rational and efficient use and integration of available data (Krammes and Rice, 1963).

Nepal has just started a watershed management program and is in the process of collecting information for developing a watershed rehabilitation strategy. Hence, the discussion about the applicability of contour trenching are based upon poor information support. However, the broad analysis reflects that there is a limited applicability of contour trenches in Nepal. Therefore, in addition to recommendations
presented in the previous chapter, the following research is needed before the extensive application of contour trenches.

**Design Storm**

There are two types of summer storms which may cause flood and erosion in Nepal: (a) the convective or local thunderstorm which produces high intensity rainfall of short duration, and (b) general storms covering vast areas for a prolonged period with gentle to moderate intensity. At present, very primitive information about the destructiveness of these storms are available. Statistical analyses based upon long term records will reflect the detailed characteristics of these storms. The resolution, projection and extrapolation of past records should be carried out using available acceptable techniques. Data from similar adjacent areas located in India and Tibet can be used in the absence of records in Nepal. Based upon these analyses, efforts should be made to find (a) the percentage of floods caused by different types of storms, (b) rainfall depths for different frequencies and durations, and (c) a suitable design storm to be used in designing structures. The design storm must be a compromise between the risk and capital cost. The valid design storm is that storm which, if used, results in minimum risk and minimum capital cost.

**Infiltration Capacity**

Storms may strike a watershed which is either in a wet or dry condition. The amount of surface runoff is greater as the soil approaches saturation. Efforts should be made to find out the percentage of rain-
fall that occurs over a saturated soil. This will provide some insight
about the applicability of contour trenches in monsoon events. The
fraction of rainfall that may appear under different soil moisture
regimes is another important parameter to observe. Infiltration tests
made under dry conditions and then repeated under wet conditions will
be helpful in deriving such a fraction. The measured runoff from these
infiltration runs can then be deducted from applied rainfall to prepare
for an infiltration capacity curve for wet and dry conditions. When
this fraction is known, the curve number method may be neglected in
estimating expected runoff.

**Design Life**

Trenches are not an ultimate solution in reducing runoff and
erosion. The primary goal of trenching is to establish a successful
vegetation cover in subsequent years. The effective life of the trenches
ceases after a few years because they lose their water impounding
capacity. If vegetation can be established in a short period of time,
the risk of failure can be minimized and smaller design storms can
be used. This will minimize the cost of construction. So, research
related to revegetation potential of different sites with or without
reseeding and with or without grazing should be carried out. The results
explaining the number of years required to revegetate under different
cultural practices will reflect the reasonable design life.
Spacing

Most of the spacing equations are based upon the area-depth relationship. Design based only upon the area-depth relation exerts little influence upon the runoff and erosion problem between the trenches especially when the spacing is far. They are mostly effective in collecting runoff and preventing accelerated gully erosion downslope. Trenches a long distance apart do not take into account the erosion between the trenches. If spacings are close, soil disturbance will be more because the slope stability of the cut and fill slopes is lowered. Closer spacings alter the runoff characteristics of the slopes. So the proper spacing of the contour trenches is a compromise between the evils of accelerated erosion on long gullied slopes and the soil disturbance necessary to build closely spaced trenches. The ideal spacing of the trenches would be at a distance such that the potential erosion of the modified topography is at minimum. Detailed research design is out of the scope of this paper. However, if field plots which measure different parameters of the Universal Soil Loss Equation are established and the allowable soil loss in tons per acre per year may be calculated.

Slope Stability

Contour trenches cut into a slope tend to increase landslide hazards by steepening slopes, changing ground water levels, providing loading on the fill side of the trenches, etc. Site specific research is needed in detail to find out soil properties, slope gradient, and the strike and dip of the bedrock. Detailed slope stability analysis should be made prior to any trenching operation.
Alternative Rehabilitation Techniques

As discussed in an earlier section, contour trenches have questionable benefits in Nepal. Large volume, long duration, and possibly high intensity rains are very complicated to handle by installing delicate structures like contour trenches. Again, engineering structures have limited application for the permanent prevention of floods and erosion because of the high costs involved compared to currently available management tools, protection such as grazing control, and simple land treatment as a good alternative of flood and erosion control.

Tremendous improvements in flood and erosion control can be achieved by increasing management skills and by mobilizing local people in the protection of natural resources. Only by reducing overgrazing can the flood and erosion hazard be reduced. Research needs for the management and improvement of rangelands is very urgent. Investigation such as how the present structure of livestock farming can be organized into viable economic units, should be carried out. Most of the rangelands are in the high Himalayas and cattle are concentrated in the mid-Himalayan valleys and in the Terai. Research should be oriented to identify the steady transformation of cattle populations from the lower part of Nepal to the upper part. The inventory of forest and rangelands are unknown. Scientific management such as deferred grazing or rest rotation grazing systems have not been applied. If research is oriented in exploring these simple unknowns, the potential damages can be minimized. Simple land treatment measures such as rehabilitation plantation, seeding, furrowing, gully plugging, grass waterways, diversion
channels, pitting, ripping or any other techniques, which have been proved effective will help in minimizing the erosion and flooding. Any modification in the existing hydrologic process may contribute to the positive as well as negative impact. Development of research to produce more rational and integrated techniques provides openings for a number of other alternatives.
LITERATURE CITED


Schmidt, L. 1977. Personal communication.


APPENDIX A

Estimation of Curve Numbers of Three Typical Watersheds in Nepal
APPENDIX A


Watershed I

Location: Dolpa (Nepal)

Land Use: Pasture (wildland, no management, good cover)

Hydrologic Condition: Good

Hydrologic Soil Group: C

Curve Number = 74

Watershed II

Location: Dhading (Nepal)

Land Use: Pasture (no management, fair cover, moderate grazing)

Hydrologic Condition: Poor

Hydrologic Soil Group: B

Curve Number = 79

Watershed III

Location: Pokhara (Nepal)

Land Use: Pasture (no management, very poor cover, heavy grazing)

Hydrologic Condition: Poor

Hydrologic Soil Group: C

Curve Number = 86
APPENDIX B

Cost estimate of contour trenching
APPENDIX B

Cost Estimate

According to a rough analysis, 100 square miles of wildlands may be suitable for contour trenching treatment. A rough cost estimate is presented below:

1 acre = 43560 ft$^2$

Assuming a square plot, the plot size in an acre = 208.7 ft x 208.7 ft.

From the design section, spacing of the trenches = 15 ft.

Therefore, number of trench/acre = \[ \frac{\text{Length of plot}}{\text{Spacing}} = \frac{208.7}{15} = 14. \]

Now total length of the trench/acre = # of trench/acre x width/acre = \( 14 \times 208.7 \text{ ft} = 2922 \text{ ft.} \)

Cross sectional cut area = 4.7 ft$^2$ (Figure 10)

Cross sectional fill area = 4.4 ft$^2$ (Figure 10)

Volume of cut/acre = 13,733 ft$^3$

Volume of gross fill material/acre = 12,865 ft$^3$

Adding 20% of fill material for compacting the fill slope/acre = 2571 ft$^3$

Height of the equalizer = 1.14 ft

Bottom width = 1 ft

Top width = 0.8 ft

Cross sectional area of the equalizer = \( \frac{1}{2} \sqrt{h^2(Z_1+Z_2)} + b \times h \)
Average width of the equalizer = \( \frac{0.8+1}{2} = 0.9 \text{ ft.} \)

Distance between the equalizer = 40 ft.

Therefore, number of equalizer/acre = \( \frac{2292 \text{ ft}}{40 \text{ ft}} = 73. \)

Now, volume of gross earth fill for equalizer/acre = 161 \( \text{ft}^3 \)

Adding 20% for compacting = 32 \( \text{ft}^3 \)

Thus, total volume earth fill/acre = 15,620 \( \text{ft}^3 \)

Table 11. Cost estimate of contour trenching per acre.

<table>
<thead>
<tr>
<th>Item</th>
<th>Volume of earth work cubic feet</th>
<th>Rate/( \text{ft}^3 ) Rs*</th>
<th>Rate/acre Rs</th>
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<td>Equipment and tools</td>
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<td>x</td>
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<tr>
<td>Maintenance</td>
<td>x</td>
<td>x</td>
<td>25.00</td>
</tr>
</tbody>
</table>

*Rupees
Subtotal  
Add 10% contingency  
Total  

$1.00 = Rs. 12.50.
Therefore, total cost/acre  
1 square mile = 640 acres  
Cost/sq. mile = $103,680.00
Therefore, cost of contour trenching for  
100 sq. miles of wildlands  

Rs. 1,848.00  
Rs. 185.00  
Rs. 2,033.00  
$ 162.00  
$ 10,368,000.00