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SHORT COURSE ON WATERSHED-BASED FISHERIES DEVELOPMENT

(20th to 24th August, 2012)

Edited and Compiled by

• M Muruganandam • PK Mishra • GP Juyal • RK Avasthe • Amit Chauhan

Sponsored by

National Fisheries Development Board (NFDB), Hyderabad

Organized by

Central Soil and Water Conservation Research & Training Institute,
218, Kaulagarh Road, Dehradun- 248 195 (Uttarakhand)

Acknowledgement

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Editors

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A short training course for 5 days on "Watershed-based fisheries development"
(20th-24th August 2012)
Sponsored by National Fisheries Development Board (NFDB), Hyderabad
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Date	Time	Title or details	Resource person(s)
20.08.2012	09.30-10.00	Registration and inauguration	H&E division
	10.00-11.30	Overview on principles and practices of Integrated Watershed Management (IWM)	Dr PK Mishra
	11.30-13.00	Engineering perspectives of design and construction of ponds and WHS	Dr PK Mishra
	13.00-14.00	**Lunch break**	
	14.00-17.00	Field visit 1 to research farm, farmers' ponds at Sahaspur, Langa project	Sh. Rakesh Kumar, Sh Suresh Kumar & Sh. KR Joshi
21.08.2012	9.00-17.00	Field visit 2 to a recreational pond and an IFS developed in mid-Himalayas	Sh. RK Arya & Sh. Rakesh Kumar
22.08.2012	9.00-10.30	Principles and practices of watershed-based fisheries and aquaculture development	Dr M Muruganandam
	10.30-12.00	Field procedures for water yield assessment and effective water harvesting techniques	Er KP Tripathi
	12.00-13.30	Bio-engineering measures for resource aggradations and ecosystem management.	Dr GP Juyal
	13.30-14.00	**Lunch break**	
	14.00-15.30	Water budgeting for aquaculture	Dr KK Sharma
	15.30-16.30	Design and construction of aquaculture ponds	Dr KK Sharma
	16.30-17.30	Aquaculture considerations for design and construction of farm ponds and watershed ponds	Dr M Muruganandam
23.8.2012	09.00-10.30	Present status and future scope of trout farming in Western Himalayas	Dr NN Pandey, DCFR, Bhimtal
	10.30-12.00	Random thoughts on soil health, rating of soil-water for agriculture and fish farming and soil management techniques to reduce pollution	Dr D. Mandal
	12.00-13.30	Fisheries technological options, aquaculture species and systems	Dr M Muruganandam
	13.30-14.00	**Lunch break**	
	14.00-17.00	Field visit 3 to sub-surface water harvesting structure at Kalimati, watershed rehabilitation project at Sahastradhara	Sh. SK Sharma Sh. Amit Chouhan & Sh. HS Bhatia
24.08.2012	09.00-10.30	Recent advancements and potential technologies of coldwater fisheries and fish farming	Dr PC Mohanta, DCFR, Bhimtal
	10.30-12.00	Stream bank and river stabilization techniques to improve water quality and biodiversity	Dr PR Ojasvi
	12.00-13.30	Interfaces between fish and fisheries and wildlife management	Dr Sivakumar, WII, D. Dun
	13.30-14.00	**Lunch break**	
	14.00-15.30	Tools and techniques for assessment of tangible and intangible economic benefits of fisheries interventions under IWM programs	Dr BL Dhyani
	15.30-17.00	Socio-cultural and agro ecosystem valuation for participatory resource management	Dr Bankey Bihari
	17.00-18.00	Feedback and panel discussion	Dr R K Avasthy

Prologue

Watershed-based fisheries development has immense potential to alleviate poverty, food security and achieve biodiversity conservation in the country.

Preface

Agriculture and animal husbandry are the first two mainstay sub-sectors in India. However, faulty management practices, coupled with increasing human and animal population threaten livelihood and food security. The challenge of bringing in meaningful strategy and workable action plans for necessary adjustments in agricultural production systems and traditional wisdom of people keeping in view of social and developmental priorities needs to be addressed very urgently and consistently. This suggests for a revamping of existing production systems and addition of new components including fisheries-based to the existing ones. While accepting watershed as an naturally defined, but hydrologically independent unit, topographically delineated area drained at a common point by a network of channels and streams forms an ideal unit of development progress than administrative boundaries, it is also proved beyond doubt that fisheries sector plays a major role in meeting the national agenda of eradicating malnutrition, poverty, unemployment bug and ecological degradation as one of the fastest growing sectors worldwide that needs proper characterization and introduction in Integrated Watershed Management (IWM) programmes in India. Ecosystem diversity, fragility, marginality, poor accessibility, bio-diversity and cultural heritage, and heterogeneity are major issues of livelihood and resource conservation in various agro-eco-regions of India. The continued dependence of growing population on finite resources, lack of viable technologies befitting to growing demands pose threat of resource depletion and continuation of poverty. The process of industrializations and population pressure threatens streams/rivers and their environments, the major reserves of aquatic species, which require scientific care and conservative management in order to sustain their services and functions. All these bring a necessity for Watershed-based fisheries development to rationalize natural resources for social and environmental demands.

At a time when fisheries resource base is declining, even as regional and national demand for fish grows, concerted effort to promote multiple use of resource to increase opportunities for responsible resource exploitation and incentives for conservation efforts become essential. Watershed management has huge scope for fisheries development and *vice versa* which in turn has immense potentials to eradicate or reduce the problems derived from the geometrical explosion of population, shrinking man-land ratio, acute malnutrition, enduring poor purchasing capacity and unemployment. Watershed-based fisheries development accounts both development and management of fisheries resources in rivers and natural systems and aquaculture in existing and developed water resources. Thus, the training on the subject is more important especially in the present scenario that requires effective communication amongst various stakeholders of the resources for a trickledown effect to promote much needed multi-commodity, multidimensional, integrated, broad based-knowledge, -systems and -technologies. Keeping in view the importance of the upcoming and potential field, the present training program was initiated with a focus on entry-level and mid-level field functionaries. This is the first exclusive training program on fisheries after first-time formatting of Watershed-based Aquaculture/Fisheries Research and Training achieved in tune with Integrated Watershed Management Programs at CSWCRTI and at National level. This manual on the training contents will be a ready reference and provide field guidance for field functionaries of IWM.

About organizer, the CSWCRTI

The Central Soil and Water Conservation Research and Training Institute (CSWCRTI) has roots from 1954 and functions under ICAR since April 1st 1974 to tackle problems of soil-water conservation and promote Integrated Watershed Management (IWM) through various modes of research and training. The CSWCRTI with its headquarters at Dehra Dun and 8 research centers across the country, viz. Agra, Bellary, Chandigarh, Datia, Koraput, Kota, Udhgamandalam and Vasad has the national mandate to conduct research and imparting training on soil and water conservation, Natural Resource Management (NRM) and IWM. The Institute has developed many successful watershed models like Sukhomajri, Relmajra, Fakot, Sainji and Kalimati in different locations of the country. The institute has been training various clients including local, regional, national and international farmers, technocrats, scientists, planners and students through regular (5½ months biannually) and many demand-based short term (1-30 days) training programs since its inception during 1950s. A total of over 10,000 beneficiaries from various organizations directly besides an equal number through indirect ways have been trained on soil-water conservation and watershed management by the Institute. The Institute has evolved or refined many technologies and published brochures on about 52 technologies including 6 brochures related to watershed based fish farming and livestock management in user friendly language, few of which are available at <www.cswcrtiweb.org>.

Fisheries section at CSWCRTI

The purview and scope of IWM at the Institute has been expanded to include fisheries and livestock management in 1996 with the introduction of few scientific and technical positions for organized research and training. The Institute has hands-on experience of introducing and managing the fisheries and aquatic sciences in to NRM and IWM by creating integration with several agricultural disciplines. Promotion of fisheries, fish farming and animal husbandry under the watershed management programs in various parts of the country is being emphasized ever since the subjects were introduced into the ongoing themes and programs of the Institute. The section has completed eight fisheries related research & demonstration projects during last 15 years. Various aspects of both river fisheries, ethno-biology of traditional fishing, fish farming and integrated farming systems (IFS) in clusters of watersheds are addressed since the problem of over-fishing and increasing demand for fish needs to be tackled simultaneously and aquaculture has the potential to reduce investment requirement in capture fisheries and reduce fishing pressure.

Background and the context of the short training course

While the importance of watershed management growing, consideration for fish farming, fisheries development and animal husbandry in various watershed management trainings or in the programs of IWM per se in the country is inadequate as compared to conservation engineering, agronomy and forestry. Lack of awareness amongst many watershed managers, technocrats, farmers and other end-users of the natural resources on the importance of fish production for food supplies, poverty alleviation and income generation prevents the percolation of fisheries interventions into IWM or NRM programs. Presently, wide gaps exist between the experts of fisheries science and other disciplines, especially soil-water conservationists or engineers of watershed management programs. This leads to ineffective WHS or structural inadequacies in them to accommodate fish culture along with other intended purposes. The existing gaps and myths on fisheries science and technologies can only be narrowed down through targeted training. Contextually, the present 5 days training program assumes greater significance.

Objectives

Main objectives of the training are

i. To provide foundation, refreshment and working knowledge on aquatic ecosystems, ecosystem restoration, fish farming and watershed management to multi-disciplinary professionals breaking the impasse between disciplines.
ii. To introduce newer and established interdisciplinary concepts and technologies of watershed-based fisheries, fish farming, river management and watershed-based agrarian scenarios.

Keywords in course content

Basics of fisheries & aquaculture, watershed management, myths & realities, water harvesting, water budgeting, runoff, rainfed ponds, Water Harvesting Structures (WHS), design & construction, seepage control, carp culture, integrated farming, soil-water quality management, sampling procedures, destructive forces in rivers etc.

Organisation of the training course and the manual

The training programme on watershed-based fisheries development is organised to different target groups drawn from the pool of inter-disciplinary professionals and varied clients including fisheries inspectors, watershed experts, and Assistant Professors. Comprehensive training module involving both in-house interactions and field exposures to give impetus to much needed, but hitherto neglected multi-disciplinary training with the focus on "fisheries interventions in integrated watershed management programmes" is contemplated. The course planned cuts across various disciplines and regions and designed to give participants a broad overview of both ecology- and watershed-based fisheries management, besides basic foundation and working knowledge on ecosystem-based development under the umbrella of IWM at local to national scales. The training will provide a platform to introduce, discuss, identify and refresh established conceptual frameworks as well as newer concepts, and technologies through technical interactions amongst diversified participants. It would help to minimise existing interfaces and continuing mythical ideas or unrefined information about fisheries development amongst stakeholders of natural resources including farmers and technocrats.

The training is aimed to strengthen and upgrade existing technological and traditional knowledge to promote aquaculture and fisheries development in India. The training program would provide necessary technical skill for the programmed fisheries development, which may provide new set of methodology and approach for rural development. The present compilation incorporates the results of the investigations carried out by the researchers on various aspects of the problems of freshwater fish culture and riverine resource management under watershed management perspectives at CSWCRTI, Dehra Dun and other resource management Institutes. The manual first introduces the subject of watershed management, elucidates the importance of watershed-based fisheries development and fish farming, water yield assessment techniques, design features of WHS, bio-engineering measures for resource aggradations, water bugeting, interfaces of wildlife management, social issues, economic assessment tools, recent advancement of cold water fisheries etc. based on field observations and research data. At the end of the manual, few articles in Hindi and brief glosaary are included for the benefit of the users. The training program and the manual would provide wider knowledge on potentials of aquatic and fisheries resources, open new vistas in fisheries and NRM.

INTEGRATED WATERSHED MANAGEMENT – AN OVERVIEW

P.K. Mishra*

INTRODUCTION

Integrated Watershed Management (IWM) is the process of managing human activities and natural resources on a watershed basis. This approach allows us to protect important water resources, while at the same time addressing critical issues such as the current and future impacts of rapid population growth and climate change. Our activities on the land impact the health and sustainability of natural resources and can threaten how much water we have available as well as how well we can adapt to the impacts of climate change. The best way to protect resources is on a watershed basis using an integrated watershed management approach. This approach allows us to address multiple issues and objectives and enables us to plan within a very complex and uncertain environment. An over-riding concern of integrated watershed development is the improvement of the livelihoods of local communities on a sustainable basis. This requires balancing their economic needs and expectations with environmental concerns so as to avert degradation of the natural resource base, in particular soil and water components. Governments and development institutions are increasingly recognizing that full community participation is essential for sustainable watershed development. With growing local participation, indigenous knowledge is now significantly influencing the planning, design, and implementation of watershed development programmes. Long-term changes and development are more likely to be adopted if communities have a say in the decision-making process. Sustainability also increases if local resources are more efficiently utilized and the use of or need for external inputs is minimized.

DEFINITION

Watershed is a topographic hydrological unit draining at a common point by a network of channels and streams. Management and conservation of natural resources like soil, water, vegetation, livestock, enterprising and human being simultaneously within this unit is expected to realize sustainability. For practical purpose, it can be classified into following three zones.

1) **Recharging zone:** Catchment with high infiltration rate, pervious strata, stream/channel/gully beds, temporary ponding areas, etc. Excessive runoff is generated from denuded steepy slopes, rocky formation and impervious catchments.
2) **Transition zone:** gentler gradient where *in situ* moisture conservation will be effective.
3) **Discharge/piedmont zone:** ideally suited for water spreading techniques or command development for harvested rain water.

Size: It is a scale dependent but for the purpose of project planning, an area of 5,000 to 10,000 ha subdivided into micro-watersheds of 500 to 1000 ha is a suitable working unit. Sometimes watershed boundaries do not coincide with the administrative boundaries. In another case, a village is at the top of the ridges and its land spreads partially over two micro watersheds. One should try to treat the whole watershed irrespective of village, block or administrative boundaries.

Moreover, the concept of forming self help groups, watershed associations and other institutions of empowerment do not recognize rigid administrative boundaries.

*** Director, Central Soil & Water Conservation Research & Training Institute, Dehradun-284 195 (Uttarakhand)**

PRINCIPLES OF WATERSHED MANAGEMENT

Watershed is a naturally defined hydrological area and is, therefore, an ideal unit of development process. This approach demands integrated development of non-arable land, arable land, rain water, vegetation, livestock, local materials, common property resources, human resources and programmes for landless in a participatory process. Livelihood gathering by increasing production of biomass, productive employment generation and conservation of resources are the most important concerns of the watershed development. Emphasis on the landless, gender issues and biodiversity utilization is also enshrined in the basic principles of watershed management.

CONCEPTS

Participatory approach

Dynamic group processes should be invoked to minimize social conflicts by ensuring partnership of the community. This concept is easy to advocate but most difficult in practice. This needs a definite input of skilled manpower and investment of resources. Different kinds of PRA exercises are designed to involve the community right from the beginning of the project. This is a bottom up approach of working with the people and not for the people. Some kind of contributions by the stakeholders and development of local institutions for sustaining the watershed management are important ingredients of participation. Participatory mode of development also demands some psychological and functional adjustments by the government functionaries. We should assume the role of facilitators unlike heavy top down officers. This approach recognizes greater role of NGOs, user groups, voluntary agencies, religious institutions, improvement of traditional skills, local materials, etc. In some watersheds, management of Common Property Resources (CPRs) by equitable sharing of benefits and responsibilities is important. Establishment of some common use institutions like collection centres for milk, eggs, mushrooms, vegetables, industrial grasses, rope, etc., improved bulls, banks, seed/fertilizer banks, veterinary services, etc. is important. Special emphasis is to be placed on landless and other weaker components of the watersheds.

Institutionalization

Cherished goals of increasing productivity, employment generation and resource conservation are expected to be realized through empowerment and partnership of the watershed communities. Several shades of voluntary organizations, self help groups and watershed association have been put in place to implement and manage the development. Voluntary federations of several village level institutions and well-structured cooperative societies like Indian Farmers Forestry Development Cooperative Limited (IFFDC) and National Tree Growers' Cooperative Federation Limited (NTGCF) are recent developments in the watershed management programme. Many of these institutions are in the developing phase and are also experiencing conflicts with Panchayats in many cases.

Integrated management

Simultaneous development of the forest, grassland, horticulture, agriculture, livestock, etc. is important to exploit their mutual benefits. All development activities within a watershed should be pooled into a unified group action. Independent and uncoordinated sectoral development does not fit into this concept. Simultaneously and harmonized use of natural resources produces several additional externalities of livelihood gathering through collective actions of the community.

Bio-engineering measures

Development of wastelands is expected to be initiated with some structural measures like bunding, gully plugging, trenching, etc. along with cost-effective vegetative measures. Effectiveness of engineering measures is limited to the extent of initiating sustainable conservation by establishing vegetation. Application of only vegetative measures or structural measures in isolation of each other was not fruitful. Planning of locally suitable grasses, fruit and fuel and timber species is recommended. Similarly, greater use of indigenous materials and building on the indigenous technical knowledge is called upon.

Wastelands/degraded forests

There is a lot of potential of restoring degraded lands and making them productive. It has been observed that protection of these areas against excessive biotic interference and conservation of moisture by trenching, loose boulders, check dams, contour barriers, contour bunds and vegetative barriers, etc. are very successful. The concept of social fencing by way of sharing benefit with the local community is very much essential. Villagers may be allowed to take the grass, fuel wood and other minor forest products in a regulated manner mutually decided by the community itself. At least 25-60% income from the sale of timber may also be agreed to be shared with the community so as to tie up their interests with resource conservation.

Mining wastes

Unscientific mining in different parts of the country in the past has produced mining wastes which have become environmental hazards. Restoration of mine spoils by establishing locally suitable vegetation with the help of locally suitable soil and water conservation measures is required. Mining pits can also be developed as rainwater recharging structures. Fixation of rolling mass of waste dumps by geojute, construction of gabion structures and planting of grasses reduced debris movement and extended duration of post rain’s flow significantly.

Landless partners

They are very important constituents of the watershed and have been enjoying some traditional rights of grazing, fuel wood, small timber and other minor forest products. They feel aggrieved or deprived when common property resources are regulated like protection by closure to grazing. Planning of income generating activities for them right from the beginning facilitate minimization of social conflicts by providing some alternative. A successful watershed management programme generates additional employment opportunities for them due to increased biomass production. They have to be explained about it for enlisting their participation.

Utilizing biodiversity

Joint forest management policy aims at creating owners of forests by the community. This can be realized sustainably by sharing some benefits with the local people. There are several kinds of wild fruit species which can be improved by budding, grafting or top working with better quality and highly priced stock. For example, budding of wild *bers* and grafting of *aonla* with improved stock could be very attractive for the community. Plots should be demarcated on the ground and *pattas* or other legal instruments signed with the individuals. When he has a stake in improved fruit trees, he will not graze or allow others to graze the area. In this process, naturally growing trees will get automatic protection and there will be a better natural regeneration. This requires a well thought off policy measures involving responsibilities as well as transparent sharing.

Water Harvesting Structures (WHS)

Our experience with the farmers has shown that harvesting or storing of runoff water and its supply for limited irrigation is very much liked by the farmers. Runoff water can be stored in small earthen dams or tanks and used for providing irrigation to the local community. Siltation of such structures due to high rate of erosion in the catchment area is a common phenomenon. Local community should be sensitized right from the beginning for protection of catchment through social fencing. This concept is, of course, expensive to start with but payback period varies from 5-6 years under suitable situation and success rate is very high.

In situ recharge

This practice is very useful for rainfed biomass production especially in the low rainfall region as well as for the planting of trees and grasses. Contour bunding, water spreading practices, deep tillage, stubble mulching and cultivation across the slope are the important practices. Reshaping of micro catchments so as to divert runoff water towards a pit where a fruit tree can be planted is a successful practice. Staggered contour trenching for *in situ* moisture and erosion conservation for establishing fuel wood, fodder and timber trees is quite successful for the improvement of wastelands.

Eco-development of ravines

Ravines are quite common in different river systems. Reclamation of ravines is generally taken up from peripheral areas which contribute water for gully formation. Bunding, terracing, construction of safe water disposal structures and peripheral bunds for safe diversion of runoff, should be of high priority. Shallow gullies can be leveled in the form of small terraces for agricultural purposes. Medium gullies can be developed for cultivation of fruit trees, forage and fodder production. Care should be taken not to plug completely the natural drainage channels. Some pre-fabricated structures can be made use of for safer passage of the runoff water. Some spillways and gully plugs can also be designed for recharging of ground water. Deep and very deep gullies should be retired into a permanent vegetative system of bamboos, *shisham, kikar*, fodder trees and grasses.

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ENGINEERING PERSPECTIVES OF DESIGN OF FISHPONDS

P.K. Mishra* and S. Patra**

Introduction

Water harvesting refers to the collection and storage of rainwater and also other activities aimed at harvesting surface and groundwater, prevention of losses through evaporation and seepage and all other hydrological studies and engineering interventions, aimed at the conservation and efficient utilization of the limited water endowment of a physiographic unit such as watershed (Adhikari *et al.* 2009). In, general, water harvesting is the activity of direct collection of rainwater. In various watershed development projects water harvesting is being pursued by government as well as nongovernmental organizations in the rainfed areas. One of the most important aspects of the watershed development is the creation of the rainwater harvesting structures which are of the various shapes, sizes and characteristics. Until recently, the water harvesting structures were not being used effectively for fishery due to constraints like seasonal and fluctuating nature of the water storage, over abstraction for irrigation and lack of technical knowledge. But, gradually the importance of the fishery in these water bodies is being realized.

Making water resources useful for fishery

The locations and design of the fish ponds is key to the success of the fish farming in the rainfed regions. In general, the watershed ponds are dugout ponds which collect water from the sloppy catchments. Many times, the watershed ponds are cheaper to create as there is no cost involved in digging the ponds due to topographical advantage. However, if there is poor soil over a portion of the pond, large amounts of clay may have to be trucked in to make it impervious, and that could make construction cost too high. The size of a watershed pond should be based on the availability of water from the watershed. The water should be deep enough to compensate for evaporation and seepage. Even during summer drought the water should be at least 3 to 4 feet deep. Ideally, the average water depth in a commercial watershed pond should be 4 to 5 feet. The pond area should contain a relatively impervious layer of clay or silty clay soils. Coarse soils containing large amounts of sand and/or gravel are unsuitable. If the soil can be formed into a tight ball that maintains its shape or is moldable, it is suitable for pond construction. A rule of thumb is that soil must contain at least 20 percent clay. The pond must be sited properly and designed for efficiency. An inaccessible location, leaks in the pond, poor seining conditions, or lack of good quality water will doom an aquaculture enterprise to failure. On rolling terrain the annual rainfall may be enough to completely fill and periodically recharge production ponds. Such watershed systems are not so dependent on groundwater. They also act as flood control reservoirs and can greatly reduce erosion and conserve the water effectively. In addition, there are diverse size and shape of the water bodies. The tiny water bodies are useful for the nursery raising, smaller water bodies for seed rearing and larger for the table fish production. As thumb rule any water bodies keeping minimum of 3-4 feet upto six month can be used for the fishery purposes.

*** Director and ** Scientist (SWCE), Central Soil & Water Conservation Research & Training Institute, Dehradun-284 195 (Uttarakhand)**

Design principles

Three steps are followed in design of a water harvesting pond. These are hydrologic design, hydraulic design and structural design.

Hydrologic design

Hydrologic design involves the estimation of peak rate of runoff to be passed safely through the pond and runoff volume generated from catchment of the pond. The runoff is generally estimated for design frequency of 25 years i.e. those values of intensity and amount of rainfall are considered which are expected to occur once in 25 years.

Rainfall intensity-duration-recurrence interval relationship

$$I = KT^n / (t+a)^b$$

Where, I = rainfall intensity for a given rainfall duration in cm/hr
T= recurrence interval in years
t= storm duration in hours
K, n, a, b are constants for a particular location

Estimation of peak rate of runoff

Q= CIA/360

Where, Q= Peak rate of runoff in cumec
C= Runoff coefficient varying from 0 to 1 depending on catchment conditions (slope, land use, soil type etc. Table 1)
I= Rainfall intensity in mm/hr for the design frequency and duration equal to time of concentration
A= Area of catchment in hectares (Schwab *et al.* 1993)

Table 1: Values of "C" to be used in peak flow estimation

Topography & Vegetation	Sand	Silt	Clay
I. Forest Land			
0-5% slope	0.1	0.3	0.4
5-10% slope	0.2	0.35	0.5
10-30% slope	0.3	0.5	0.6
II. Pasture Land			
0-5% slope	0.1	0.3	0.4
5-10% slope	0.1	0.36	0.55
10-30% slope	0.2	0.42	0.6
III. Cultivated Land			
0-5% slope	0.3	0.5	0.6
5-10% slope	0.4	0.6	0.7
10-30% slope	0.5	0.72	0.82

Estimation of runoff volume (SCS Method)

$Q = (P-0.2S)^2/(P+0.8S)$

Where, Q = actual runoff in mm
P= rainfall in mm
S = potential maximum retention
CN = 25400/(254+S), CN = curve number, CN has a range from 0 to 100; lower numbers indicate low runoff potential while larger numbers are for increasing runoff potential. The lower the curve number, the more permeable the soil is ((Schwab *et al.* 1993)

Hydraulic design

This includes determination of storage capacity and storage dimension (length, width and depth) of the pond and dimensions of spillways for safe disposal of excess inflow to the pond. Water should flow through the structure safely without overtopping the embankment. Standard weir formula is used for determining the crest length of the spillway

$Q = CLH^{3/2}$

Where Q is the peak discharge, C is a constant, L is length of the crest and h is depth of flow over the crest of weir

Capacity of pond:

Capacity of the pond is calculated by Trapezoidal or Simpson's rule (Schwab *et al.* 1993)

Trapezoidal rule

V = h/2 (A1+A2)

Where, V is the volume of storage between two contours. A1 and A2 are the area enclosed by the contours and h is the interval between two contours

Simpson's rule

V = h/3 (twice the area of odd contours + 4 times the area of even contours + area of first and last contour)

For using this formula, the number of contours should be odd (Schwab *et al.* 1993)

Generic equation for pond design

In order to minimize the seepage area as well as the evaporation losses, a dugout farm pond (Fig.1) can be best designed for a given storage volume (V), depth (D) and side slope Z:1 (Z horizontal to 1 vertical) using the following equations (Mishra and Sharma 1994)

$X = (0.5/C)\,[\sqrt{\{DZ(1+C)\}^2 - 4C\{2D^2Z^2 - (V/D)\}} - DZ(1+C)]$ …….. (Eq. 1)

Where X, Y = Two sides of the dugout pond (rectangular) at the bottom and C = Y/X

For a square section (C = 1, i.e. X=Y) the above equation is simplified as follows:

X = $\sqrt{[(V/D) - D^2Z^2]}$ -DZ ……….. (Eq. 2)

For a square bottom section having side slope1:1 (Z = 1) the Eq. 2 can be further simplified as:

X = $\sqrt{[(V/D) - D^2]}$ -D …………….. (Eq. 3)

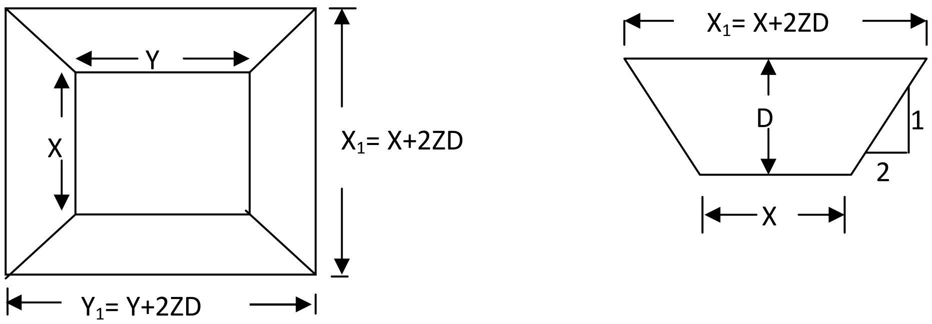


Fig.1. Design of a dugout farm pond

Soils

If a dugout pond is to be fed by surface runoff, enough impervious soil at the site is essential to avoid excess seepage losses. The most desirable sites are where fine-textured clay and silty clay extend well below the proposed pond depth. Sites where sandy clay extends to adequate depths generally are satisfactory. One should avoid sites where the soil is porous or is underlain by strata of coarse-textured sand or sand-gravel mixtures unless prepared to bear the expense of an artificial lining. The performance of nearby ponds that are fed by runoff and in a similar soil is a good indicator of the suitability of a proposed site.

Planning the pond

Although excavated ponds can be built to almost any shape desired, a rectangle is commonly used in relatively flat terrain. The rectangular shape is popular because it is simple to build and can be adapted to all kinds of excavating equipment. Rectangular ponds should not be constructed, however, where the resulting shape would be in sharp contrast to surrounding topography and landscape patterns. A pond can be excavated in a rectangular form and the edge shaped later with a blade scraper to create an irregular configuration. The capacity of an excavated pond fed by surface runoff is determined largely by the purpose or purposes for which water is needed and by the amount of inflow that can be expected in a given period. The required capacity of an excavated pond fed by an underground water bearing layer is difficult to determine because the rate of inflow into the pond can seldom be estimated accurately. For this reason, the pond should be built so that it can be enlarged if the original capacity proves inadequate.

Selecting the dimensions of pond

The dimensions selected for an excavated pond depend on the required capacity. Of the three dimensions of a pond, the most important is depth. All excavated ponds should have a depth equal to or greater than the minimum required for the specific location. If an excavated pond is fed from ground water, it should be deep enough to reach well into the water bearing material. The maximum depth is generally determined by the kind of material excavated and the type of equipment used. The type and size of the excavating equipment can limit the width of an excavated pond. For example, if a dragline excavator is used, the length of the boom usually determines the maximum width of excavation that can be made with proper placement of the waste material. The minimum length of the pond is determined by the required pond capacity. To prevent sloughing, the side slopes of the pond are generally not steeper than the natural angle of repose of the material being excavated. This angle varies with different soils, but for most ponds the side slopes are 1:1 or flatter.

Lining the pond

Excessive seepage in ponds is generally because the site is poor; that is, one where the soils in the impounding area are too permeable to hold water. Selecting a poor site is often the result of inadequate site investigations and could be avoided. In some places no satisfactory site is available, but the need for water is great enough to justify using a site that is somewhat less than satisfactory. In this case the original pond design must include plans for reducing seepage by sealing. To prevent excessive seepage, the permeability of the soils is reduced to a point at which losses are insignificant or at least tolerable. The method depends largely on the proportions of coarse-grained sand and gravel and of fine-grained clay and silt in the soil. Some pond areas can be made relatively impervious by compaction alone if the material contains a wide range of particle sizes (small gravel or coarse sand to fine sand) and enough clay (10 percent or more) and silt to effect a seal. This is the least expensive method. Because seepage losses vary directly with the depth of water impounded over an area, the thickness of the compacted seal is increased proportionately. Commercially available lining materials such as concrete, brick-masonry, ferro-cement, fiber glass, UV resistant plastic can also be used for arresting seepage loss in highly permeable soils. However, the cost of construction will greatly vary depending on the cost of lining materials (Table 2)

Table 2: Comparative cost of construction of water harvesting structures (lined)

Sl. No.	Material	Cost/litre (Rs.)
1.	Concrete	4.00-5.00
2.	Brick Masonry	3.00-4.00
3.	Ferro-cement	1.50-2.00
4.	Fiber-glass	4.00-5.00
5.	Clay (partial seepage)	0.05-0.10
6.	UV resistant plastic (silpaulin)	0.15-0.20

Source: (Samuel and Mathew 2008)

An evaluation study by Mishra *et al.* (1994) shows that the HDPE (black containment liner, 150 micron) lined pond though initially effective, proved to be ineffective in the fourth year of laying and permitted heavy seepage. Other materials like soil-cement and asphalt lining were worse: they suffered much more from the seepage problem as time passed. Only the brick lined pond with cement plaster withstood well in the field situation and proved to be most cost effective in storing water for reuse in Telengana region of Andhra Pradesh.

Construction details of fishponds

The construction details and the procedure of construction vary from place to place and from purpose to purpose. It is also not really possible to anticipate and plan all the details of constructions. However certain amount of planning and procedures can be identified. They are as follows.

1. Preparing a master plan

Whether the pond is small or big, single or complex, single line or in blocks whether for home use or for commercial purposes, a master plan should be prepared before one actually start digging the fish pond. Decide the length, width, depth at various comers and middle of each pond and the locations of the inlet and outlet estimate the volume of the soil to be excavated while digging the pond or making the dikes or bunds. The slope of the sides are also estimated depending on the type of soil.

2. Slope of the sides

Depending on the type of the soil, various possible tentative slopes can be given. For very clayey soil we can give a slope of 1:1 to 1:1.5; for the sandy soils we should give a slope of 1:2.5 to 1:4; for the soils coming in between these two types and depending on the proportion of the clay or sand the slope is determined. More the sand lesser the slope. Such slopes are given when the sides are made of mud only. If the pond is deep there should be steps or platform all around the sides for every 4 to 4.5 ft continuous sloping distance.

If the sides are constructed with brick or stone walls, then the above mentioned slopes are not applicable. Needless to mention that it is always advantageous in the long run to construct the sides with brick or stone fortified with cement. Because it will avoid the chances of the formation of horizontal holes and small caves which will lead to the collapse of the sides. Besides, vertical sides will increase the water volume of the pond. However while constructing the sides it is better to provide as many pockets of clay as possible so that sufficient flora and fauna can grow on these pockets to provide natural feed to the fishes. The clay pockets can be easily prepared by the arrangement of well baked clay bricks in a honey comb fashion on all the sides.

3. Inlet for water

The inlet for the water to the pond should be constructed in such a way that water should come into the pond without eroding neither the sides nor the bottom. If there is any possibility of the silt coming into the pond along with the water, then proper silt catching structures such as ditches, trenches, bunds or any other suitable structures should be provided upstream. A properly constructed water inlet must fulfill the following conditions: (i) it must assure a regular supply of water to the pond; (ii) it must prevent the escape of fish, (iii) it must keep out undesirable fish which might come in through the water fed into the pond. For this, a single or double screened case bitters can be installed at the inlet. The inlet could be a common one for a group of ponds or for individual ponds. The clogging of the screen by the debris etc. could be prevented by building a small check or weir and the debris collected should be cleaned off periodically. Where the water enters the pond through a masonry chute structure, the chute portion may be constructed with steps to facilitate aeration.

4. By-pass

Along with the inlet there should be a by-pass to divert the excess water that could possibly be coming into the pond during the rainy season. The depth and the size of the by-pass channel depend on the situation of the place and the position of the pond in relation to the incoming water and the slope of the area from which the water is coming. The by-pass can also be constructed with bricks or stone and cement which are ideal for long term commercial fish ponds.

5. Bottom of the pond

The bottom of the pond should be made firm and leak proof. This can be done by repeated puddling of the bottom soil mixed with clay and allowing it to settle for a week and then again puddling it and allowing it to settle for a number of times till one find that water seepage is almost nil. Cementing or laying bricks or tiles etc. are other types of pond bottom treatment which of course will be very costly. It is better to make the bottom of the pond slightly sloping towards one side or to the drainage at the bottom of the pond.

6. Drainage or outlet

Every pond should be fitted with a drainage by which we can drain out water whenever we need. This can be done by fitting a big pipe from underneath the pond towards the lower area outside the pond. The outside end of the pipe can be fitted with a flexible pipe which can be fixed vertically up with its end rising high above the water level in the pond to preserve the water in the pond and put down on the ground to drain out the water from the pond. Only at the beginning of the outlet there should be proper screens and checks fixed so that the outlet is not blocked either by mud or by any other materials from the pond. This is also needed to prevent fish coming out. But this type of drain is possible only when at least one side of the pond is lower than the bottom of the pond.

The drainage structure can be of varying types and sizes as per availability of the designs such as sluices (an artificial channel for conducting water fitted with a gate at the upper end for regulating the flow) and monks (monk is a device resulting from the combination of sluice and an underground drainage pipe). Siphoning is another easy method of draining the water from the pond.

7. Screens at the inlets and outlets

One of the difficulties that arise during the management of fish ponds is the frequent clogging of inlets and outlets. Therefore both at the inlet and outlets suitable screens or filters or traps have to be fitted. There are several designs for this and it is better to consult an engineer for the suitable designs.. For the inlet the easiest structure is to have a rectangular top-open box like tank fitted at the inlet. The first half of the tank receives incoming water. The second half of the tank is fitted with vertically sliding screens. These could be more than one screen in succession with sufficient space for collection of clogging materials which can be periodically removed. For the outlet the easiest way is to use siphoning into a lower area or a well from which water is pumped out.

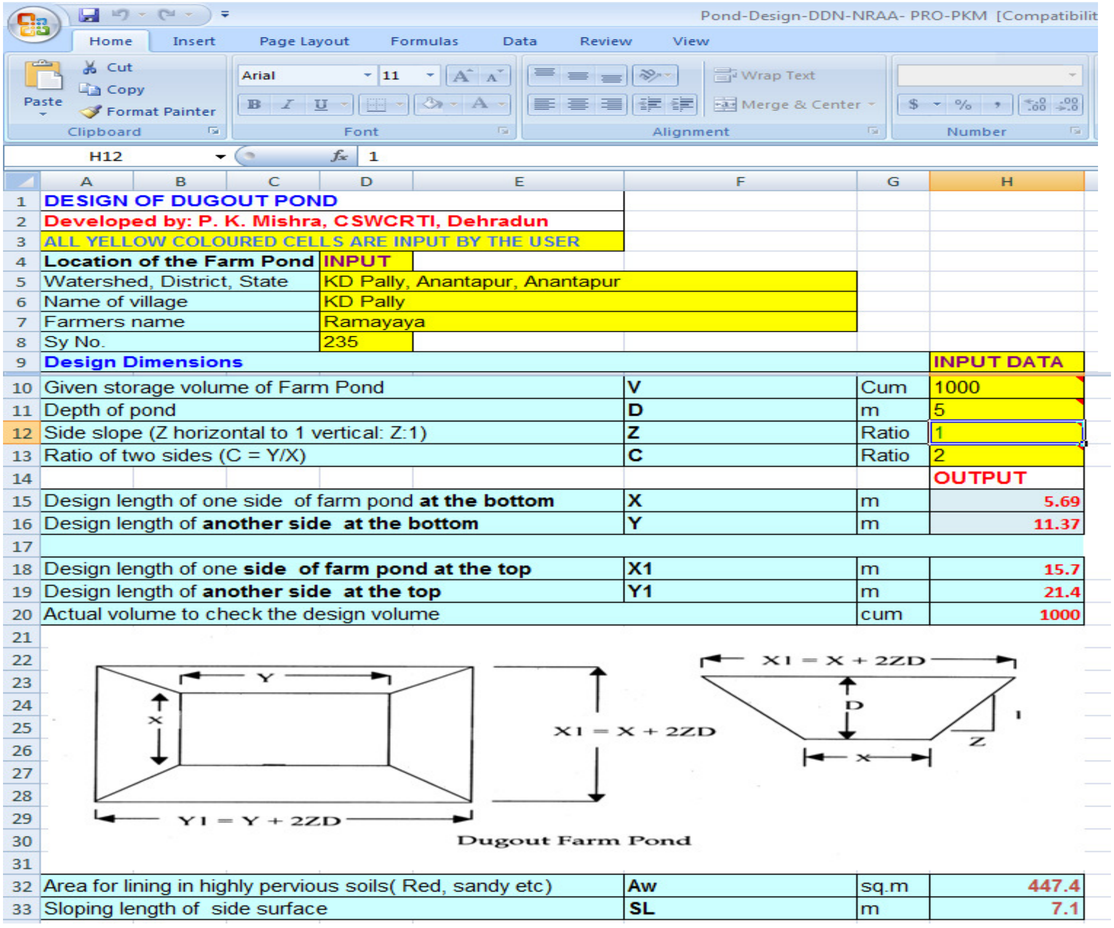
8. Bunds or dikes around the pond

All around the pond there should be a bund sufficiently broad enough to be used as path to go around the pond for doing various kinds of pond management activities. The height of the bund should be about two feet above the water level. However too high or too low bunds should be avoided. If there are several ponds the bunds of all the ponds are linked together with connecting paths. This will enable easy movement of the people, implements, and instruments and in some cases even vehicles. The bunds should be covered with grass to avoid soil erosion, breakage and collapse. Selected trees could be planted around the bunds to provide partial shading to the pond in areas where very high intensity of sun rays and summer is prevalent; however they should not be too many to break the bunds by sending the roots or shading beyond 50 per cent of the area. Generally trees with tap root system should not be planted. If there is any problem of shading, prune sufficient number of selected branches to provide sun- light to the pond.

Excavated ponds are the simplest to build in relatively flat terrain. Because their capacity is obtained almost solely by excavation, their practical size is limited. They are best suited to locations where the demand for water is small. Because excavated ponds can be built to expose a minimum water surface area in proportion to their volume, they are advantageous in places where evaporation losses are high and water is scarce. The ease with which they can be constructed, their compactness, their relative safety from flood flow damage, and their low maintenance requirements make them popular in many sections of the country. Two kinds of excavated ponds are possible. One is fed by surface runoff and the other is fed by ground water aquifers, usually layers of sand and gravel. Some ponds may be fed from both of these sources. The general location of an excavated pond depends largely on the purpose or purposes for which the water is to be used and on other factors discussed previously. The specific location is often influenced by topography. Excavated ponds fed by surface runoff can be located in almost any kind of topography. They are, however, most satisfactory and most commonly used in areas of comparatively flat, but well-drained terrain. A pond can be located in a broad natural drainage way or to one side of a drainage way if the runoff can be diverted into the pond. The low point of a natural depression is often a good location. After the pond is filled, excess runoff escapes through regular drainage ways. Excavated ponds fed by ground water aquifers can be located only in areas of flat or nearly flat topography. If possible, they should be located where the permanent water table is within a few feet of the surface.

Spreadsheet tool for design of ponds

Commercially available software for pond design is available (e.g., Aquacad, Autocad Land Desktop), however, much technical skill is required for appropriately using both these versatile, expensive tools (Tollner *et al.*2008). We therefore choose to develop a simple Microsoft Excel based spreadsheet tool for design of a dugout pond (Fig.3).Given the storage volume, depth, side slope (Z horizontal to 1 vertical: Z:1) and ratio of two sides (C= Y/X), the programme calculates the design length of one side of pond at the bottom, design length of another side at the bottom, design length of one side of at the top, design length of another side at the top, actual volume to check the design volume and area for lining the pond.



DESIGN OF DUGOUT POND				
Developed by: P. K. Mishra, CSWCRTI, Dehradun				
ALL YELLOW COLOURED CELLS ARE INPUT BY THE USER				
Location of the Farm Pond	INPUT			
Watershed, District, State	KD Pally, Anantapur, Anantapur			
Name of village	KD Pally			
Farmers name	Ramayaya			
Sy No.	235			
Design Dimensions				INPUT DATA
Given storage volume of Farm Pond		V	Cum	1000
Depth of pond		D	m	5
Side slope (Z horizontal to 1 vertical: Z:1)		Z	Ratio	1
Ratio of two sides (C = Y/X)		C	Ratio	2
				OUTPUT
Design length of one side of farm pond **at the bottom**		X	m	5.69
Design length of **another side at the bottom**		Y	m	11.37
Design length of one **side of farm pond at the top**		X1	m	15.7
Design length of **another side at the top**		Y1	m	21.4
Actual volume to check the design volume			cum	1000
Area for lining in highly pervious soils(Red, sandy etc)		Aw	sq.m	447.4
Sloping length of side surface		SL	m	7.1

Fig.3. Spreadsheet tool for design of dugout ponds

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PRINCIPLES AND PRACTICES OF WATERSHED-BASED FISHERIES DEVELOPMENT PLANS (WFDP)

M. Muruganandam*

Introduction

Growing need to increase global food production up to 70% to feed an additional 2.3 billion people by the year 2050 besides the present over 950 million people suffering from hunger necessitates effective and responsible utilization of water resources, to which fisheries and aquaculture production can contribute immensely. Despite importance, aquaculture growth is declining from 11.8% during 1985-1995 and 7.1% during 1995-2003 to 6.1% during 2004-2006, may be due to increasing environmental problems, declining number of small farmers, inputs of global warming and declining water resources (Gupta, 2010). Although fisheries and aquaculture production in India has grown tremendously, it is too less standing at 136th rank among 160 countries in the world in terms of annual per capita (9 kg) fish consumption as against 19 kg of world average despite its abundant water resources and as compared to China, the leader in fish production with about 20 mt per year. Growth rate of freshwater fish production from aquaculture in India is one of the lowest as compared to many Asian countries like China, Bangladesh, Vietnam, Thailand, Indonesia and world average (FAO, 2000).

If watershed-based approach is adopted for fisheries development, the targeted total global aquaculture production of about 210 mt from the present level of about 42 mt within the next four decades by 2050 (FAO 2004; Avinmelech 2006) and the targeted fish production of about 8.4 mt from the present 6.4 mt of fish production of India with a projected 8 per cent and 2.5 per cent growth of inland and marine fisheries sectors, respectively before beginning of the 12th five-year plan (Ayyappan et al. 2009) can be a reality. Similarly, if fish farming is included in IWDP, the present 2nd position of India after China in freshwater aquaculture, 4th position in total fish landings, 136th position in per capita fish consumption and mere 2% fisheries contribution to the GDP of India can progress further.

Watershed-based Fisheries Development or Sustainability Plans (WFDP) introduced in British Columbia (BC), Canada as a new approach to the management of fish stocks and fish habitats on a long term basis in 2001, in which watersheds, associated processes and inter-connections of both in-stream and upland are planned and executed with "fish first approach" (Tamblyn and Crost, 2003). Various components of the approach are executed in bits and parts by various agencies or groups in India, which needs consolidation through concerted effort towards the unified approach of WFDP as proposed by agencies of British Columbia. Towards this, the acquired hands-on experience during the past ten years in introducing and managing the fisheries and aquatic sciences under integrated Natural Resource Management (NRM) and community-based watershed development programmes by creating an integration with essence of several agricultural disciplines have proved potential for development of fisheries production and effective resource utilization. The compiled knowledge and accrued information suggest for the extension of such studies and efforts to wide range of agro-climates.

*** Senior Scientist (Fisheries), Central Soil & Water Conservation Research & Training Institute, Dehradun-284 195 (Uttarakhand)**

Principles and practices

Complex interactions between different fish species and between fish and other watershed elements including animal and plant exist within watersheds. It works from river basins, sub-basins to watershed scale based on identified priority watersheds, species or habitats at risks. Needs of all fish species instead of single species are addressed using all available scientific data, traditional ecological knowledge and needs of communities. The WFDP becomes necessary since all aquatic ecosystems, watersheds, rivers, oceans are interconnected through upstream-downstream cords and riparian-upland ecosystems affect one another and in-stream conditions. Trade-offs between and upstream is internalized in the approach. The approach recognizes that ecological, social, political and economical factors influence the status of fish and habitat, which need categorical consideration. In the approach basins, watersheds, habitat, fish species etc. are prioritized for protection, restoration and sustainability enhancement with the principle that prevention is better than cure or restoration. WFDP builds on the lessons of the past to help government agencies and other stakeholders including fish interests and non-fish interests. It is a commitment to work jointly in watershed fish production planning processes on consultation with stakeholders.

Importance of watershed-based development

While India is divided over 112 catchment and 3237 watersheds (AISLUS 1990), Uttarakhand has 8 catchment, 24 watersheds, 116 sub-watersheds and 1110 micro-watersheds (500-5000 ha) covering a total of 53,23,116 ha. The largest catchments are Alaknanda, Bhagirathi, Ganga, Kali and Yamuna. The Yamuna catchment has 18 sub-watersheds and 160 micro-watersheds covering 5,50,162 ha and the Yamuna watershed has 7 sub-watersheds and 80 micro-watersheds with total area of 2,29,185 ha. Dehra Dun and Tehri districts have 95 micro-watersheds with 3, 05,043 ha and 134 micro-watersheds with 4,14,588 ha respectively (Sharda *et al.* 2008). Estimates indicate that by the late 1990's an annual budget of over US$ 500 million from all sources was being spent for watershed development programs in the country (Kerr *et al.* 2002) which was being executed by a diverse group of institutional players including State Governments, Panchayat Raj Institutions, Non-Governmental Organizations (NGOs), NGOs-Government collaborations, bilateral agencies etc. The ongoing centrally sponsored schemes like IWDP, National Watershed Development Program for Rain-fed Areas (NWDPRA), Drought-Prone Area Development Program (DPAP), programs or schemes under "*Hariyali*" guidelines, "*Bharat Nirman*" etc. besides State government sponsored programs like Watershed management and many initiatives by NGOs stand as testimony to the growing importance of IWM. A synoptic view on watershed management in India was given by Shah (1998) and Sharda *et al.* (2008). A target of about 63.5 million ha with the total investment of Rs. 75,800 Crores for treatment by the end of the 13th plan period in addition to the already treated area of 37.4 million ha up to 1993 - 94 is being envisaged by Planning Commission of India through a 25 years perspective plan (Rita Sharma 2002). Overall, about 50.964 million ha area with the involvement of Rs. 19036.47 Crores have been treated since the inception of soil and water conservation and watershed management to till the end of 10th five-year plan through various schemes of ministries of agriculture and rural development, Government of India (Bali 2009).

As early as in the 1960's, the necessity for comprehensive and inclusive multi-disciplinary knowledge and cross-cutting abilities of fish biologists and soil-water conservationists was emphasized (Leedy 1968; Berg 1968). This called for co-operative efforts of departments including soil conservation with biologists and other multi-disciplinary team and local people for comprehensive periodical inventorization and management of soil, water and related natural resources including fish, aquatic life and wildlife habitats (Miller *et al.* 1986). Potential of fisheries and importance of Integrated Watershed Management (IWM) for Natural Resource Management (NRM) and rural development are constantly growing in India. Development of water Harvesting Structures (WHS) and water resources for multiple goods and services is one of the prime interventions in watershed management programmes, which would vehemently favor promotion of fisheries resources, aquatic ecosystems and accommodate fish farming. Introduction of water harvesting techniques and management of water resources in upstream watersheds would help to manage downstream regions effectively while providing in situ benefits to locals that may include fish farming based benefits. The watershed approach strives to reduce soil loss, nutrient loss, land degradation, water depletion, production-dependent wastes and promote land aggradations, water availability, agricultural production and overall human well being may help fish production mutually, if right orientation is given.

IWM has proved to be an effective tool for conservation of natural resources and fisheries development as catchment-wide management of fisheries resource would promote sustainable fisheries (Collares-Pereira and Cowx 2004). For example, soil-water conservation programs could improve fish and wildlife habitats by reducing accelerated erosion, resultant sedimentation and siltation that cause degradation in quality of aquatic ecosystems, aquatic life and habitats reducing carrying capacity of rivers and other water bodies (*e.g.* Bolen and Robinson 1999). Natural or man-made WHS with multipurpose use have been observed to be common throughout the developing countries like India and China for subsistence of agriculture.

Given the importance of aquatic ecosystem, fisheries and aquaculture globally (Kent 1997; Hickey and Diaz 1999; Akpaniteaku *et al.* 2005) and in India (Jhingran 1985; Ghafoorunissa 2001; Gupta 2006), their level of association in IWM and NRM projects is surprisingly low and contributing little for the benefit of society. Though importance of soil-water conservation with emphasis on soil-water conservation engineering, as a measure for anti-erosion, water conservation and utilization in India begun as early as 1900, much before a similar decision was taken in USA to conceive and proceed in a big way since 1933 by creating the Soil Conservation Service and Soil Conservation Act (SCA) of 1935 (Kaushik 1956). But in USA the SCA was comprehensive and included upgradation of aquatic ecosystems (*e.g.* Guy and Ferguson 1970; Smart *et al.* 1981; Jackson *et al.* 1989), fisheries considerations for the conservation of fish and wildlife (*e.g.* Cottam 1958; McBroom 1961; Jahn and Schenck 1991) and fish farming (Rhodes and Unwin 1981) under soil and water conservation, IWM and NRM much early than India (Muruganandam and Samra 2001).

Why watershed-based fisheries management is needed?

- In the present scenario of increasing demands and decreasing resource-base, riverine and riparian ecosystems are put to constant restrains causing irreversible loss in ecological integrity and economical utility. Many fish populations in India declining due to varied and combination of factors. Urban and industrial development, timber harvesting, mining, dams, overfishing and climatic change contribute to decline. Entire ecosystem is likely to suffer due to one or other ways, when fish populations decline.

- Most often, the declines or damages are silent or unnoticed for quite long period.
- If watershed priorities are identified and addressed through comprehensive plans and cooperation between all concerned stock recoveries may be achieved.
- Health of watersheds can be monitored and improved using fish population, fish-ability and fish health since most fish species and their habitats often viewed as end-points indicators. Often water courses accumulate pollution and aquatic organisms are negatively affected since watersheds are utilized for agriculture and undergo urbanization and changes in the complex pattern of erosion and sedimentation cause profound impact on the function of the interstitial zone in streams and rivers.
- Additionally, the ecology and fisheries of upland Rivers require attention as they have enormous bearing on the development of their catchments and rivers *per se*. All these are fundamental for organized fisheries and aquatic environment-based development, as they are complementary to understand the continuum of existing hydrological processes, products and services.

How watershed-based fisheries management plans are achieved?

- It aims for conservation of fish populations and their habitats by creating a greater awareness and understanding on the needs of all fishes.
- Advocates protection of all fish populations and their habitats in everybody's interests and health of watershed ecosystems.
- Restoring damaged habitat (*e.g.* Rebuilding channels, placing stumps to shelter fry, planting riparian trees and promoting improved stock management.
- It demands stronger voice for fish conservation interests by identifying common goals and drawing attention of non-fish interests towards fish interests.
- Attending all points in upstream-downstream reaches to address complex interactions between fish, animals, plants and human beings.
- Brings all available information including traditional local and scientific knowledge on resources, conservations and development. Tries to fill knowledge gaps.

Table 1: Stages of WFM plans

Sl. No.	Stages	Activities
1.	I	Identification of fisheries sensitive watersheds on river basin-wide region through bio-physical and socio-political profiling: Establishing regional priorities.
2.	II	Produces a biophysical and socio-political profile of each priority watershed units *i.e.*5000-50,000 ha out of watersheds identified in Stage I along with objectives and strategies.
3.	III	Detailing of development plans with objectives and strategies for implementation.
4.	IV	Actions and commitments based on State III-Monitoring and reviewing periodically for feedbacks and improvements.

Note: All state, central and local governments and other interested group need involved.

Indian continent as such is divided into 7 large basins, and 3237 large watersheds, which again further divided into number of sub-basins, sub-catchments and micro-watersheds (Table 2). For example, Uttarakhand has 1130 micro-watersheds (Table 3), which can be taken as development unit for WFDP. Delineation of watershed and a micro-watershed is depicted in Fig. 1.

Table 2: Hydrological units of Water Resource Region

Units	Regions						Total
	R_1	R_2	R_3	R_4	R_5	R_6	
Basins, Nos.	7	4	4	8	8	4	35
Catchments	12	22	14	34	26	4^+	112^+
Sub-catchment, Nos.	51	126	55	175	78	15	500^+
Watersheds, Nos.	302	836	330	1150^+	513	106^+	3237^+
Total area of WRR , M-ha	30.8	82.0	29.1	113.0	43.0	27.3	325.2

Note: + likely to added few more, *Source:* AISLUS (1990).

Details of Water Resource Regions (WRR)

R_1 - Rivers falling into Arabian Sea; R_2 - The Indus basin in India;
R_3 - Rivers falling into Bay of Bengal; R_4 -The Ganga system;
R_5 - The Brahmaputra systems; R_6 -Rajasthan river-mostly ephemeral drainage

Table 3: Watersheds in Uttaranchal

Sr. No.	District	Number of Micro-watersheds	
		Total	Snow-covered
1.	Pauri	127	10
2.	Dehradun	98	2
3.	Chamoli	150	28
4.	Uttarkashi	147	33
5.	Tehri	133	1
6.	Rudraprayag	48	4
7.	Almora	105	0
8.	Bageshwar	62	9
9.	Pithoragarh	124	90
10.	Champawat	27	8
11.	Nainital	82	19
	Total	**1130**	**204**

Source: WMD (2005).

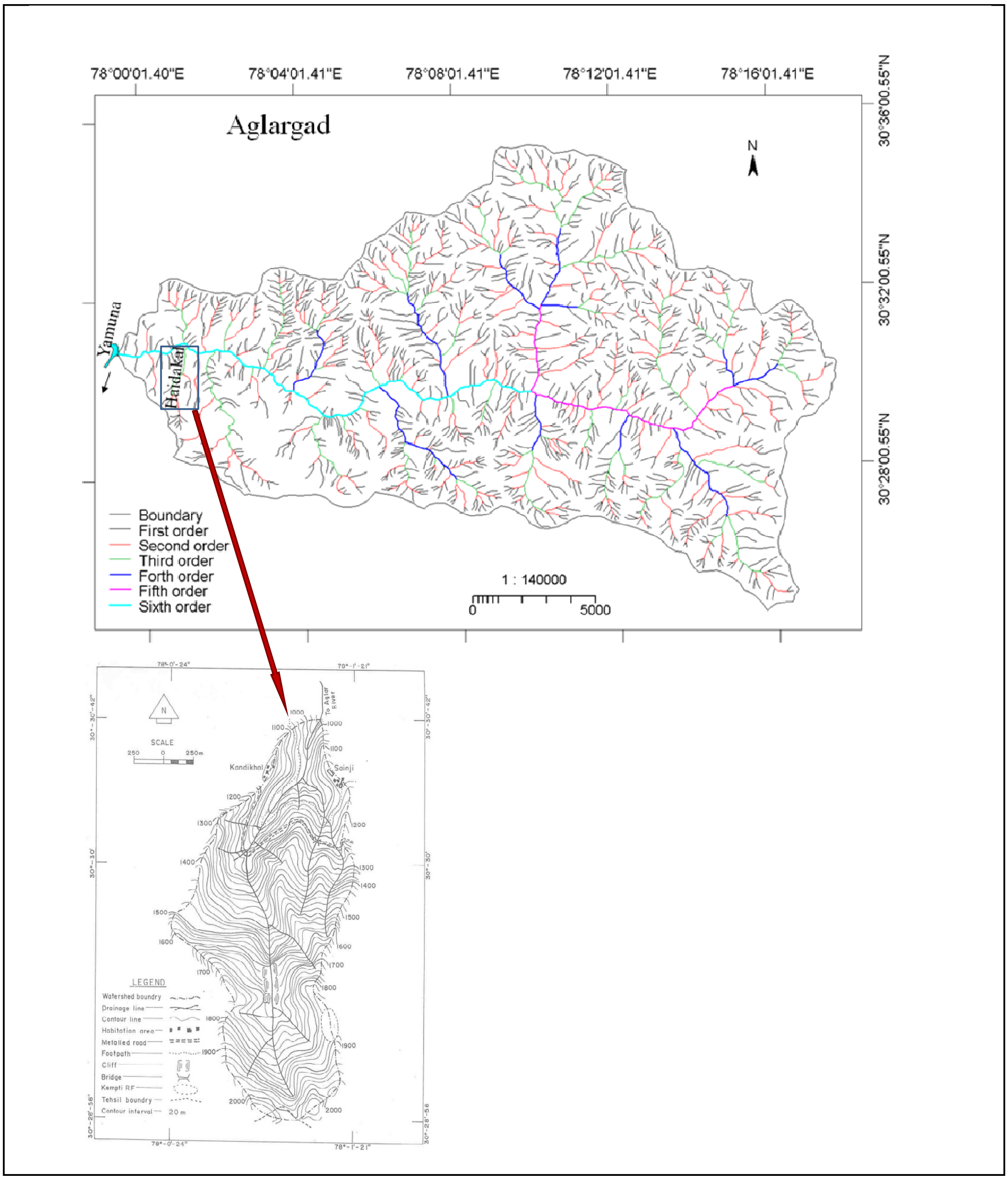

Fig. 1: Aglar catchment and Sainji watershed in the sub-set

Of late, few watershed-based fish management modeling tool kits like Watershed Health Assessment Tools-Investigation Fisheries (WHAT-IF) are being evolved. The WHAT-IF tool kit includes hydrologic and stream geometry tools, fish assemblage predicator tool, fish habitat suitability tool based on depth, temperature, substrate, % riffles, cover and type of riparian vegetation and bio-accumulation and aquatic system simulator (BASS) (Rashleigh et al. 2006).

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WHY IS AQUACULTURE IMPORTANT IN WATERSHED MANAGEMENT AND RURAL DEVELOPMENT?

M. Muruganandam*

Introduction

Fisheries and aquaculture play major role in supplying protein rich food especially for rural- and resource-poor people of developing countries in Asia and Africa. Off late, their importance is received from many other avenues of development like employment generation, recreation and sporting, ornamental farming, area reclamation, resource conservation, ecological literacy enhancement, biomedical extraction and foreign exchange earnings, besides being major food suppliers toward food security and poverty alleviation. With the growing knowledge base and demands, dimensions of fisheries and aquaculture expand radically. One such expansion is fish farming under integrated watershed management and is conceived as a potential thrust area towards building self-sufficiency in nutrition, employment, better environment and living at gross-root levels. In this widening perspective, an attempt is made here to comprehend the role, potential, requirements, and package of practices for fish farming under watershed management.

Watershed may be defined as a naturally delineated area that is drained by a common stream or channel. Management of watersheds through multi-disciplinary approach in a holistic pursuit with ridge to valley treatment and people's participation is termed as Participatory Integrated Watershed Management (PIWM). In integrated watershed management, development of water resources is one of the prime objectives. It promotes harvesting of rainwater, excessive runoff and water conservation besides many other interventions like land-water, soil and nutrient conservation, control of land degradation, promotion of biological productivity and sustainable development. The developed water resource provides basic opportunity for fish farming and associated benefits. However, for the want of development policies and support facilities the opportunities are not been leveled to full potential. While the origin of fish farming as such dates back to centuries ago, its recognition in integrated watershed management as opportune for development was received recently. At this juncture, requires more closely integrated approaches to fisheries, fish farming and other sectors aimed at sustainability of watersheds and natural resources at regional, national and community levels.

Principles of watershed management and fisheries

Principles of watershed management revolve around participation, bottom-up approach, social fencing, synergism, ridge to valley bio-engineering treatment, natural resource conservation, responsible exploitation, bridging gap between potential and actual yields. It strikes for rationalization of land, water and biological potential to eradicate malnutrition, natural resource degradation and to ensure sustainable development. Emphasis on the landless, gender issues and bio-diversity use is also parts of watershed management. Areas with under-utilized resources are planned out to bring under optimal use in the approach. It identifies productive areas to bridge the gap between potential and actual yield on priority. Bridging the yield-potential gap requires strategic approaches backed with the principles and techniques of watershed management are as follows:

*** Senior Scientist (Fisheries), Central Soil & Water Conservation Research & Training Institute, Dehradun-284 195 (Uttarakhand)**

1. Appropriation and exploitation of land-water uses according to production capability, environmental resilience and constituents of life support systems through integrated watershed (holistic) management with multi-sectoral involvement.
2. Identification of production potentials bringing more land-water into productive use with paradigm shift encompassing environmental, ecological, economical and social parameters based on a better understanding the dynamics of land, water, vegetation and other resources.
3. Arresting land degradation through bio-engineering measures such as contour bunding, contour farming, terracing with appropriate raiser/slopes, trenching, gabion check-dams, diversion drain, nallah bunds, loose boulder with vegetative checks, gully plugs, green fencing, conservation forestry, soil binding plants like *Agive americana, Ipomea carnea,* bamboo spp., other grasses etc for stream or stream bank and landslide stabilization.
4. Aggradation of farming lands, waste land-water resources through alternate land-water use including aquaculture, bio-organic recycling and minimum chemical use.
5. Control of nutrient loss through conservation agronomical practices such as mulching, green manuring, conservation tillage, integrated nutrient management, organic farming etc so as to avoid eutrophication, and nutrient pollution in the streams and impoundment. Moisture conservation and water harvesting for multi-purpose use including fish production.
6. Promotion of afforestation and carbon trading for climate amelioration. Protective cover management of forests and mountains by Sloping Agricultural Land Technology (SALT), Multi-Purpose Trees (MPTs) and soil cover management. Regulated and carrying capacity based grassing to avoid extension of barren lands, excessive erosion and attendant problems like aquatic pollution and production loss.
7. Promotion of the concept of conservation by eco-systems and not by only single entity or species in isolation.
8. Reorient our agriculture policies, resources and infrastructures to contain the challenges of sustainable development, globalization and World Trade Agreement.
9. Enhancement of energy (renewable and non-renewable) and input availability to optimize resource exploitation.
10. Socio-economical measures such as bottom-up approach, participation of farmers, local mass, social fencing, progressing with local wisdom, Indigenous Technical Knowledge (I.T.K.), promotion of self-help group, income generating activities and educating local mass on environment, ecology, carrying capacity and sustainability. Promotion of dynamic group processes through empowering people to reduce social conflicts and induce contribution by stakeholders, local institutions, Non-Governmental Organizations (NGOs), user groups, voluntary agencies, religious institutions, self-help groups, watershed management comities etc. for equitable and sustainable yield from Life Supporting Systems (LSSs) of watersheds. Psychological and functional adjustment of governmental functionaries is also to be sensitized.
11. Adoption of gene revolution for biotechnological and microbiological process and products. Identification, evaluation and utilization of genetic resources judiciously reducing monoculture practices.
12. Utilization of advanced techniques and tools like remote sensing, Geographic Information System (GIS), expert system, computer modeling, space technologies through INSAT systems for communication, broadcasting and meteorological forecasting and IRS systems for satellite based earth observation to provide details on crop, forest, underground water, surface water, coastal resource cover etc for better planning and exploitation at various levels.
13. Bringing-in information revolution through internet, satellite communication, exchange and outreach meetings etc for mass awareness.

The concept of management by watershed

Management by watersheds not only would reinstate the degraded streams and aquatic environment, but also improve productivity towards self-sufficiency and food security. Focus by NGOs, user groups, voluntary agencies, religious institutions and refinement of Indigenous Technical Knowledge (ITK), local resources etc. with the facilitation from research and Government units is institutionalized in management by watersheds. In short, management by watersheds is the process of guiding and co-coordinating use of land-water resources in a watershed. In management by watersheds the intricate linkages among land-use activities, soil, vegetation, water, biological diversity that affect the functioning and sustainability of ecosystems within watersheds are resolved in an inter-disciplinary systems approach. An acute shortage of trained manpower in inter-disciplinary approach as presently most of the academic training and experiences are pointed to any single scientific discipline. It is imperative to build up multi-disciplinary team for the success of watershed management processes as anthropogenic and developmental changes within watersheds are multifaceted and dynamic in nature. Realising this need the CSWCRTI is actively engaged in orienting the development officials through regular training and demonstration. Participatory management by watersheds will yield better resolution in the production function of inputs-transformations-outputs to eliminate undue pressure on life support systems so as to secure a sustainable future. For example, resolving the problems associated with religious feelings such as traditional negative belief of fishing and fish eating as a social taboo and sin would contribute to enhanced fishery production and consumption. Empowerment of people, self-help group and local institutions would provide equitable sharing to create social fencing as proved in Sukhomajri and Relmajra watershed live models demonstrated by CSWCRTI in the foot hills of Shiwaliks. An integration of multiple stakeholders and a framework to balance the economic and ecological sustainability are essential for management by watersheds. Creation and involvement of watershed management committee and other institutions will bring more democratic and transparent prosperity.

Management by watersheds ensures sustained water resources at every naturally delineated landscape that provides opportunities to balance the diet through the development of fish farming. Water harvesting in over 3 % of country's land could store almost a quarter of the average annual rainfall of 400 m ha-m for productive and conservative use. Further, the results on the water yield potential of different agro-climatic regions of India encourage watershed based aquaculture propagation. Efforts to harvest runoff will provide avenues for fish farming in addition to providing valuable usage such as life-saving irrigation, animal watering and bathing and reducing potential eutrophication in small impoundments. The site specific Water Harvesting technologies developed at the institute for watershed management proved to be effective in sustainable aquaculture development. However, the suitability of various watersheds for specific fish farming varies widely on the basis of the hydrographical, hydrological, ecological, physico-chemical, biological and productivity parameters and is to be analysed critically. Because, although, aquaculture depends on self-renewable natural resources it interacts with the environment and other variables, which influence production efficiency, profits and sustainability of the watersheds. Similarly, any restoration attempt to be successful must address both biotic and abiotic processes within watersheds or basins as it will stabilise ecological and biological compositions. Integrated watershed management programs emphasis integrated farming systems for greater production efficiency. In integrated farming efforts, allocation of land and water for fish farming should consider the whole range of farming systems that can be practiced in the area, the maximum area that can be occupied by an enterprise, the maximum harvest admissible in each production unit in relation to waste disposal requirements and the sanitary measures to be adopted. Sustainable cold water fisheries development requires multi-pronged guidelines to work in association with all the stakeholders including researchers, administrators, politicians and local people.

Runoff quantity and water quality are important for programming aquaculture and these can be optimised through soil and water conservation measures combining earth works and improved land management practices like conservation tillage, buffer strips, careful timing and placing of required fertilisers. Establishment of gully control structures, contour cropping, absorption bank, gully filling, pasture improvement, controlled grazing, afforestation and periodic top dressing of grasslands will reduce soil and nutrient erosion, improve water quality and fish production.

Table 1: The requirements for watershed based fish farming

1.	Land and soil	• 7 to 20 ha catchment for 1 ha surface water. • Minimum 20% clay soil in pond areas. • < 5 % sloppy land for pond construction.
2.	Source water	• Mainly rainfall runoff. • Ground or other surface waters, if available for conjunctive use.
3.	Seed	• 3-10 Seeds/m^3 stocking density. • Seed price - Rs.75-125/1000 seeds. • Species - Cold water species like mahseer, trouts, *Schizothroax* spp., *Barellius* spp., common carps and other plain species such as catla, silver carps, grass carps, magur, rohu, mrigal.
4.	Feed	• Good natural feed management. • Artificial supplementary feed. • Ingredients - rice bran, wheat flour, oil cake, tapioca powder, fishmeal, agricultural, slaughter and household wastes. • Locally farm preparation.
5.	Labour	• For feeding, soil and water testing, watch and warding, harvesting and marketing.

Fish farming - The concept and potential

Broadly, fisheries include both wild hunting (fishing) and farming (aquaculture or fish farming). Age-old practice of fishing resembles wild hunting that entails harvesting of fish or animals from open common access water resources. The science and technology of fisheries further classified into varied groups according to land-water environments and level of management and input intensities involved. Some of the groups are fresh water, brackish water and marine water fisheries and traditional, extensive, intensive, rural and industrial fisheries or aquaculture. Fisheries and aquaculture play major role in supplying protein rich food especially for rural and resource poor people of developing countries like India and China. Off late, its importance is received from many other avenues of development like employment generation, recreation and sporting, ornamental farming, area reclamation, resource conservation, ecological literacy, biomedical extraction and foreign exchange earner, besides being major food suppliers toward food security and poverty alleviation. Aquaculture is akin to farming and animal husbandry as it involves rearing and management of living aquatic organisms in controlled environments in water for food, profits and other benefits. Fishing resembles wild hunting that entails harvesting of fish or animals from open common access water resources. Fish farming is one of the potential propositions of many uses of farm ponds. In fact, it is non-consumptive water use proposition as fish do not consume water and rather they use water as medium of living. The expanding aquaculture activities have viable puissance to alleviate poverty and ensure livelihood securities at national level particularly in Asia as they possess immense potential to effect positive impact on integrated watershed management efforts.

Importance of fisheries and aquaculture

Fisheries sector plays a major role in meeting the national agenda of eradicating malnutrition, poverty, unemployment bug and ecological degradation. It is one of the fastest growing sectors all over the world that needs proper characterisation and introduction in integrated watershed management programmes in India. Aquaculture being more remunerative than agriculture in most situations is developing into a prime industry tapping enormous turnover of bio-energy to meet the challenges posed by fast marching population such as starvation, malnutrition, etc. Aquacultures in general and shrimp and carp farming in particular have become very popular among third world countries. Fish farming is one of the many culture avenues of aquaculture and has potential for effective utilisation of farm ponds and aquatic environments. Fish farming has immense potential for rationalizing natural resources to the social and environmental demands, especially in the pursuit of integrated watershed management (IWM) as a holistic approach. Watershed being a topographically delineated hydrological unit drained at a common point by a network of channels and streams, management of fisheries and aquaculture by watersheds offers potential for sustainability of resources and rural development. In essence, aquaculture and aquacultural systems have as many as 27 interrelated positive points for consideration as an active sub-sector in water resource management, rural development and watershed management programs as described below.

1. First of all, it is an easy enterprise that any person who has farming spirit and little exposure to aquatic science and fish culture can practice. It has minimum risks and high returns.
2. Fish farming can be done in various aquatic systems like ponds, tanks, cages, reservoirs, streams, and water channels.
3. Fish meat is cheap, non-risky, protein-rich and easily digestible with most essential nutrients including Poly-Unsaturated Fatty Acids (PUFA)-α-fatty acids (Eichosopentanoic and tocosohexanoic acids), amino acids and vitamins required by human beings to balance diet and avoid food related medical problems.
4. Being cheap, it can be nutritious food for almost all sections of the society. Increasing availability of fish and fishery products in rural areas would minimize under- or mal-nutrition problems.
5. Fish can be harvested individually as fresh meat on need without requiring refrigeration or preservation. It is more suitable in areas where no electricity, refrigeration or icing is possible.
6. The shelf-life of majority fish species is relatively better in hills due to lower temperatures.
7. Fresh fish are normally free from pollutants, pathogens and any adulterations.
8. Fish farming reduces fishing pressure in wild environments, streams, Oceans as it provides demand-driven supply to markets and hence minimizes species endangering pressure and bio-diversity loss.
9. Aquaculture catalyses foreign exchange earnings if export oriented cultures are done.
10. Aquaculture can be practiced to extract bio-medical and chemical compounds for medical and human welfare purposes.
11. Fish farming is a non-consumptive water use proposition since fish do not consume water and uses water only as medium of life. The water loss if any in developed water resources could be due to other ways and means like seepage, evaporation and irrigation. Hence, fish farming would be an incentive for water resource conservation.

12. Fish are essentially weightless in water and thus expend little energy for locomotion or to maintain upright position. They are cold-blooded animals and do not expend energy to maintain a relatively high temperature as do poultry, swine or cattle. Thus, the amount of food energy required to produce a kilogram of fish is much lesser than the amount required to produce an equal weight of terrestrial livestock.
13. Integration of fish farming in watershed management provides greater opportunities for many sub-sectors like agriculture, horticulture, animal husbandry, poultry, agro-estology, forestry, watermills and such others in one form or another. The used and the exchanged water from Water Harvesting Structures (WHS)/fishponds stands to be enriched with necessary plant nutrients especially nitrogen and phosphorous through fish and fish farming activities like excretes of fish and aquatic organisms, applied fertilizers, uneaten feeds, underwater decomposition and demineralization. So, the integrated agriculture crops that receive this enriched water tend to require minimum or no external fertilizers and provide more profit.
14. Additionally, pond dykes can be utilized to raise vegetables, horticulture crops, grass for cattle and other shallow rooted Multi-Purpose Trees (MPTs). Here, integrated use of land-water, soil, biomass, agricultural and animal wastes, labour and other infrastructures is internalized in a real sense of holistic approach. In effect, maximum benefits from lesser space through effective utilization of resources are achieved.
15. Watershed management practices like reclamation, renovation, waste recycling, pollution minimization and resource optimization would provide opportunities for fish farming as one of the potential resource users. Further, pressure for fish farming in watersheds necessitates creation of additional water resources, augmentation of water, stabilization of catchment, drainage systems and streams that may ultimately avert watershed degradation. Essentially, untapped or underutilized land-water resources could be effectively utilized through aquaculture using principles of conservative water use and recycling for enhanced productivity.
16. Perennial component of aquaculture systems once established become permanent source of income.
17. Stored pond water may serve as a catalyst for rural development because a variety of different activities may be stimulated for simultaneous progress. Water storage in fishponds makes water available for supplemental and life-saving irrigation, livestock watering, domestic needs, fire fighting, flood control and moisture maintenance.
18. Aquaculture enhances employment opportunities as is a labour oriented, better remunerative and employment-potent enterprise that absorbs work forces from varied sections of the society including women, men, school drop-outs and landless labourers for various activities such as fish stocking, feeding, pond/farm security, pond fertilization, fish harvesting, transportation and marketing.
19. An upsurge to develop aquaculture may induce many other subsidiary and associated enterprises like fish seed hatcheries, nurseries, seed-banks, feed mills, fish containers' factory, ice plant, fish based food industries and cottage enterprises, fish-medicine shops, aqua-labs, mobile labs and such others for resource mobilization, employment generation and economic well-being.
20. In all, promotion of aquaculture and related enterprises may enhance purchasing capacity and small-scale enterprises.

21. An intuition for fish farming creates environmental awareness and increased ecological literacy rate. Because, the concept of fish farming necessitates farmers and entrepreneurs to essentially know about primary producers, the phytoplankton, secondary producers, the zooplankton, consumers, the fish, and decomposers, the benthos and microbes; food chain, food web, pond ecology, fertilization, feeding, biomass enhancement and other associated cognizance in aquatic ecosystems. This necessity provides ample scope for informal education and profound knowledge sharing on conservative resource utilization, ecological preservation and their inter-linkages.
22. Further, fishponds or watershed ponds act as trap-reservoir to store and redistribute eroded soil and nutrients from catchment or up-slope regions to their original source. Hence, fishponds in erosion prone areas could be of great help to maintain soil and nutrients. In essence, soil loss and runoff can be moderated with fishponds created in watersheds.
23. Also, fishponds and impoundments built may improve ground water recharge and hydrological cycle for betterment of nature.
24. Development of fishponds and fish farming promotes wetland ecology, wildlife that is associated with water resources and aesthetic beauty. Many a times, fishponds can also be bird sanctuaries, reserve of aquatic organisms and pools of endangered or vulnerable species. Hence, fishponds develop one more flip to conservative farming. However, impacts of birds and other organisms on fish and aquaculture species and vice versa need to be studied, categorized and accordingly management needs must be imposed.
25. Fish farming in WHS/ponds can promote local sport fishing, recreational farming and attract villagers for pond-based activities like bathing and boating to derive joy. The villagers may develop a long-lasting involvement towards ponds for responsible utilization.
26. Besides all these, with the help of many indicator aquatic species in various specific systems extent of aquatic pollution and land degradation can be studied and monitored.
27. Overall, if managed properly, ponds and aquatic systems provide water, food and shelter for a variety of wild and aquatic species while providing fish and fishing to local people besides helping them to have better living.

Table 2 Fish farming improves water quality and aquatic ecosystems

Variables	**Before fish farming**	**During fish farming**
Plants	Profuse growth of vegetation including grasses, weeds and wild plants	Negligible
Animals	Excessive wild fish – about 7500 number weighing 82 kg More frogs, tortoise, leaches, snakes	Nil - Negligible
Water quality	Poor, obnoxious smell	Good, Fishy smell
Aesthetic Values	Poor	Good

Out of many multi-sectoral planning and engineering measures of watershed management efforts, development of water resources and Water Harvesting Structures (WHS) is a vital intervention point which supports fish farming immensely. Virtually, development of ponds and WHS and fish farming therein has many inherent advantages under watershed management interventions. Presently, since multi-purpose water resources, pond and manpower are essentially developed under watershed programmes, inclusion of aquaculture to promote fish production is increasingly thought-out throughout the world to supplement production and net returns with least additional investment.

It is well conceived now that there is an immediate need to manage wetlands and streams for fisheries development in general and aquaculture in particular by watersheds. Watershed based fish farming can make a giant leap forward to enhance per capita fish production and consumption. Fish farming in water harvesting structures is a potential land-water use proposition and would fetch higher profit through intensive utilization of harvested water. With the bare minimum extra expenditure added to already developed resources like pond, water and manpower for fish farming under watershed management effort, the benefits realized are promising towards building food and economic security. Both fish farming and watershed management have immense potential as well as challenges for sustainable development that need to be harnessed through resource optimization. But the concept of fish farming in watershed management is not being trickled down to the resource managers and farming communities. Still, despite the fact of vast fishery resources, good compatibility of aquaculture with other sectors and its high land-water use potential, the sector has not been given due consideration in land-water use planning and watershed management programs. It requires very urgently augmenting sustained productivity. Presently, fisheries management interventions in watershed programmes are very recent and it requires a strategic plan to match the demand-supply and resource generation-exploitation. There is, thus, an immediate need to deliver the developed expertise and conceptual ideas to watershed functionaries and local farmers. Although fish farming and landscape development through water harvesting are two age old activities, aquaculture till recently has not been placed appropriately in land use planning and watershed management programmes in the country, despite the fact of vast Indian fishery resources, its good compatibility with other sectors and high land use potential.

Table 3: Importance of Water Harvesting Structures (WHS) for aquaculture

1.	Provide water source for fish farming, cattle and wild animals
2.	Promote integrated farming system involving multi-sectoral development.
3.	Minimize the wasteland - water masses through improving the utility of natural and human resources.
4.	Establish wetland sanctuaries or aquatic reserves to conserve aquatic and terrestrial bio-diversity *in situ*. (Serve as rehabilitation structures of endangered or vulnerable species).
5.	Reduce the pressure of water demand on rivers, streams and ground water for aquaculture.
6.	Train the run-off and moderate the turbidity problems in rural fish farming.
7.	Increase employment opportunities to the locals.
8.	Educate the local and seek their co-operation and possible investment for resource management.

Table 4: General features of rainfall runoff-fed fishponds

1.	Yields additional benefit and protein-rich food, yet, has following features of negativity,
2.	Water source is mainly or only rainfall runoff,
3.	Water level fluctuates according to rainfall, evaporation and seepage potential,
4.	Therefore, Gives limited scope for water exchange or water addition and implementation of other water management practices,
5.	Wide water level difference between start (during monsoon, July-Aug.) to end (between Dec. - May) of fish culture exists (generally ranges from initial > 4 m to final < 0.5 m),
6.	Therefore, production space gradually reduced giving opportunity for disease to occur,
7.	Favours continuous fish culture without giving scope for drying and bottom scrapping,
8.	Overall, limits intensive and organized fish culture.

Many watershed ponds have structural inadequacy to accommodate fish farming, may be due to varied problems (Table 1).

Table 5: Structural inadequacies of ponds present in foothill Himalayas for fish farming

Sl. No.	Descriptions	Total ponds observed (Nos.)	Structural deficiency	
			Nos.	%
1.	Inlet with screening net	47	44	94
2.	Outlet with screening	47	45	96
3.	Willful draining	47	46	98
4.	Sediment Detention Structures	47	46	98
5.	Regular shape in prevailing wind direction	47	44	94

Importance and inclusion of fisheries activities in integrated watershed management

Watershed Approach is getting momentum because of the inherent advantages experienced. Mismanagement of watersheds or catchments will directly affect aquatic eco-systems and overall productivity. For example, about 1-2 % of storage capacity of major and medium reservoirs is observed to be lost due to unchecked erosion in their catchments. The importance of fisheries in integrated watershed management requires no emphasis for its possible impact on food security, employment generation, resource conservation and management. Any thrust to promote watershed oriented aquaculture and fisheries activities would optimize land-water use planning. Although aquaculture and watershed management practices are long established practices, it is only quite recent that both had interaction and received substantial research efforts. Till recent, fisheries components in the development programs were very limited and isolated. Moreover, interventions backed with fisheries and aquaculture sciences did not appear adequately in most of the watershed management attempts in the country as a whole.

Until now, impact of soil and water degradation and conservation efforts on the fisheries resources including coastal ecosystem is not adequately researched and characterized. Planned investment in organized research on designing, planning, comprehending surface, sub-surface hydrology and water yield, implementing water harvesting technologies in different agro-ecological regions to accommodate aquaculture in integrated watershed management efforts is one of the hitherto neglected critical issues that needs immediate attention. Nonetheless massive efforts and adequate information are being generated for general fisheries by diversified fisheries research institutes and many interests of aquatic environment, scientific data on inter-linkage of hydrology, catchment characterizes, land-water use features and fishery biology on watershed or catchment basis under diverse agro-climatic situations of the country is quite inadequate. While eight main research institutes with their widespread research centers besides few auxiliary institutions under ICAR system and many State fisheries Colleges and Departments are functioning to address the general and board spectrum problems of fisheries and aquaculture development, the critical absence of an institute for fisheries and aquaculture development by watershed management was felt by ICAR. Ultimately, it has identified CSWCRTI, Dehradun to take up the task. As a result, a scientific pursuit towards fisheries science is built up at CSWCRTI, Dehradun to foster management by watersheds for the first time in 1996 by the ICAR vide approval dated 12th April, 1996. At this juncture, the CSWCRTI with the national mandate on natural resource management realized the importance of fisheries and aquaculture in watershed development for the mobilization of natural and Common Property Resources (CPR). Considering the poor status of fisheries development in integrated watershed management programs and potential of the sub-sector, the CSWCRTI, Dehradun expanded in principle and programmes to include fisheries and aquaculture interventions for socio-economical and environmental sustainability. The on-going activities on watershed management programmes were strengthened to include fisheries since 1996 with the introduction of a scientific position to comprehend fisheries and aquaculture sciences. Management by watersheds as a new dimension in fisheries development is conceived and propagated for the sustainable prosperity.

Future needs

In conclusion, the sub-sector in the country is presently constrained by a number of factors and needs a fresh look with the principles of watershed management to promote many low productive and fish deficit areas so as to ensure as highly productive and self sufficient regions in a short while. A thrust to promote fish farming and eating habits among the villagers through established extension and popularization techniques is very urgently required. Appraisal of watershed based resources and marketing for fish products would provide opportunities for sustained fisheries development. In management by watersheds the intricate linkages among land-water use activities, soil, vegetation, water, biological diversity that affect the functioning and sustainability of ecosystems within watersheds are to be resolved in an inter-disciplinary systems approach. An acute shortage of trained manpower in such an inter-disciplinary approach as presently most of the academic training and experiences are pointed to any single scientific discipline. It is imperative to build up multi-disciplinary team for the success of watershed management processes as anthropogenic and developmental changes within watersheds are multifaceted and dynamic in nature. Realizing this need the CSWCRTI is actively engaged in orienting the development officials and farmers through regular training and demonstration. Training, demonstration and exposure tours to the development functionaries and farmers will enable the stakeholders for marked fisheries production. Various soft loans, subsidies for limited periods along with necessary operational inputs may be essential to attract induced investments in fish production. Ensuring the active participation of the farmers and resource managers would eliminate the existing flaws in watershed based fish farming. Beginning with the local wisdom and sharing of success stories with the farmers would have an enduring effect on establishing fisheries in watershed management programmes. Research on critical issues in watershed based fisheries activities are very indispensable in this direction. Identification of appropriate land-water uses, resource generation avenues and integration of various sectors including potential fisheries according to the opportunities and environmental resilience would multiply the output of watershed programmes many-fold. Adequate Fish Farmers Development Agencies (FFDAs) and inter-linking of them with other development organizations would be essential to coup up the shortage of manpower and development intuition. Compromising the site-specific soil and water characteristics for fish production through appropriate pond design and production mechanisms would lead to the quantum jump in fisheries yield. This would require identification of future markets and consumers as well.

Suggestions on policy and developmental perspectives for western Himalayas

Scenario analysis of existing fish resources and demand and availability of water in the Himalayas indicate clearly that the confronting issues of water resource aggredation, extension and adoption of fish farming technologies, fish seed shortages etc. need to be tackled through concerted efforts by all the stakeholders of natural resources including researchers, planners, extension specialists, administrators, farmers and the general public. This is necessary so that future IWDP includes fish farming and aquatic ecosystem management as one of its integral components and provides adequate impetus to promote fish farming, IFFSs and fisheries management in the State. These would include development of infrastructures for supply of technical and critical inputs, markets and institutional arrangements for capacity building of stakeholders including farmers and technocrats, demonstration and extension besides assistance from financial institutions for scientific fisheries management and fish farming. The issues are briefly described below:

Identify potential areas in Uttarakhand where fish farming on a commercial scale can be taken up. Develop WHS with appropriate design matching the water yield potential of watersheds at strategic locations that can provide favorable water yield, soil characteristics etc. for integrated use including fish culture, which would in turn serve the purpose of increasing fish farming systems. Improvement of existing Common Property Resources (CPRs) of Panchayat and watersheds viz. ponds, WHS and other water resources would reduce the need for extra land and water resources to produce fish towards meeting the targeted demand. A massive drive to provide fish culture-support facilities like nursery tanks, proper inlets and outlets with screens and fertilizer soaking pit for Panchayat or village ponds or fishponds along with capacity building would improve fish production from Panchayat, village ponds and other WHS. Increase leasing period of Panchayat ponds, WHS and other Common Property Resources (CPRs) for at least a period of 10 years.

Propagate appropriate fish stocking density, feeding, water quality management to optimize phytoplankton and zooplankton production for higher increased initial survival and harvesting principles and practices for increased yields. Make provisions for 3400 - 3600-m^3 water source per ha pond area during the summers for supplemental use, if continuous fish culture is planned. The region being moist-subtropical to sub-temperate with relatively low minimum temperature as compared to plains, which restricts aquatic productivity, reschedule the fish farming calendar by stocking during March - April against normal period of July - August and harvesting during November - January due to low temperature for 4 - 5 months in a year. For this, maintenance of buffer seed stock in small ponds near main ponds or in warmer locations to supply bigger size seedlings at appropriate time is necessary. If no small ponds or bigger size fish seedlings are available, continuous stocking of hatchery-fresh fish seedlings during July - August and partial harvesting during November - January with 11 - 18 months culture sequence can be practiced. Establish anti-bird nets or birds' scares during winter and fencing for snake problem during summer may be necessary. Consider culture of *Clarius gariepinus* (Thai magur) with suitable regulation instead of blanket ban since it is already established in some prime locations of natural environments and present in Indian market from 1993 as that of its prevalence in about 20 countries producing over 3703 mt per year. As a candidate species for culture it is hardy, has good resistance to diseases and amenability for high stocking density besides potential for fast growth with slaughterhouse or household waste as feed material. Possibility of using sterile population for farming as in other species like *Tilapia* can be explored.

Expand the content of different ongoing training programs of soil-water conservation and reorient watershed management to include neglected aspects of fisheries science and fish farming as one of the potential sub-sectors in IWM. Organization of tailor-made courses on watershed-based fisheries management and fish farming for various stakeholders of natural resources including farmers, field functionaries of watershed management projects, Project Implementing Unit (PIU), project evaluators, managers, researchers and planners would need to be educated about water availability for fish farming and accommodate fish farming based interventions in IWDP. Improvement of knowledge on pisciculture can lead to change in the livelihood of individuals by bringing about a collective action plan for resource conservation. Production potential of fish farming in strategic locations should be demonstrated to enterprising farmers through established reference models. Practices of accommodative agriculture instead of intensive agricultural activities and effective water resource management in watersheds should be promoted.

Promotion of mini-hatcheries, networking of fish producers, and low-input management with more dependence on organic and inorganic fertilization rather than supplementary feeding, emphasizing more on profit than high production would bring more number of local farmers into the fold of fish farming. Besides, development of basic infrastructure through centralized "aqua-shops" for supply of seed, feed etc. and marketing facilities along with effective State policy for promotion of aquaculture would improve fish production and consumption. Improvement in facilities for transport of harvested fish and seedlings is of critical importance, due to risk involved in transport of grown-up seedlings and life fish, which yields good return, in difficult terrains of Himalayas. This will involve suitable fabrication and the use of refrigerated or air conditioned trucks, handy and battery operated aerators for live fish and fish seed transport, all weather roads, cold storage facilities at collection centers etc.

Devise relevant policy frameworks for management of aquaculture and capture fisheries along with institutional arrangements involving local municipalities, village Panchayats and other organizations besides local farmers and fishermen for strict regulation of fishing activities and contain destructive fishing like fishing festivals. Promote conservative production and improvement in availability of fish by habitat restoration activities and ecological stabilization activities of IWDP in addition to artificial ranching and organized harvests of local species with effective management measures of closed seasons, bio-reserves and restrictions on fishing gear along with economic and regulatory incentives for conservation to revive lost fish stock as well as maintain the existing ones in terms of quality and volume both for conservation towards biological equilibrium of biodiversity and consumption purpose. Improvement in existing traditional fishing gears and development of suitable new gears with the understanding of environment, behavioral adaptations and structure of fish populations to improve CPUE should receive attention of research and development agencies. Provision of alternate employment and fish production sources like aquaculture may help to avoid intensive and illegal fishing-dependent ecosystem damages. Provide subsidies, credit facilities and tax-holidays for limited periods to progressive farmers so as to promote adoption of scientific fish farming. Sport fishing and angling as source of revenue need to be given due attention with proper infrastructures to revamp lost potential and tap tourism-based recreational fisheries of hills.

Recommendations for fisheries development in western Himalayas

Policy issues for State Governments

1. **Value addition of water harvesting structures & ponds:** Partitioning of bigger size ponds over 2 ha for easy management, strengthening bunds, strong & tall inlet & outlet net lines in required heights, provision of tube well or supplementary water source, water diversion channel for safe disposal, if surplus water exist, small nursery pond near main pond, approach road, outdoor entertainment facilities like boat etc.
2. Fish farming should be brought under agriculture to use electricity and canal or irrigation water at a concession rate instead of commercial & industrial purview and values.
3. Suitable insurance provisions should be devised to tackle eventualities like that of the heavy loss incurred by all pond or lease owners during last year (2010) due to flood.

Recommendations for research organizations

1. Research to promote fish farming in irrigation canals, small streams (*gad* and *gadhera*) and reservoirs suitably by providing engineered structures like cages, net barriers, supports and flow regulators to accommodate fish farming.
2. Evaluate, demonstrate and promote situation specific IFS technologies including all suitable components. Trout farming facilities & marketing, farming of local cold water species like masher, snow trout and spiny eel need to be further researched.

Recommendations for extension agencies

1. Input support: Supply bigger size fish seeds or yearlings for nominal stocking density of 1-2 per m^2 and reschedule culture period to March-Dec. instead of usual July-Dec.
2. Expand training programs to include various tailor-made courses to introduce & improve fish farming activities in new and existing ponds or tanks.

Photo 1: Fish produced from runoff-fed ponds

ASSESSMENT OF RUNOFF FROM CATCHMENT FOR DESIGN OF WATER STORAGE STRUCTURES

K.P.Tripathi*

Assessment of expected runoff from the catchment is of paramount importance for determining the capacity of the water storage structure and design of other relevant component as depth/height, width and length of the structure; design of spillway and its possible potential uses. In case of live stock management and of fish cultivation it will also help us to plan the stocking density and period and quantum of partial harvest. Some of the terminology associated with runoff is given below:

Surface runoff

- Percent of rainfall(0/0)
- Depth of runoff (mm)
- Volume (Cubic meter)

Runoff

- Peak Rate of Runoff
- Surface Runoff
- Sub –surface Runoff
- Water Yield

Factors affecting runoff / peak rate of runoff

- Rainfall and its characteristics
- Soil and its characteristics
- Topography (watershed characteristics viz. area, slope, time of concentration etc.)
- Vegetation *i.e.* land cover
- Management practices.

Estimation of runoff /peak run off rate can be done by:

(i) Using simple rain fall – run off equations applicable to the watershed conditions
(ii) Mathematical equations using rainfall, climatological parameters, watershed characteristics and parameter coefficient
(iii) Empirical equations of Rainfall, Area and coefficient
(iv) Simple empirical models using detailed information of watershed, management practices, vegetation, rainfall and other such parameters affecting run off
(v) Computer aided complicated models using more detailed information of watershed, management practices, vegetation, rainfall and other such parameters affecting run off

Assessment of runoff from a catchment:

The simple method of computing run off is:

$$V = C * A * RF$$

Where:

V= Volume of the runoff from a homogenous catchment
C= Runoff coefficient
RF= Rainfall from which runoff is to be assessed

*** Principal Scientist (SWCE), Central Soil & Water Conservation Research & Training Institute, Dehradun-284 195 (Uttarakhand)**

Assessment of runoff from a catchment:

The simple method of computing run off is:

V= C* A * RF

Where:

V= Volume of the runoff from a homogenous catchment
C= Runoff coefficient
RF= Rainfall from which runoff is to be assessed

Example 1: Compute run from a rainfall of 150 mm from 1000 square meter of catchment area from the following land cover:

(i) Cemented catchment
(ii) Hard clay soil
(iii) Sandy soil
(iv) Sandy soil with vegetation
(v) Sandy soil with vegetation and field bunding, contour bunding, ponds etc

Under above problem the only variable is land cover which varies from cemented floor to soil with vegetation and management practices. Now the cement floor is unlikely to absorb any rain fall and all the rainfall is expected to occur as runoff (100 per cent) minus some evaporation losses and so the runoff coefficient can be taken as 1. However in hard soil some rainfall is expected to be retained in the soil and the runoff coefficient will be less than 1 and the runoff coefficient goes on decreasing proportionally with degree of absorption of rainfall. In case of Sandy soil with vegetation and field bunding, contour bunding, ponds etc it may be 0.3 or so. The runoff computation for above problem is tabulated below:

Sl. No.	Area (m^2)	Land cover	Rain fall (m)	Runoff coefficient*	Runoff (m^3)	Remarks
1	1000	Cemented catchment	0.150	1.0	150	* Assumed
2	1000	Hard clay soil	0.150	0.8	120	
3	1000	Sandy soil	0.150	0.6	90	
4	1000	Sandy soil with vegetation	0.150	0.4	60	
5	1000	Sandy soil with vegetation and field bunding, contour bunding, ponds etc	0.150	0.3	45	

This is simple way of understanding the process of runoff. The slope also plays an important role in runoff. More the slope more will be runoff. In case of heterogeneous land cover weighted value of run of is computed.

Direct runoff from the catchment for a given rainfall:

Among various methods used for computing runoff from a catchment Curve Number (Soil Conservation Service) method is widely used.

There are number of methods and empirical formulae to estimate runoff. The method described as follows is used for small watersheds.

Curve Number Method

In this method of runoff prediction, the relationship between runoff and rainfall is of the form:

$$Q = \frac{(P-Ia)^2}{(P-Ia) + S}$$

Where, Q is actual runoff, P is rainfall, S is potential maximum retention and Ia is initial abstraction during the period between beginning of rainfall and runoff (0.2S).This is used in the following form.

$$Q = \frac{(P - 0.3S)^2}{P + 0.7S} \quad \text{for black soil region, AMC I and all other regions}$$

$$Q = \frac{(P-0.2\,S)2}{P + 0.8S} \quad \text{For Ia=0 .2 Used by SCS}$$

$$Q = \frac{(P - 0.1S)^2}{P + 0.9S} \quad \text{for black soil region, AMC II \& III}$$

Where,

Q = Actual runoff in mm

P = Rainfall in mm

S = Potential maximum retention in the watershed and is given by

$$S = \frac{25400}{CN} - 254$$

Where, CN is an arbitrary curve number varying from 0 to 100

The amount of rainfall (P) is also affected by duration. For design considerations, maximum runoff volume is required. It is established that minimum storm duration for flood estimation can be taken as 6 hours. But in certain conditions design rainfall for greater durations can also be taken.

Procedure for Using SCS Curve Number Method

1. Divide the watershed area into uniform hydrologic soil cover groups.
2. Find out the antecedent moisture condition (AMC) based on 5 days total rainfall in previous days.
3. Find out the CN for each soil for AMC II. If required, convert CN for AMC II to AMC I or AMC III conditions by multiplying AMC II value with conversion factor.
4. Determine weighted curve number

$$CN = \frac{N_1 \times A_1 + N_2 \times A_2 + \ldots + N_n \times A_n}{A_1 + A_2 + \ldots A_n}$$

5. Compute S
6. Compute direct runoff using the equation.

The various parameters affecting curve number is given below in detail:

Table: 1. Parameters affecting curve number (CN)

Sl. No.	Parameter	Details	Sensitivity to changed Temperature & Rainfall
1.	Soils	Hydrologic soil group A, B, C, D	No significant change
2.	cover	Land use Cereals, Coarse grains, Legumes	The change of crop sequence shall affect the CN
3.	Land Treatment or practice	Straight Row, Contouring, Terracing, Residue management	Yes, the treatment shall change
4.	Hydrologic condition	Poor, Fair, Good	No significant change

A. Soils (Soil group as per their hydrologic properties)

Group A (low runoff potential): Soils having high infiltration rates even when thoroughly wetted, consisting chiefly of sands or gravel that are deep and well to excessively drained. These soils have a high rate of water transmission (Final infiltration rate, 8-12 mm/h).

Group B Soils having moderate infiltration rates when thoroughly wetted, chiefly moderately deep to deep moderately well to well drained, with moderately fine to moderately coarse textures. These soils have moderate of water transmission (Final infiltration rate, 4-8 mm/h).

Group C soils having slow infiltration rates when thoroughly wetted, chiefly with a layer that impedes the downward movement of water, or of moderately fine-to-fine texture and a slow infiltration rate. These soils have a slow rate of water transmission (Final infiltration rate, 1-4 mm/h).

Group D (High runoff potential): Soils having very slow infiltration rates when thoroughly wetted, chiefly clay soils with a high swelling potential; soils with a high permanent water table; soils with a clay pan or clay layer at or near the surface; and shallow soils over nearly impervious materials. These soils have a very slow rate of water transmission (Final infiltration rate, < 1 mm/h).

B. Hydrologic condition for various cover (vegetative)

(i) Crop rotation

Poor	Row crops, small grains and fallow in various combinations
Good	Close-seeded legumes or grasses that will improve tilth and increase infiltration. The effect of such crops will carry over into the second or third year

(ii) Native pasture or range

Hydrologic condition	**Vegetation condition**
Poor	Heavily grazed, no mulch or having plant cover on less than about 50 per cent of the area
Fair	Moderately grazed; between about 50 and 75 per cent of the area with plant cover
Good	Lightly grazed, more than about 75 per cent of the area with plant cover

Classification of Native Pasture or Range by Density and weight sampling.

Arial density (per cent)	**Air-dry weight of plant and litter, tonnes/ha**		
	< 1.25	**1.25 to -3.75**	**> 3.75**
Less than 50	Poor	Poor +	Fair
50 to 75	Poor +	Fair	Fair +
Over 75	Fair	Fair +	Good

(iii) Permanent meadow: Ungrazed, native grassland with 100 per cent cover. It represents the upper limit of watershed grass cover

(iv) Woodlands (farm wood lots)

Hydrologic condition	**Vegetation condition**
Poor	: Heavily grazed or regularly burned so that litter, small trees, and brush are destroyed.
Fair	: Grazed but not burned; there may be some litter, but these woodlands are not fully protected from grazing.
Good	: Protected from grazing so that litter and shrubs cover the soil

C. Land treatment

(i) Straight row farming: A type of farming where ploughing, planting, cultivation, and other farm operations are carried on without regard to the slope of the land

(ii) Contour farming: A type of farming where farm operations are carried on by following the general contour of the land occasionally dense vegetation (strip cropping) is also provided in addition to contour farming on higher slopes.

(iii) Terracing: The practice of constructing dikes or dike-ditch combinations to control runoff from farm land. Terraces can be graded, open end level, or closed end level,

Table 2: Antecedent rainfall conditions

Condition	Description	5-day Antecedent Rainfall, mm
I	Low moisture condition, wilting point to dry	< 36
II	Average conditions	36-53
III	Wet moisture conditions, heavy rainfall prior to the day under consideration	> 53

Table: 3. Curve Numbers for antecedent rainfall condition II

Landuse or cover	Treatment or practice	Hydrologic condition	Hydrologic soil group			
			A	B	C	D
Fallow	Straight row	-	77	86	91	94
Row crop	Straight row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Terraced	Poor	66	74	80	82
	Terraced	Good	62	71	78	81
Small grain	Straight row	Poor	68	76	84	88
	Straight row	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	73	81	84
	Terraced	Poor	61	72	79	82
Close-	Terraced	Good	59	70	78	81
seeded	Straight row	Poor	66	77	85	89
legumes or	Straight row	Good	58	72	81	85
rotation	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
Pasture or	Terraced	Poor	63	73	80	83
range	Terraced	Good	51	67	76	80
		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
Woodlots	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
		Poor	45	66	77	83
Roads		Fair	36	60	73	79
		Good	25	55	70	77
			74	84	90	92

Table 4: Factors to convert N for condition II to other conditions

Curve number for condition II	Factors to convert Curve Number for condition II to	
	condition I	Condition III
10	0.40	2.22
20	0.45	1.85
30	0.50	1.67
40	0.55	1.50
50	0.62	1.40
60	0.67	1.30
70	0.73	1.21
80	0.79	1.14
90	0.87	1.07
100	1.00	1.00

Example 2:

Determine the estimated maximum volume of runoff for a 25-yr return period that may be expected from the watershed of example 1. Assume that antecedent moisture 5 days prior to storm was 40 mm of rainfall. Take critical duration of the storm as 6 hours.

	Area, A (ha)	Soil group	landuse	Curve Number, N	NA
	20	B	Agriculture	72	1,440.00
	15	B	Pasture good	61	915.00
	15	B	Forest good	55	825.00

Total	**50**	**-**	**-**	**-**	**3180.00**

Weighted curve number, N = 3180/50 = 63.60

S = 25400/63.6 - 254 = 145.37

$Q = (170-.2 \times 145.37)^2 / (170+.8 \times 145.37)$

= 68.68 mm

= 50*10000*68.68/1000 = 34340.00 m^3

= 34340/10000 = 3.434 ha-m

BIO-ENGINEERING MEASURES FOR TREATMENT OF DEGRADED LANDS TO IMPROVE DOWNSTREAM REACHES

G.P. Juyal*

Minespoils, landslides and torrents are mass wasting problems in watershed management causing heavy soil erosion and massive degradation of land and water resources. The soil erosion may be as high as 550 t/ha annum at such degraded sites compared to 3 t/ha/annum from a well forested watershed (Juyal et al., 1995). They cause considerable damage to the ecosystem and pose a constant threat to the life and property of the inhabitants. These problems are discussed in brief as below:

MINE SPOILS

In India mining is spread over an area of 9,43,380 hectares under 7365 mining leases (Anonymous, 1992), more than 90% being surface mines. The mineral deposits occur mostly on forest lands and hilly regions having delicate ecological balance. Mining invariably entails removal of all plant cover on the land surface and the productive topsoil, destroying the habitat for all flora and fauna. The mining of bauxite in Amarkantak (Madhya Pradesh), for example, has denuded large areas of rich soil forests on the hills. Mining operations leave behind huge overburden or debris dumps which are easily subject to erosion. The land disturbing activity of mining carried out in fragile upstream ecosystems has its ill effects reflected far downstream also in the form of pollution of rivers by toxic substances, heavy sedimentation and floods. Some mines, for example, produce various type of waste waters like acid mine drainage water, tail pond discharge, runoff from waste dumps etc. These waters find their way into and degrade the water courses, both surface and underground.

- In order to carry out mining in scientific and systematic manner, Govt. of India, in the National Mineral Policy under Mineral Conservation and Development Regulations, has taken up several steps to ensure an eco-friendly mining, outlined below.
- Acquisition of clearance from Ministry of Environment and Forests (MOEF) under Forest Conservation Act, 1980 and Environmental Protection Act, 1986.
- Environmental Impact Assessment (EIA) Report.
- Environment Management Plan (EMP) - action plan.
- Biological Reclamation Plan.

LAND SLIDES

Landslide is downward movement of a mass of rock or soil as a result of slope failure. The main reason for landslide occurrence is gravity force involving failure of the earth material under shear stress, i.e. when the shear stress exceeds the shear resistance of the soil mass. The landslides adversely affect utility services like roads, power generation units, dams, reservoirs, human settlements, agriculture, forests, pastures, orchards, trade, tourism and all other developmental, cultural and economic activities. Major land slides in Himalayas result in an annual loss of more than 50,000 man-hours and 5, 000 vehicle hours per km on hill roads per year due to disruption of communication alone.

*** Principal Scientist (SWCE) & Head (H&E Division), Central Soil & Water Conservation Research & Training Institute, Dehradun-284 195 (Uttarakhand)**

The country sustains a loss of Rs.350 million annually towards the cost of removal of debris from these roads and loss of vehicle hours (Bansal and Mathur, 1976).

Causes of Landslide formation may be:

1. Non preventable (Natural)

- Weak and unstable geological formation
- Seismic disturbances
- Hydrological - pore water pressure in soil or seepage water flow

2. Preventable or man made

- Deforestation
- Overgrazing
- Unscientific agriculture on steep slopes
- Unscientific mining and road construction
- Forest fires etc.

TORRENTS

An area of 2.73 million hectares is estimated to be affected by torrent damage in India (Anonymous, 1985). In the foothills of the Himalayas and Shiwaliks, hill torrents (locally known as 'Rao' or 'Cho') cause extensive damage to life and property as a result of the frequent changes in their course and associated flash flows with heavy debris loads. However when the streams reach the relatively flat valley, their debris carrying capacity diminishes due to drastic reduction in flow velocities and the debris gets deposited in the watercourses in the form of gravel bars and islands. As a result, the flow tends to braid and migrate laterally overtopping and undermining the low erodible banks and affecting the adjoining forest/agricultural lands and utility services such as roads and bridges etc.

REHABILITATION MEASURES

The soil and water conservation (SWC) measures for rehabilitation of the degraded sites discussed above consist of bio-engineering measures comprising engineering and vegetative measures adopted in an integrated manner on watershed basis.

Engineering measures

Providing a good vegetative cover to a degraded site is the final answer for its rehabilitation. However, in highly degraded lands, establishment of vegetation is difficult due to high runoff/debris movement, lack of moisture and absence of fertile soils. Engineering or mechanical measures are therefore often needed before revegetation programme to stabilize the slopes and create conditions conducive to plant growth by arresting fine soil and improve moisture status. They are, therefore, also called as 'first line of defence'. The engineering measures must be followed by vegetative measures so that both of them act in unison as a bio-engineering measure, supplementing each other.

Vegetative measures

The vegetative techniques as well as the choice of species should aim not only at regreening of the area but to rehabilitate the site ecology in a way which ensures sustainable utilization of the eco-system components in ecologically and socio-economically compatible way. The reclamation approach should be of ecological succession through natural evolution of the site, supported by artificial means. Therefore, species which are found locally and those which are capable of colonizing degraded areas, should be preferred. The vegetative species should be selected with following points in view :

- adapted to the climate and soil conditions of the area
- provide quick green cover and are soil binding
- are fast growing and of primary colonizing nature
- have good erosion control characteristics
- can fix atmospheric nitrogen and ameliorate the soil by addition of organic matter through plant litter
- can attract birds, butterflies and other forms of wildlife and also encourages soil fauna
- are of social and economic values to local population and serve their requirements in terms of fuel, fodder and MFP's

Grasses have been found the best proposition for quick establishment of the initial vegetative cover. Leguminous species like Leucaena leucocephala *(*Subabul) which is also a multi-purpose tree (MPT) and *Pueraria hirsute* (Kudzu), for example, are good soil conservation species which enrich the soil by fixing atmospheric nitrogen.

The bio-engineering measures may be mainly grouped as:

1. Slope stabilization measures
2. Channel stabilization measures
3. Torrent control measures

SLOPE STABILIZATION MEASURES

Diversion drains

Diversion drains are made across the slope to divert runoff water away from the unstable area and discharge it safely into a natural waterway or vegetated water course. The gradient of diversion drain should preferably be 0.5 percent. In exceptional cases, the gradient may be increased to 2 percent.

Trenches

Continuous/staggered contour trenches break the velocity of runoff and store whole or, a part of runoff, as soil moisture. Generally trenches may be dug with a cross-section of 0.3 x 0.3 m.

Staggered trenches may be made upto 15 m in length with inter-space between them. The trenches may be designed to collect runoff expected from storms of 5-10 years recurrence interval.

Crib structures

Steep slopes (more than 40%) can be stabilized by constructing log wood scrub structures filled with stone/brush wood. The inter-space may be vegetated with suitable quick growing protective/productive plant species.

Retaining walls

The retaining walls are constructed for stabilizing precipitous hill slopes. A general rule of thumb method for calculating the bottom width of gabion walls upto 6 m high is to take two-third the height. For example, a wall of 6 m high would require a bottom width of 4 m. The width is reduced in steps to 1 m at the top if there is no surcharge. Where there is surcharge, a 2 m top width may be adopted.

Geojute

Geo-jute is essentially a jute matting which has been successfully used for stabilization of landslides, mine spoil areas and constructed slopes (Fig.1). Afforestaiton of denuded lands and sand dunes can be quickly rehabilitated with the help of geojute. Vegetation planted in a mine spoil site using the geojute established within a period of three years (Juyal et al., 1994).

Kutta-Crate structures

For stabilization of lime stone minespoil slopes in Doon Valley, check dams formed by filling minespoil in used cement gunny bags (Kutta-Crate Structures) have successfully been utilized by U.P.Forest Department. The filled gunny bags are laid in a row over one another in three layers to make a height of about 0.6 m as shown in Fig 2. The special arrangement of bags as shown in the plan and sideview in the Fig. 2 ensures better stability of the structure.

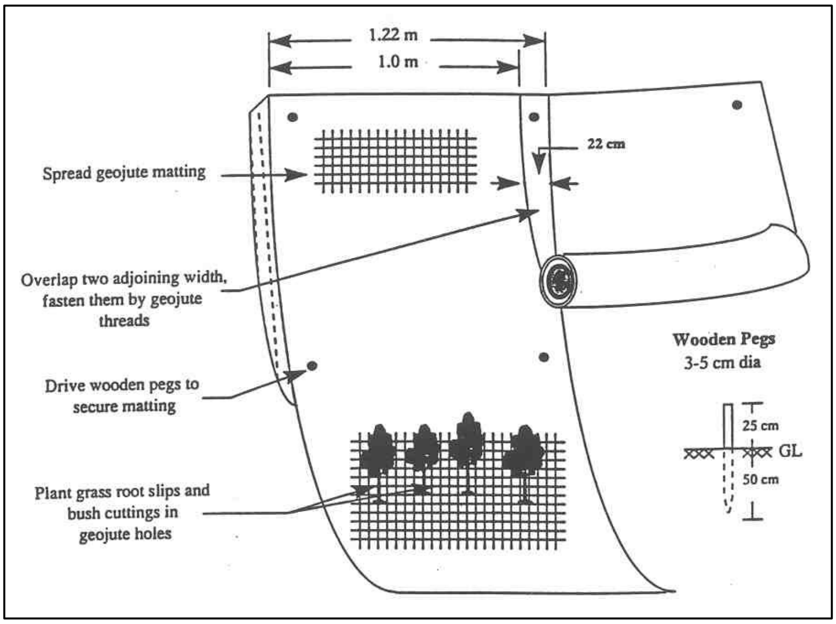


Fig. 1: Technique for stabilizing degraded slope with geojute

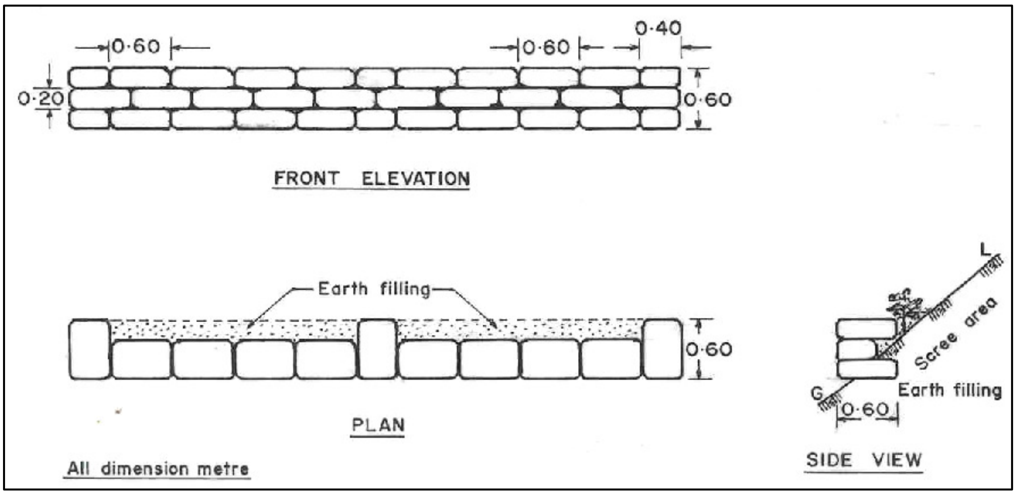


Fig. 2: Gunny bag structures for mine spoil stabilization

GULLY/CHANNEL STABILIZATION MEASURES

Drainage channels/gullies are the carriers of runoff and sediment in a watershed. Steep bed gradient (slope) of a channel causes high runoff velocities with associated heavy sediment flow. Hence channel gradient needs to be reduced in order to bring the runoff velocities within permissible limits. Check dams are used for this purpose. They may be:

1. Temporary check dams
2. Gabion check dams

Temporary check dams

First order gullies/channels receiving small quantities of runoff can be stabilized by temporary check dams, constructed of loose stone masonry, brush wood, log wood etc. Their, design life is usually 3-5 years, during which the vegetation will establish and later provide protection to the surface.

Gabion check dams

The gabion check dams may be constructed in second and third order (main) gullies/channels for retention of debris and soil accumulation without ponding (Fig.3). The debris carrying capacity within the inter-structure reach reduces due to reduction in channel gradient. The check dam encourages good plant cover not only along the bank but also in the bed of the stream due to increased moisture regime.

Cross barriers are suitable in the head water reaches in higher order streams/main drainage channels receiving relatively large quantities of runoff and debris flow.

Gabion structures are made with stones/boulders packed closely in wire mesh cages made with G.I. wire of 10 gauge thickness. The boxes may be fabricated with a dimension of 3m x 1m x 1m (Fig.4&5) or any other suitable dimensions with a mesh opening size of 10-20 cm depending on the stone size.

Gabion structures are preferred in soil conservation works as they are: a) Flexible (bend without breaking), b) Porous (water can seep through them), c) Stable, and d) Economical, as compared to cement structures.

As general rule the check dams should be so located that the compensation gradient (the slope between the bottom of one structure to the top of immediate structure down below) is within the permissible slope limit which is usually upto 3-5 per cent.

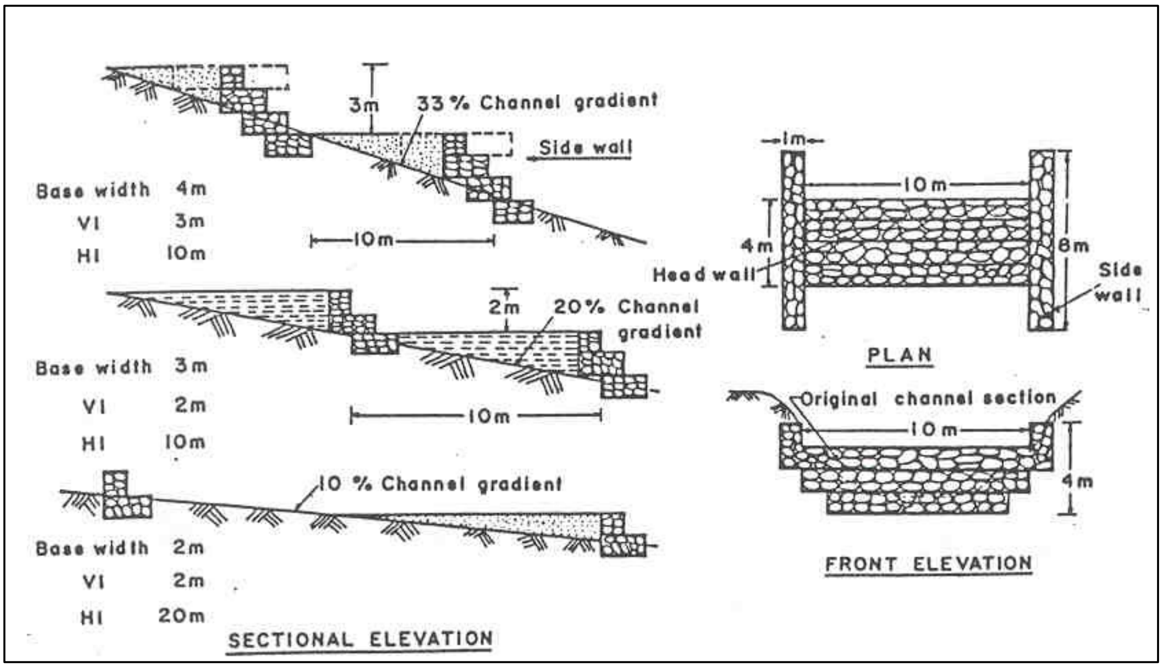
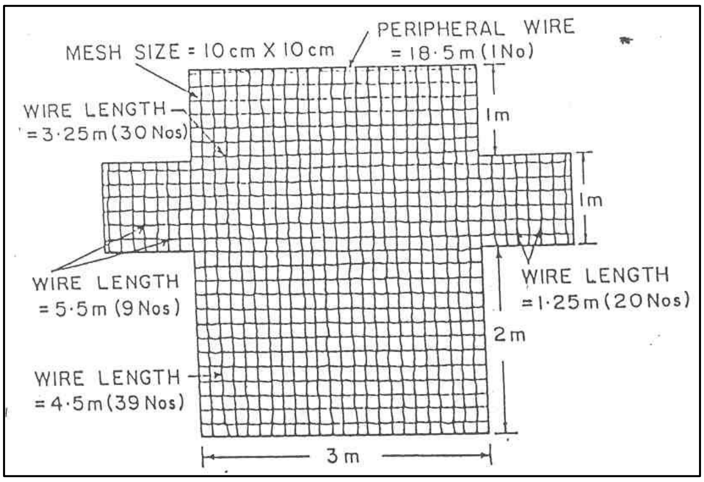


Fig. 3: Structural design of gabion cross barriers on different channel gradients



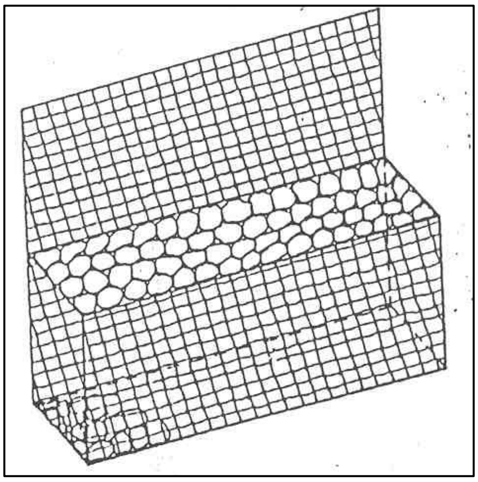


Fig. 4: Details of finished wire mesh **Fig. 5: Gabion box (Rectangular)**

3. TORRENT CONTROL MEASURES

Spurs

Spurs (also known as groyne or spur dikes) are commonly used for torrent control. Spurs are structures constructed at an angle to the stream flow, extending from the bank into the stream. Their man functions are to guide the stream flow along a desired alignment and to prevent bank erosion. A well designed series of spurs built along an eroding bank will, firstly, check the erosion, and secondly induce siltation in the quite water between the spurs (Fig.6) . The silted banks may be put under perennial plantations subsequently.

According to the function served spurs are classified as i) Repelling type (pointing upstream), ii) Attracting type (pointing downstream) and iii) deflecting type (at right angle to flow). Repelling and deflecting type of spurs induce sedimentation on upstream as well as downstream sides of the spurs (Fig.6) but the nose is subjected to greater scouring. The attracting type of spurs does not induce sediment deposition on the upstream side. However there is lesser scour at the nose and hence greater stability as compared to the former types.

The projected length of a spur should not exceed 30 per cent of the stream width. A spur would protect a certain length of the bank, hence a series of spurs are used to give a continuous effect. The spurs may be spaced 3-4 times its length in a straight reach, whereas on a curved reach the spacing may reduce to about 2 times the spur length.

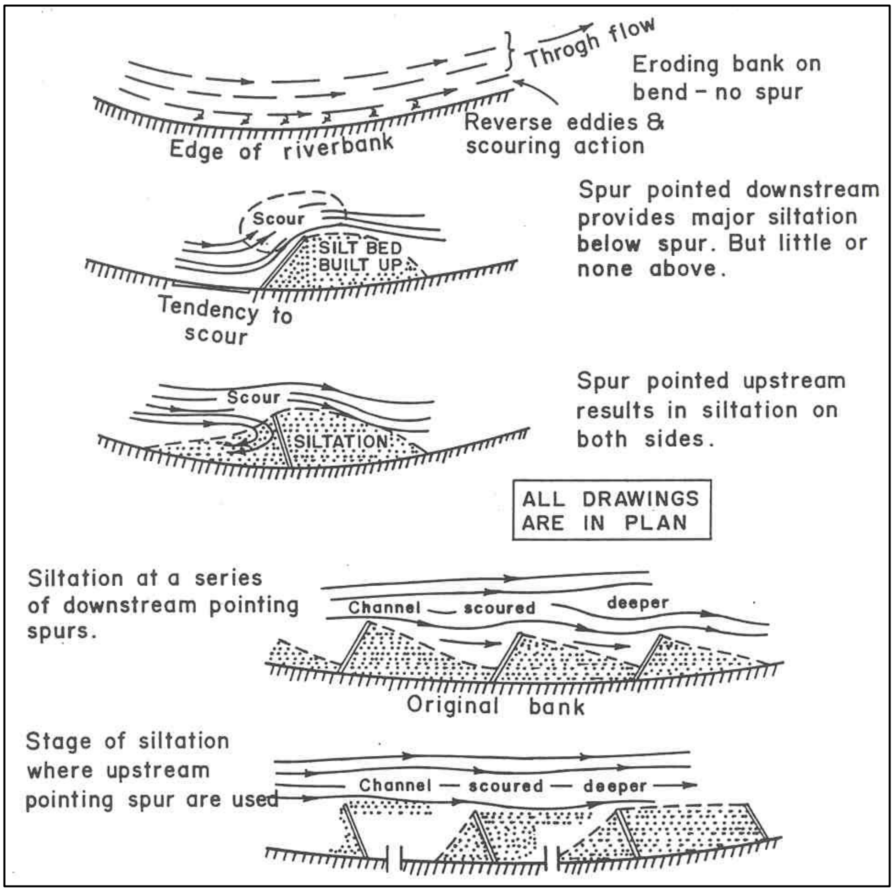


Fig. 6: The principle of spurs (storm, 1962)

Retards: The retards serve the purpose of dampening stream velocity sufficiently near the bank to prevent erosion of the banks or scour its toe by inducing deposition. There are three types of retards.

a) **Live hedges:** Live hedges are commonly employed in small streams and torrents successfully. Shoots of *Ipomoea carnea, Arundo donax, Hybrid napier, Jatropha carcas* etc. may be planted in trenches (60 cm wide) to serve as live hedges. *Arundo donax* (Narkul) as very strong root and shoot systems to resist the flood flows and is thus ideally suited for bank protection..
b) **Jacks:** Jacks are wooden posts of 8 cm dia and 2 to 3 m in length, which are placed in series along the eroding bank, and are tied together.
c) **Jetted posts:** These are green posts of 2 to 2.5 m in length and 6 to 12 cm dia which are erected along the actively eroding banks in two rows, 1.0 m apart.

Fuel, fodder, fiber and even horticultural plantations can be raised in the reclaimed lands along the banks of the torrents . Horticultural plantations of Lemon, Mosambi and Kinnow on the bouldery river bed in the Doon Valley could provide a net return of Rs.3000-7000 per ha (Arora and Vishwanatham, 1995).

RESTORATION OF DEGRADED LANDS BY RECLAMATION MEASURES

As a result of reclamation, degraded land becomes productive, water regime improves, lean flow period extends, flood peaks reduce and debris movement cut down. The vegetation improves and flora and fauna restores. Eco-restoration of mines area by soil conservation measures is presented in Table-1 (Juyal et al., 1995). Conservation measures also improved the water quality (Table-2).

Table 1: Eco-restoration of mined watershed at Sahastradhara (Dehradun)

Particular	Before treatment	After treatment
Vegetation cover (%)	10	80
Debris flow (t/ha/yr)	550	08
Monsoon runoff (%)	57	37
Lean period flow (days)	60	240
Channel slope (%)	38	20

By rehabilitation of the mined watershed, an amount of more than Rs.1 lakh per year was saved, which previously the State P.W.D. used to spend on removing the huge debris coming on the road.

Table 2: Water quality improvement by treatment of mine spoils area.

Site	Calcium	Magnesium (ppm)	Sulphate
Treated mine	74	34	138
Untreated mine	389	120	756
Water quality standards	75	50	250

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ANNEXURE-I

ESTIMATE FOR GABION WORKS

A sample estimate of gabion crate (3mx1mx1m) i.e. for 3 cm is worked out as below. However, the actual cost may vary depending on the prevailing cost of material (wire and stones) and labour.

A. Material and labour requirement

Material particulars	**Quantity**
1. G.I. wire* 10 gauge, cages with 10 cm x 10cm opening of 3 m x 1m x1m size.	17.92 kg say 18 Kg
Total surface area- 14 sq.m, weight of GI wire required @ 1.28 Kg/m2 (including wastage)	
2. Stone of size greater than 225 mm including wastage at site	3.75 cum
Labour	
1. Wire netter	1/2 No.
2. Semi skilled worker (Mason)	1 No.
3. Mazdoor	1 No.

* Hot dipped zinc coated galvanized iron wire conforming to IS: 280-1978 (with amendments, if any)

B. Cost

Material Cost	**Amount (Rs.)**
1. Cost of G.I. wire 18 Kg (10 gauge) @ Rs.25/Kg	450.00
2. Cost of stones 3.75 cum @ Rs. 80 /cum including quarrying , royalty etc.	298.00
Labour Wages	
3. Wire netter 1/2 No. @ Rs. 100/day	50.00
4. Mason (semi skilled) 1 No. @Rs. 70/day	70.00
5. Mazdoor 1No. @Rs. 60/day	60.00
Total (for 3 cm of gabion work)	**928.00 or say 930.00**
Therefore cost per cum of gabion is Rs. 310. The cost of gabion construction is almost 1/2 to 1/3rd of the cement masonry one.	

DESIGN AND CONSTRUCTION OF WATER HARVESTING STRUCTURES

K.P. Tripathi*

The term water harvesting refers to collection and storage of rain water and also other activities aimed at harvesting surface and ground water, prevention of losses through evaporation and seepage and all other hydrological studies and engineering interventions, aimed at conservation and efficient utilization of the limited water endowment of a physiographic unit such as a watershed.

Various aspects of water harvesting structures (WHS) are:

1. Construction of permanent/portable storage structures.
2. Farm ponds, either as surface storage for multiple uses or for augmentation of ground water.
3. Percolation tanks at appropriate sites based on geological consideration.
4. Reclamation/revitalisation of traditional water arresting structures.
5. Artificial recharge through wells.
6. Control of evaporation from surface water bodies.
7. Prevention of seepage losses in appropriate situations.
8. Enhancement of runoff through mechanical and chemical treatment in catchment area.
9. Construction of embankments over streams with low perennial flow
10. Sub-surface dams to arrest base flow of ground water.

Water harvesting structures are constructed for two purposes;

- Storing surface runoff so as to be used subsequently for supplemental irrigation, domestic use and for livestock/aquaculture.
- Storing surface runoff for ground water recharge.

The design and construction of water harvesting structures thus depends upon the above mentioned objectives in addition to other parameters viz; site condition, construction material and catchment characteristics .

Water harvesting systems have multiple objectives and provide benefits to the local community, thus minimising social conflicts. Micro-level water harvesting, storage and recycling systems are beneficial in providing protection and improving biological productivity of catchment as well as cropped area in the command. These have resulted in ground water recharge, floods and drought moderation, employment generation, improved socio-economic and rehabilitation of watersheds. The water harvesting structures have some life depending upon the objectives, investment made and material used. Normally it varies from 25 to 50 years. In addition to capital cost needed for its initial construction it also needs repair and maintenance budget as well. Loss of water through evaporation and seepage is also to be minimised because the reduction in water losses are equal to cost needed for new construction. Normally we do not pay much attention to control loses.

*** Principal Scientist (SWCE), Central Soil & Water Conservation Research & Training Institute, Dehradun-284 195 (Uttarakhand)**

Percolation ponds/tanks

Percolation ponds are small storage structures constructed across natural streams and nalas to collect spread and impound surface runoff to facilitate infiltration and percolation of water into the sub-soil for augmenting ground water recharge. The site should have highly porous soil and sites with heavy soils or impervious strata should be avoided. There should be a number of irrigation wells in the zone of influence up to about 1 km from the pond to benefit from the ground water recharge. The pond may be designed to store about one-third of the annual water yield from the catchment and to reduce the cost of 1 1/2 to 2 fillings during the monsoon are assumed. The general design principles of earthen dams are applicable to design percolation tanks.

Sub-surface water harvesting

Some specific locations in the valley portions of undulating topography in the hilly region yield sub-surface runoff due to different monolith layers of soil profile. This provides an ample scope of harvesting sub-surface flow, which is free of sediments. This can be achieved by constructing diaphragm ponds and/or sub-surface barriers to arrest and store sub-surface runoff for storage and recycling. In a similar experiment conducted at Research Centre, Udhagamandalam a polyethylene diaphragm of 2 m height and 30 m length was placed across the valley to impound water and reduce seepage. Thus a mini pond of 120 m^3 capacity was created behind the diaphragm with an earthen embankment on downstream side. RCC circular ring wells were driven at five places inside the mini-pond to a storage capacity of 10 m^3 especially to utilise water in the dry period. The harvested sub-surface runoff was lifted for irrigating the crops on bench terraces. This system was found to have good potential for hill regions on southern hills.

Collection wells in the swampy areas or near streams having perennial flow is another form of sub-surface water harvesting system. These shallow wells may be 2 to 4 m in depth and 1.5 to 2.0 m in diameter and the water is pumped from the wells for recycling.

Planning and design procedures

Water harvesting structures are site specific and designed to fulfill multiple objectives. General design procedure will include site selection, hydrologic, hydraulic and structural design. The surface water harvesting can be achieved through;

1. Dug out or excavated farm ponds (surface or sub-surface fed).
2. Small earthen embankments (including earthen gully plugs or nalla bunds or percolation ponds).
3. Embankment-cum-dugout ponds.

The planning and construction of these will follow certain general procedures, which are explained below:

(i) Determination of the volume of the water to be stored.
(ii) Catchment
- Should be large enough to produce required volume of runoff for storage.
- Should produce silt free runoff
- Should produce quality runoff water

(iii) Site
- Should be nearer to the field where water is to be applied.
- Impervious bottom in the water spread area in case of irrigation ponds.
- Pervious bottom in case of percolation pond

(iv) Suitable location for spillway is available
(v) Prepare the map of the catchment with present landuse, topographical features and proposed major land use changes, if any.
(vi) Compute 25 years return period peak rate of runoff.
(vii) Complete grid survey of the water sub-mergence area and draw height-volume curve.
(viii) Compute evaporation, seepage, conveyance and application losses of water.
(ix) Temperature, open pan evaporation, wind velocity and humidity data need to be compiled.
   - Soil profile in water submergence area is to be studied.
   - Method of water conveyance and application.
(x) Compute expected quantity of water needed to be stored adding the losses towards evaporation, seepage, conveyance and application to the quantity of water needed for irrigation, domestic and livestock/aquaculture.
(xi) Arrive at the height of the embankment at which required quantity of water will be available.
(xii) Add the height towards spillway depth (including free board) and consolidation @ 15% in case of earthen embankment.
(xiii) Design the cross-section, core wall, cut-off trench, berm, riprap, boulder pitching, grass soding, grass turfing, blanket, filter, toe wall etc. and find out the cost.
(xiv) Execute the work
   - Site cleaning
   - Foundation
   - Embankment
   - Spillway

Assessment of water requirement for surface storage

The irrigated crops are grown utilizing the ground water or canal water. In watershed management, the excess runoff is stored and recycled for providing only supplemental irrigation. Further this excess runoff water is also used to meet the water requirement of humans and cattle. The water availability and its requirement in any watershed/locality can be properly studied by drawing weekly rainfall and potential evapotranspiration/open pan evaporation.

In case of percolation pond, the capacity of the pond is not decided in advance rather the prevailing situation decides the capacity. In case of percolation ponds the embankment height is kept varying from 0.90 m to 2.5 or 3.0 m depending upon the soil availability at site due to creation of depression and shaping the site. The spillway design however has to be done very carefully.

Site selection for an irrigation and percolation pond

Very distinct difference between the site of irrigation pond and percolation pond is observed. The bottom of a percolation pond should be pervious whereas that of an irrigation pond should be impervious. The water submergence of a percolation pond should be larger (so as to have more area contact for infiltration/seepage) and that of an irrigation pond should be lesser so as to avoid excessive evaporation. The depth naturally becomes shallow in case of percolation pond and deeper in case of irrigation pond.

Definitions of common terminology

Storage capacity

The capacity of a pond is determined depending upon the expected runoff or water yield from the catchment, the purpose (i.e. for estimating demand), seepage losses and siltation in the pond. Rainfall - runoff relationships for the region are used in estimating runoff. On a conservative estimate, a value of 10 to 25 % of the annual rainfall can be expected to go as surface runoff in black, red and laterite soils.

Earth fill

Earth fill material should be impervious and have enough body to stable under the load imposed. A sandy clay soil is most desirable. If there is a variation in the fill material that is available, the more impervious material should be placed in the upstream two-third and that which is more pervious be used on the downstream one-third. Earth fill material should be free from sod, roots, brush and other deleterious material. The fill material should be spread in layers not exceeding 0.2 m thickness.

Foundation

The most satisfactory foundation is one, which consists of, or in underlain at a shallow depth by a thick layer of relatively impervious consolidated material. Such foundations cause no stability problems. It is sufficient to remove the top soil and scarify or disk the area to provide a bond with the material in the dam.

Where the impervious layer is overlain by pervious material and compacted clay cut off, extending from the surface of the ground into the impervious layer, is required to prevent possible failure by piping and excessive seepage.

Where the foundation consists of highly pervious sand or sand gravel mixture and any impervious clay layer is very deep, detailed investigation should be made and corrective measures will be required to prevent an excessive seepage and possible failure.

A foundation consisting of or underlain by a highly plastic clay of in consolidated material require a very careful investigation and design in order to obtain stability.

Water impounded on bed rock foundation seldom gives a cause for concern unless the rock contains fissures or crevices through which water may escape at an excessive rate. Whenever a rock is encountered a careful investigation is necessary.

Core wall

It is a centrally provided fairly impervious wall in the dam. It checks the flow of water in the section of the dam. Generally, the core wall extends from the ground level upto High Flood Level (HFL). The core wall may be constructed of various materials, namely; 1. Puddle clay; 2. Masonry; and 3. Concrete.

Cut-off

It is a fairly impervious barrier provided at the foundation in the Centre of the base of an earth dam. There is flow to water in the foundation under pressure. The cut off tries to increases the path of percolation. It generally extends up to the impervious rock bed if it is near or goes sufficiently below in the foundation.

Foundation cut-offs

Where the foundation consists of pervious materials at or near the surface with rock or impervious materials at a greater depth, seepage through the pervious layer should be reduced to prevent piping and excessive losses. Usually a cut off joining the impervious stratum in the foundation with the base of dam is needed.

A trench is cut parallel to the centre line of the dam to a depth that extends well into the impervious layer. The trench is extended into and arrive up the abutments of the dam as far as pervious material exists that might allow seepage under the embankment. The trench should have a bottom width of not less than 1.2 m but adequate to allow use to equipment necessary to obtain proper compaction. Its sides should not be steeper than 1:1. The trench should be filled with successive thin layers of relatively impervious material, each layer being thoroughly compacted at near optimum moisture conditions before the succeeding layer is placed. Any water collected in the trench should be removed before back fill operation are started.

Embankment side slopes

The side slopes of a dam depend primarily on the stability of the material in the embankment. The greater the stability of the fill material, the steeper the side slopes may be. The more unstable materials require flatter side slopes.

Saturation gradient

When the water is impounded on the upstream side of the dam, there is a head of water equal to the height of water stored. Under this head, water seeps in and percolates through the body of the dam. As protection water moves towards downstream, it looses head en-route.

Naturally, the head of water goes on decreasing towards the downstream end and it meets the base at some point. Thus the saturation line is the line of demarcation between saturated soil and unsaturated soil in the same section.

The slope of the saturation line is called saturation gradient. For stability of the dam it is essential that the saturation line should meet the base within the dam section.

Phreatic line in an earth dam

It is already mentioned that the saturation line is the line of demarcation between saturated and unsaturated zones in the earth dam. Similarly, phreatic line is the line which joins the points in the dam section, at which pressure is equal to the atmospheric pressure.

Breaching section in an earth dam

Overtopping of an earth dam by flood water causes failure of the dam by washout. Hence, every precaution is taken to avoid overtopping. To achieve this objective, a natural saddle on the periphery of the reservoir is selected. In the saddle, an ordinary retaining wall is constructed. The top of the retaining wall is kept about 1 m lower than the top of the dam. However, the top of the retaining wall is higher than Full Reservoir Level (FRL). When the water level in the reservoir rises dangerously, the flood water breaches the periphery at this section. To carry out the flow safely, good channel is provided below section. Thus the flood water finds its way out the reservoir without damaging the main dam. If a natural saddle is not available, the section can be constructed artificially at a suitable site away from the earth dam.

Berms

Berms at suitable intervals are essential. A berm on the upstream about 1.5 m below the minimum reservoir level to support the foundation of riprap on the upstream is the minimum required. Berms on the downstream slope serve the following purposes:

- Increases slope stability by increasing dam width.
- Reduces surface erosion by breaking the continuous downstream slope.
- Provides roadway.

Stone pitching

It is a protection provided to the upstream face of the dam. This protection extends from the natural surface to about 1 m above the HFL.

Stone pitching bears the brunt of water pressure and protects the upstream slope. It is constructed with stones firmly packed and embedded on the slope. The stones are laid perpendicular to the sloping face. The thickness of pitching varies from 0.3 to 0.6 m. The pitching is laid over a layer of murrum or gravel of 15 cm thickness.

It is also a protection provided to the sloping faces upstream and downstream of the dam to protect the slopes from waves, men, cattle, rains etc.

Blanket

It is a layer of impervious material laid at the natural ground level on the upstream side. It increases the path of percolation to reduce seepage pressure.

Filter

When the saturation line goes beyond the limits of the dam or when it meets the downstream sloping face, a layer of graded coarse material is provided in the dam section on downstream side at the base.

As the filter attracts the flow of water, the saturation line is brought within the limits of the section of the dam.

Sodding and turfing

It is a grass turf on the downstream sloping face of a dam to protect it from heavy rainfall etc. If the downstream face is unprotected, rills/gullies may be formed. The transplanting of grass slips over the exposed surface is termed as sodding, whereas pasting of grass cover along with subsoil at exposed surface is termed as turfing.

Free board

Free board is the added height of the dam provided as safety factor to prevent waves or runoff from storms greater than the design frequency for over topping the embankment. It is the vertical distance between the elevations of high flood level after the settlement has taken place. Normally 10-15 per cent is adapted as free board.

Minimum free board is provided so that the dam abutment is not overtopped due to:

- Wave action
- Settlement of dam more than the amount anticipated.
- Malfunctioning of spillway.
- Occurrence of inflow flood larger than design inflow flood.

Allowance for settlement

Settlement includes the consolidation of the fill materials and the consolidation of the foundation materials due to the self-weight of fill material and the increased moisture caused by the storage of water. Settlement or consolidation depends on the character of the materials in the dam and foundation on the methods and speed of construction. The design height of earth dams should be increased by an amount equal to 5 % of design height.

Borrow pit

It is advisable to take advantage of earth removed to fill in providing additional capacity for water storage. Where conditions are satisfactory, the bottom pit should be located immediately upstream from the tow of the embankment, to increase depth and capacity of pond. A minimum of 0.6 m of impervious layer should be best over any strata, if present. Borrow pits located outside the pond area should be selected so as to destroy the minimum of land and be dressed up at the conclusion of work.

Optimum moisture content

Even compacted soil contains water and air in small pores. Naturally, its density also depends on the percentage of volume of the moisture content and the air in small pores. Optimum moisture content is that percentage of moisture in the soil which gives maximum dry density when compacted with this percentage of moisture. If moisture content is increased or decreased, then the dry density of compacted soil reduces. To achieve the maximum weight for stabilizing earth dam under its own weight, it is very essential to consolidate the embankment with optimum moisture content.

Dug out ponds

Dug out or excavated ponds are the most common and simplest type of farm ponds for location having relatively small water requirement. It can be designed to fit into an individual farm or number of farms or as a village/community pond. These are usually constructed in a relatively flat area by excavating a pit or deepening/widening a natural depression and forming an embankment around it by the excavated earth (i.e. embankment-cum-dugout). Surface water ponds are most common, while ground water fed ponds can also be located where shallow sub-surface flow exists, as in the case of valley portions of mid slopes in the hilly terrains. Collection wells in Nilgiris are example of sub-surface water harvesting ponds.

Site selection

The site should have enough catchment to provide runoff sufficient to fill the pond. The low point of a natural depression is considered a good location. From economic point of view, a pond should be located where the largest volume can be stored with least earth work. Location should also have a favourable outlet condition for excess runoff disposal from the pond. The sub-soil should allow minimum seepage as far as possible. In case the seepage rates at the site are excessive, good fill material or lining material should be available in the vicinity.

The selection of a suitable pond site should be with preliminary studies of possible sites. Then only detailed estimate should be prepared.

Pollution of farm pond water should be avoided from drainage, from farm stead, sewage lines, mine dumps. Where this cannot be done successfully, it is recommended that water from such areas should be diverted from farm pond.

The studies conducted at CSWCRTI, Research Centre, Udhagamandalam have indicated that for storage capacity of 1 ha-m of pond water under different land covers with lateritic soils, the contributing catchment area varies from 8 to 20 ha. Irrigation requirement is estimated from depth and number of irrigations and area to be irrigated, while domestic and livestock demands are determined using local standards. Generally, a provision of 5 to 10% of the capacity is made for siltation.

Shape and size

Ponds can be constructed to almost any shape; however, a rectangular or square shape is preferred for its convenience. Dugout ponds are generally 2.5 to 4.0 m deep with side slopes of 1:1 or flatter. It could be of any length and width, depending upon the local site conditions, mode of construction and capacity.

Volume of a pond

The volume of a pond is arrived by using the following Formula:

$$V = \frac{d}{6} (A_o + 4 A_1 + A_2)$$

Where,

V = volume of pond, m^3
d = depth of pond, m
A_o = area of the pond at the bottom, m^2
A_2 = area of the pond at the top, m^2 and
A_1 = area of the pond at d/2 depth below the top of pond, m^2

Also,
$V = d\,(A_1 + A_2)^{1/2}$

Where,
V = volume of earth work, m^3
A_2 = area of the pond at the top, m^2 and
A_1 = area of the pond at bottom of the pond, m^2

Construction procedure

Clear the pond site and waste placement area of all vegetation. The excavation and soil placement areas are demarcated and excavation is done in the form of steps with successive steps conforming to designed side slope of the pond. After reaching the designed depth, the steps are scrapped to form a uniform slope. The slope of spread material should be no steeper than the pond side slopes.

Example 1:

Design a dugout pond for storing water required to provide one supplemental irrigation of 5 cm depth to 0.5 ha field. Estimate the cost assuming that the pond is to be lined with stone slabs.

Solution:

Step 1: Compute water requirement and capacity Irrigation requirement

$= 0.5 \times 5 = 2.5$ ha-cm
$= 2.5 \times 100 = 250\ m^3$

Assuming 20 % of storage (seepage and evaporation) losses

Losses = $250 \times 0.20 = 50\ m^3$

Assuming 10 % allowance for siltation = $250 \times 0.10 = 25\ m^3$

Design capacity of pond = $250 + 50 + 25 = 325\ m^3$

In this example, it is presumed that pond will have sufficient watershed area to contribute the required runoff.

Step 2: Design dimensions

Assume depth of pond	= 3.0 m
Side slopes	= 1:1
Bottom dimensions	= 7.5 x 7.5 m (Fig.3)
Top length	= 7.5 + (3 x 1)2 = 13.5
Top length	= 7.5 + (3 x 1)2 = 13.5
Area at top (A^2)	= 13.5 x 13.5 = 182.25 m^2
Mid length	= 7.5 + (1.5 x 1)2 = 10.5 m
Mid width	= 10.5 m
Mid area (A_1)	= 10.5 x 10.5 = 110.25 m^2
Bottom area (A_o)	= 7.5 x 7.5 = 56.25 m^2 .ls1

$$\text{Volume (V)} = \frac{[182.25 + (4 \times 110.25) + 56.2] \times 3.0}{6}$$

= 339.75 m

Hence, these dimensions can be accepted to provide 325 m^3 storage capacity.

Step 3: Surface area for lining

Length of each sloping side wall = $\sqrt{3^2 + 3^2}$ = 4.24 m

Surface area of one sloping side wall =

$$= \frac{(\text{Length at top + length at bottom})}{2} \times \text{length along sloping side wall}$$

$$= \frac{(13.5 + 7.5)}{2} \times 4.24 = 44.52 \text{ m}^2$$

Since the shape is square,

Surface area of all the 4 sides = 4 x 44.52 = 178.08 m^2

Bottom area for lining = 7.5 x 7.5 = 56.25 m^2

Total surface area for lining = 178.08 + 56.25 = 234.33 or say 235 m^2

Step 4: Cost estimate

(i) Earth work in excavation = 339.75 say 340 m^3

Cost of earth work @ Rs.25 per cubic meter for excavation from 0 to 3 m depth and its placement = 340 x 25 = Rs.8,500.00

(ii) Lining: Taking rate of 70 mm to 100 mm thick stone slabs and laying (rouged dressed) including cement pointing complete @ Rs.100 per sq.m

Cost of lining = 235 x 100
= Rs.23, 500.00
Total cost of pond = 8,500 + 23, 500 = Rs.32, 000

Seepage control

One of the problems of water harvesting ponds/tanks is high seepage of stored water from unlined ponds. Results of the sealant studies conducted in red soil region at Bangalore and Hyderabad reveal that soil: cement (8:1) to a thickness of 5 cm may prove suitable when sizable initial investment is not possible to go for brick./stone lining. The result of a study conducted with lateritic soils at CSWCRTI/Research centre, Udhagamandalam in small ponds revealed bitumen application (3 mm thick) as the effective, though a relatively costlier sealant. This was also tested for its durability in a large sizes field tank. Seepage losses were found to be 42 % of the unlined pond with soil: cement (12:1) of 5 cm thickness. For a small farmer with less affordability, soil: cement appears to be one possibility. Low density polyethylene (LDPR) sheets may also be tried in small pond, but they are costly.

Small earthen embankments dams

The term 'earth dam' denotes an embankment construction across a water course for diversion (i.e. diversion dam) or storage i.e. storage dam to store surface runoff for irrigation, ground water recharging or for other useful purposes or to store the silt. These are suitable for harvesting and collecting water across *nala* in common lands for multiple uses in promoting wasteland development and enhancing the productivity by conserving moisture and creating local water resources.

From an economic view point, a pond should be located where the largest storage volume can be obtained with the least amount of earth fill. This condition will generally occur at a site where the valley is narrow, side slopes are relatively steep and slope of the valley floor is mild with large deep basin. Such sites tend to minimise the area of shallow water. Except where the pond is to be used for wild life large shallow water should be avoided due to excessive evaporation losses and the growth of noxious aquatic plants. Where water must be used for irrigation, ponds should be located as close to the point of use as is possible.

Site selection

1. The site with narrow side slopes, steep and deep valley with wide valley floor above, permitting large storage volume with least amount of earth fill is the most economical.
2. Avoid large area of shallow water submergence to reduce evaporation losses where main purpose is irrigation.
3. Borrow material of good quality and in sufficient quantity must be available for the embankment.
4. Sub-soil should provide sufficient bearing power to prevent excessive consolidation displacement etc.
5. Site should be as close to the demand point as possible to minimise cost of water recycling and distribution network.

Survey and planning

1. Carry out the engineering survey of the selected site by laying the grids at 10 to 30 m interval depending upon the area.
2. Draw the contour map of submergence area.
3. Demarcate the borrow area to know the suitability for dam construction.
4. Locate the position of spillway at a suitable place having natural site, preferably it should be on firm ground.
5. Capacity between two contour = $\frac{\text{Sum of areas of the two consecutive contour}}{2} \times$ Distance between two contour

Design criteria for earth dam

Embankment top width

Empirical relations

$$W = \frac{H}{5} + 3.0 \text{ for low dams}$$

$$W = \frac{5}{3} H1^{/2} \text{ common practice}$$

Where,

W = top width (m)
H = maximum height of dam embankment (m)

Minimum width is generally dictated by roadway requirement
Normally the top width of the embankment is fixed by the equation

$$W = \frac{H}{5} + 1.5$$

Where,

W = width of crest, m and h
H = height of embankment

Where the top of the embankment is to be used for a road way, the top width should provide for a shoulder on each side of the travelled way to prevent travelling. The top width in such cases should not be less than 4.5 m. Recommended top widths for earthen embankments of different heights are given in Table 1.

Table: 1. Recommended top widths for earthen embankments

Height of dam, m	Top width, m
Under-4	3.25
4 to 6	3.50
6 to 8	3.75

Construction technique

Embankment is constructed in a step like to achieve uniform side slopes and compaction after adding adequate moisture. The embankment is raised in 0.30 m steps.

Design steps

1. Determine peak rate of runoff and volume of runoff expected from the watershed for the given rainfall, soil type and land use. Peak rate of runoff may be computed by rational formula or hydrologic soil cover complex method. Knowing the rainfall depth and values of runoff coefficient K (i.e. runoff to rainfall ratio) for area under different land uses, calculate the runoff volume as below:

$$\text{Volume of runoff (V)} = \frac{KPR}{1000}$$

Where,

R = runoff volume, ha-m
K = runoff coefficient (varies from 0.3 to 0.5 for urban areas, 0.05-0.20 for forests and 0.05 - 0.30 for parks, farms and pastures)
P = rainfall depth, mm and
A = watershed area, ha

For design of storage dams, normally the seasonal rainfall may be considered.

2. Decide the adequate storage capacity (storage dam design is considered for this exercise) as a sum of live and dead storages. Live storage is provided to store expected runoff from watershed as obtained above. Dead storage is provided for storing sediment as per the expected sediment yield from the watershed during the life of dam.

3. Fix up the height of dam to provide the required storage (i.e. dead, live and temporary storage). It is decided from the storage-elevation (depth) relationship of submergence area. While fixing the height, care should be taken to see that the adjoining good agricultural land and property are not submerged. This should also include depth of flood flow provided to the spillway.

Total height of the dam = High flood level + free board + settlement or consolidation Allowance (i.e. 5% of design height)

Normally 10-15 % of height of full reservoir level is provided as free board to take care of wave action. A minimum of 0.60 m is to be provided as free board for small dams.

4. Top width of the embankment (W) is determined as (H/5 + 1.5) where H is the height in meters. Usually a minimum of 3 m top width is kept, but if it is to be used as road, 3 to 4 m width is provided.

5. Decide the side slopes to be provided on upstream and downstream sides depending upon the soil type from the Table given below:.

Type of material	Upstream slope	Downstream slope
Homogeneous well graded material	2.5:1	2:1
Homogeneous coarse silt	3:1	2.5:1
Homogeneous silty clay or clay height less than 15 m	2.5:1	2:1
Height more than 15 m	3:1	2.5:1
Sand or sand and gravel with clay core	3:1	2.5:1

6. Determine base width of the dam with known values of top width, height and side slopes. Cross section of a typical water harvesting dam is shown in.

In case of homogeneous earth fill dam, ensure that the seepage or phreatic line is within the base of the dam otherwise dam is not safe. If phreatic line meets the d/s face flatten the d/s slope and or provide berm of required length on the d/s face in order to keep the phreatic line within the base of dam. To ensure better safety, provide a stone filter on d/s side at toe.

Approximate values of the seepage line slope for different soils

Type of soils	Seepage line slope (H:V)
Clayey soil	3:1
Sandy loam soil	5:1
Sandy soils	6:1

A core wall of puddled clay may be provided to the central portion of the embankment up to the height of full reservoir level where the fill material of good quality is not available.

7. Determine the size of cut off trench to be provided parallel to centre line of dam in the foundation for stability of dam. Depth of trench may be kept 1 to 2 m in small dams. But it should extend up to impervious layer. A minimum of 1.2 m bottom width is sufficient, provided side slopes is 1:1.

DESIGN AND CONSTRUCTION SPECIFICATIONS OF FRESHWATER FISHPONDS

K. K. Sharma*

1. Introduction

Aquaculture is the art and science of breeding and growing of aquatic biota. Specially 'the aquacultural engineering in it' is the application of engineering principles and procedures for development of the aquatic condition for enhancement of production in the system. Though the aquaculture is in practice since more than 2000 years 'but the realization of its role in meeting the world protein food demand to develop it as an industries is more recent. The over growing human population of our country demands speedy enhancement in production of fish and prawn to provide high quality protein food and valuable foreign exchange. Our country is having a very rich potential for the development of aquaculture in inland water sources like ponds; tanks lakes and rivers etc. Out of 2.25millions/ha or freshwater ponds and tanks; only about 0.90million ha are being utilized. Adoption of scientific aquaculture with appropriate engineering input is highly essential at the moment to meet the increasing pressure on demand of aquacultural products by utilizing all types of water bodies. For all such development the aquacultural engineering is required to be played an important role. The essential engineering studies and investigations conducted prior to finalisation of detailed design and layouts of different aqua-structures for establishment of aquacultural complex are briefly discussed in this chapter.

2. Site selection

To be profitable, an aquaculture pond must be sited properly and designed for efficiency. An inaccessible location, leaks in the pond, poor seining conditions, or lack of good quality water will doom an aquaculture enterprise to failure. To be profitable, an aquaculture pond must be sited properly and designed for efficiency. An inaccessible location, leaks in the pond, poor seining conditions, or lack of good quality water will doom an aquaculture enterprise to failure. Ponds do not have to be built on land as flat as the delta regions. On rolling terrain the annual rainfall may be enough to completely fill and periodically recharge production ponds. Such watershed systems are not so dependent on groundwater. They also act as flood control reservoirs and can greatly reduce erosion on land previously scarred with unsightly gullies. Watershed ponds are constructed by building dams across valleys to form reservoirs that store rainwater. Some aquaculture facilities have large reservoirs that, in turn, fill smaller ponds with captured runoff. Considerable thought and planning should go into selecting sites for commercial fish production ponds. Construction costs ease and cost of operation and productivity can be greatly affected by the site selected.

The freshwater fish and prawn are the most suitable species for cultivation in tropical and sub-tropical climates. To delineate suitable cropping pattern and management measures for obtaining optimum sustainable fish production in different climatic regions, selection of suitable site and proper layout of the fish farm are prerequisites.

*** Senior Scientist (SWCE), Central Soil & Water Conservation Research & Training Institute Research Centre, Chhalesar, Agra- 282006 (Agra)**

Hence, site selection for a fish farm depends mainly on climatic conditions along with other important factors such as topography of the area; soil type; source, quality and quantity of freshwater. The quality of freshwater derived from underground sources (tube well) should be checked for hardness (carbonates, bicarbonates, sulphates, chlorides, etc.), iron manganese and other heavy metals. The soil at the site should be tested for any residual pesticides. The soil texture should be of sandy-loam or sandy-clay loam or silty-clay loam with more than 85% water retention capacity. According to the Indian Roads Congress (I.R.C) the particle size of different textural constituents of soils are as follows:

Gravel	-	2.0 mm
Coarse sand	-	0.2-2.0 mm
Find sand	-	0.02-0.2 mm
Silt	-	0.002-0.02 mm
Clay	-	below 0.002 mm

Seepage in fish ponds is one of the most important factor required to be studied properly, while initial site selection procedure is followed. Investigations conducted on the design and construction of some of the existing fish and prawn farms in different regions of the country indicated that they are not profitable from a commercial point of view due to improper planning. The main reasons of failure of many such farms are because of severe seepage problem at the pond surface and due to lack of suitable water intake and management system. Further, no due attention is also given to investigate the underground water source which could balance the water management problem to some extent in such cases. Hence the important aspects related with selection of an appropriate site and the remedial measures of seepage problem in fish farms are discussed in the paper.

Watershed ponds are usually filled by surface runoff from an area above the dam. This area, the watershed, can be estimated by drawing a line on a topographic map that follows the ridge lines forming the perimeter of the watershed. The watershed area and pond acreage can be roughly estimated using a planimeter. The entire watershed area of a proposed pond must be investigated to determine whether runoff might be polluted. Large chicken and hog farms, extensive areas of row crops, grazing livestock, industrial sites and other water quality hazards in the watershed could preclude the operation of a watershed pond. Springs or streams can be used as a water source. Large streams flowing through watersheds may require some kind of diversion device. Streams can be contaminated with wild fish or manmade pollutants, so it's a good idea to get the water tested before construction begins. Also, large inflows of soft water in acid soils may hinder any long-term remedial effects of liming.

The availability of abundant and assured quantity of good water at low cost is a basic need for proper planning and designing of fish farms. Therefore, it is desirable to construct ponds along irrigation canals, springs, nullahs, lakes and convenient to construct ponds in water logged areas, commanded areas or in marginal lands. In these areas comparing with other locations, construction of ponds is much cheaper mainly due to its limited depth of cutting. For example, a pond of 100m x 40m size of water area requires 3251.6 m^3 of earth to construct around a dyke of 2 m high above ground level (G.L) with side slopes 2:1 and crest 1.5 m. Similar quantity of earth (3267.5 m^3) is obtained from 1.1 m depth of pond cutting and maintains 2.5 m of required pond water depth excluding 0.6 m free board. The following dimensions are given to know the details of the dyke/pond section of the above case (Fig. 1).

Pond size at water level	-	100 m x 40 m
Pond size at ground level	-	94.4 m x 34.4 m (earth cutting starts)
Pond size at bed level	-	90.0 m x 30.0 m
Dyke and pond slope is	-	2:1
Central length of dyke at GL	-	295.6 m

Prisimodial formula adopted to derive pond earth excavation

i.e., volume [V=D/6 (A+4B+C)]

Where,

V=Volume of earth is excavation in cubic metres
A=Area of ground level from where earth cut starts, in m^2
B=Area at mid-depth of cutting in m^2
C=Area at pond bottom, in m^2
D=Depth of excavation, in m.

In this case the water depth is 1.4m (above G. L.) more than the excavated depth 1.1 m totaling to water depth 2.5 m and this is only possible in irrigated/water logged areas, where surface water level is always maintained above G.L., due to irrigation or percolation from channels. Two meter high dyke above G. L. may not required, but sometimes it is suitable to balance the earth required for dyke with the quantity of earth excavated from the pond.

When it is difficult to get the water table near the G. L. throughout the year, it is necessary to cut deeper in view of locating water for a longer period which leads to higher expenditure owing to greater excavation and utilization of excess earth. However, full consideration is to be given to the effects of floods, sudden accumulation of water due to heavy rains, in case ponds are constructed in low-lying areas to get the above water holding benefit due to less excavation. Construction of fish ponds in hilly areas, relates to factors like (i) availability of large catchment areas, (ii) availability of impermeable (non-porous) soil strata at pond bed level, and (iii) occurrence of sufficient underground water at low depth. In this case proper attention is required to construct escape/by pass channels with ponds inlet and outlet structures, so that farm ponds are not damaged from flood or heavy rainfall during monsoon.
Under rainfed fish farming systems, the resources management is to be done on watershed basis. Creating the irrigation potential through runoff harvesting can ensure the sustainability of the production system. Hence the site selected in rainfed areas should have adequate catchment area for the water harvesting structure at the upper zone of the farming complex.

The amount and quality of water entering the pond from the surrounding watershed is dependent on several factors—slope, soil type, vegetative cover and the amount of precipitation. There are no set criteria for determining whether a watershed is sufficient for a given size pond, but there are some general rules. Watersheds containing mostly pasture with heavy clay soils may supply more water from small lands. At the other extreme, timberland on sandy soil may require maximum area. Excessively large watersheds can be just as problematic as limited watersheds. Too much water may dilute water amendments such as lime and salt, allow valuable fish to escape during floods, and make it necessary to install expensive flood or diversion devices. Ponds with excessive watersheds also may fill in faster with sediments, requiring frequent and costly renovations. An undersized watershed may cause pond water to remain shallow, allowing weeds to get a foothold and preventing the use of emergency aeration devices when fish become stressed.

Soils at the pond site have the important role in water quality and retention. Soils are porous mixtures of inorganic particles, decaying organic matter, air and water. They also contain a variety of living organisms. The pH and mineral composition of soil have a direct effect on the acidity and presence of toxic metal ions in water supply. As most of the soils are mixtures of sand soil and clay, the water retention in ponds is dependent on them. The soil with more percentage of clay retains water for longer period (Stern, 1979). The soils with low infiltration rate are most suitable for prawn/fish pond construction. A soil having 15-50% clay, 5-40% silt and 25-55% sand is normally preferred for pond construction. The infiltration rates of different types of soils are as follows:

Soil type	**Infiltration rate (mm/h)**
Clay	1-5
Clay loam	5-10
Silty loam	10-20
Sandy loam	20-30
Sand	30-100

As far as possible, permeable soils are avoided for pond construction and the loss of water by seepage poses a great problem in pond water management. Laboratory analysis of soils, collected from different parts and depth of site should be done before planning and designing of fish farm construction.

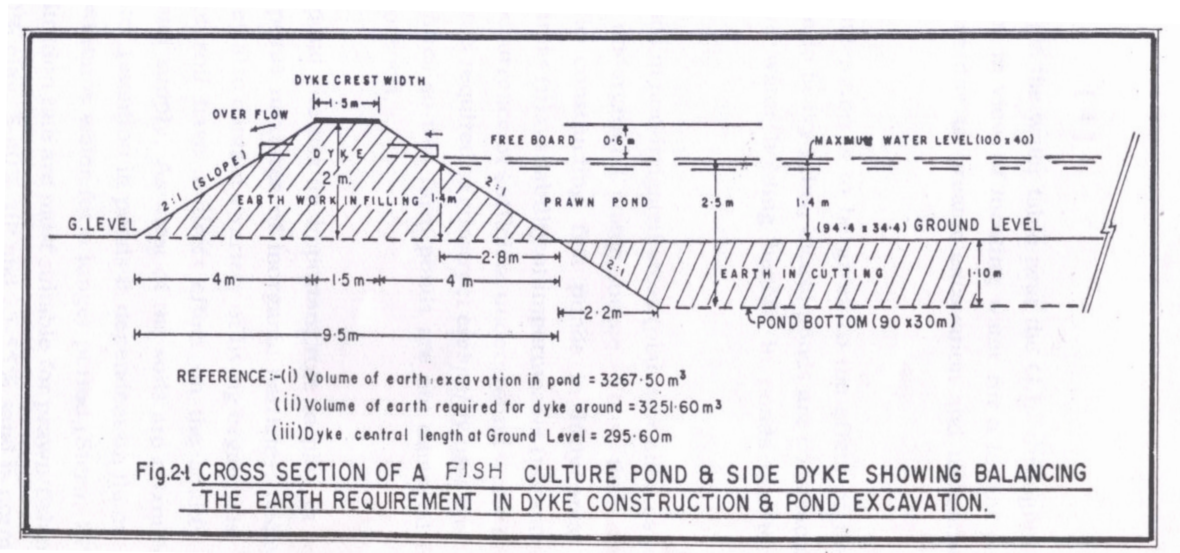


Fig. 1: Cross-section of a fish culture pond and side dyke showing balancing. The earth requirement in dyke construction and pond excavation

The topography or the surface features of the area proposed for fish farm construction is one of the most important factors for designing the ponds and other farm structures. The site with gentle sloping to one side (about one percent) is ideal for laying out the farm structure. For large farm area detailed engineering surveys are most essential for proper planning.

The other related factors in this regard required to be considered are mentioned below:

- Climatic condition
- Species to be cultured
- Sources and availability of stocking material
- Type and scale of the project including production target and area required.

- System of culture to be adopted i.e. whether intensive, semi-intensive or extensive.
- Operational method i.e. whether monoculture, polyculture or integrated culture
- Effect on the environment due to the project implementation
- Total development plans of the project area
- Availability of the land, ownership and cost of the land including the legal restrictions and rights.
- Accessibility of the site i.e. proximity to all weather road and rail including telecommunication facilities.
- Availability of electricity and unit power cost.
- Cost and availability of construction material, equipment and labour.
- Cost and availability of manpower, equipments, feed etc. needed for running the fish farm.
- Location of market for produce and determination of demand including transportation preservation and storage facilities.
- Information on local financing methods or credits.
- Social and political acceptance.
- Reasonable amenities for the permanent staff i.e. school, medical and shopping facilities.

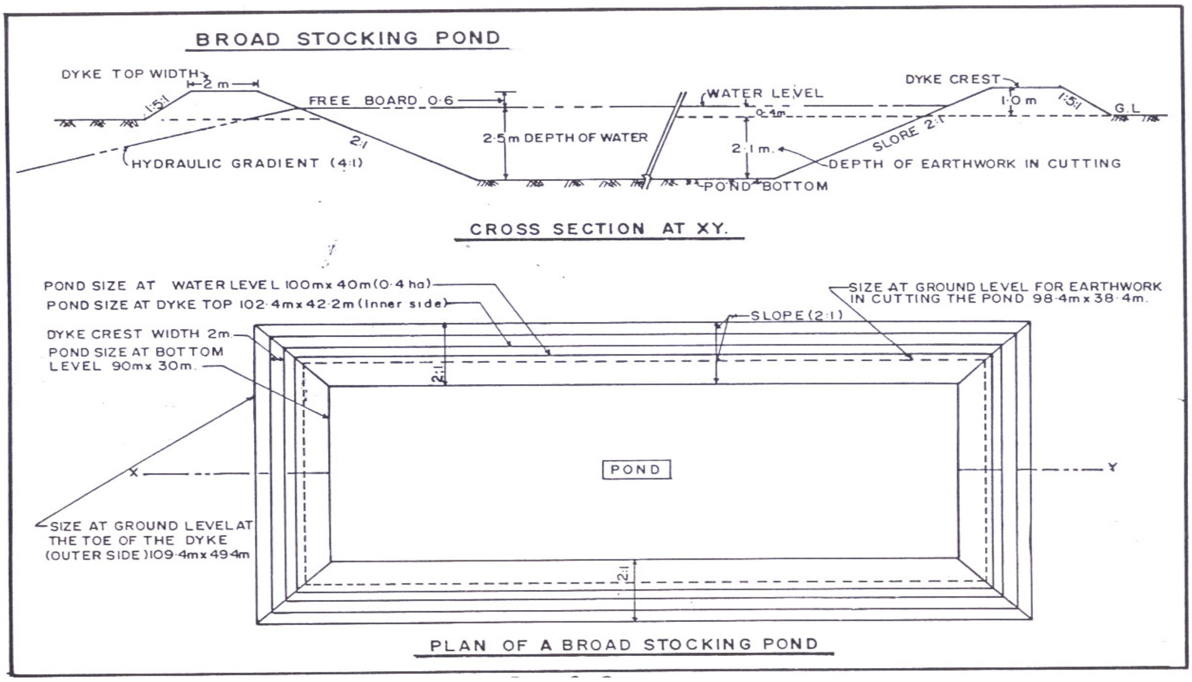


Fig. 2: Broad stocking pond

In connection with site selection the following studies are required to be undertaken prior to finalization of site plans and designs for construction programme of the farming complex.

- Study on climatic condition of the site
- Study on site seepage and evaporation loss
- Study and investigation on sources of water
- Study on site soil quality
- Test on safe bearing capacity of soil
- Survey on topography point of view

3. Layout and design of ponds

The pond orientation should take into account of the direction of the prevailing wind. The longer sides of rectangular ponds should be oriented parallel to the general prevailing wind direction (most probably south to north) to increase the pond water aeration as a result of wind diffusion through increased surface turbulence.

Referring to contours (level of the ground), the larger ponds should be positioned on lower contours and smaller ponds like nurseries requiring less depth may be positioned proportionately higher levels in view of limiting the depth of earth in excavation to make the construction economical. Farm buildings like hatcheries, office, store, etc. should be laid out on higher lands in the area. The water supply system should be straight and short with smooth bends. The layout of channels and dykes are fitted as closely as technically possible for existing land slopes and undulation Channels should be at a suitable contour for making possible of gravity flow to all sections of farm area. Farm discharge outlets along with main drainage channel should be located at lower level of site, which is also connected with other catch water drains in the farm. Used water from the culture ponds should have provision of drainage to ensure that it is not recycled back to the ponds (Upadhyay, 1994). The wells and tube wells should be located at suitable locations referring to the study of underground soil-water strata of the proposed site. Necessary test-borings are done to ensure the availability of water layers under the ground.

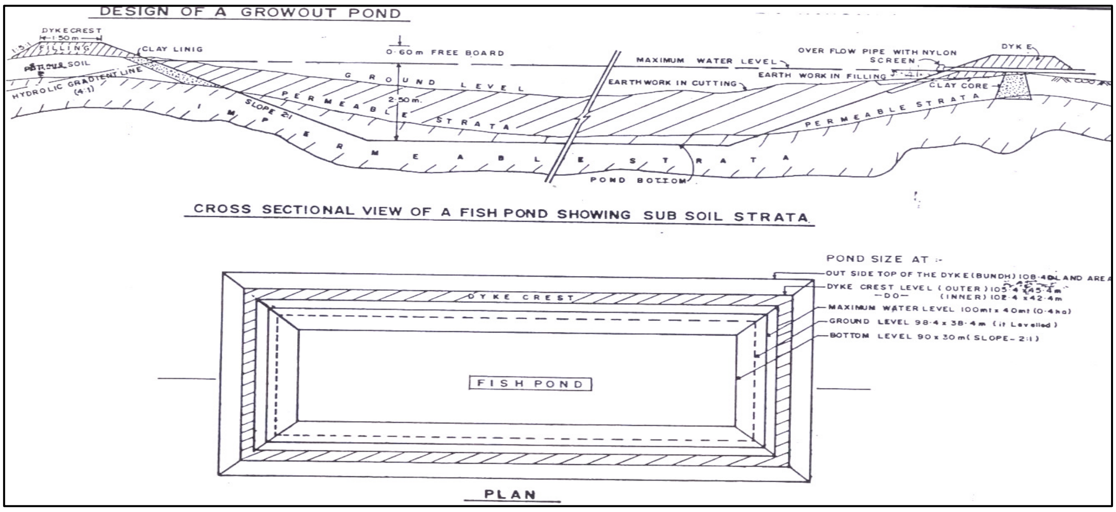


Fig. 3: Design of a growout pond

The design of pond should be such to have maximum net water area for culture, and the dyke section is designed perfectly to its required size, avoiding unnecessary over dyking of the excess earth from the pond excavation. In case most part of the area is waterlogged or swampy, it is better to plan for larger ponds limiting the width to 40-50 m to help in management and to avoid operational difficulties. It is always better if the farm layout and design permits complete drainage of the ponds during the production process and specially in the rainy season.

3.1 Shape, size and type of ponds

The pond shape and size mainly depends on the purpose of its use, whether it is for nursery, rearing, grow-out or for any other culture system to be employed and also upon the topography of the area. Ponds can be constructed different shapes such as circular, square, rectangular and triangular. Circular and square shape ponds are economical from the construction point of view, but large circular and square size ponds are not suitable from management and operation point of view, as the circular ponds create problems in layout. However, small square and rectangular ponds are suitable for nursery and rearing purposes. The larger ponds preferably rectangular ponds are more suitable from management point of view, as they have a large water surface for the effect of the wind which maintains a higher level of dissolved oxygen and enables mixing of upper and lower water levels.

For aquaculture mainly two types of ponds preferably square and rectangular are required and accordingly one type is used for nursery and other is used for growth of fish/prawn. The suitable size for nursery pond is 20m x 20m on 10 m, and for grow-out ponds 20m x 40m, 25mx50m, 25m x80m, 30mx100m, 40 mx100m on 200m, 40mx250m. Limiting the maximum width to 40m the length of the pond may be increased as desired. Considerable increase in width only creates culture management problem. The detailed design of an one acre (0.4 ha) pond is shown in Fig. 3. The design of grow-out ponds (Fig. 4, 5 and 6) and nursery pond (Fig. 7) are also given.

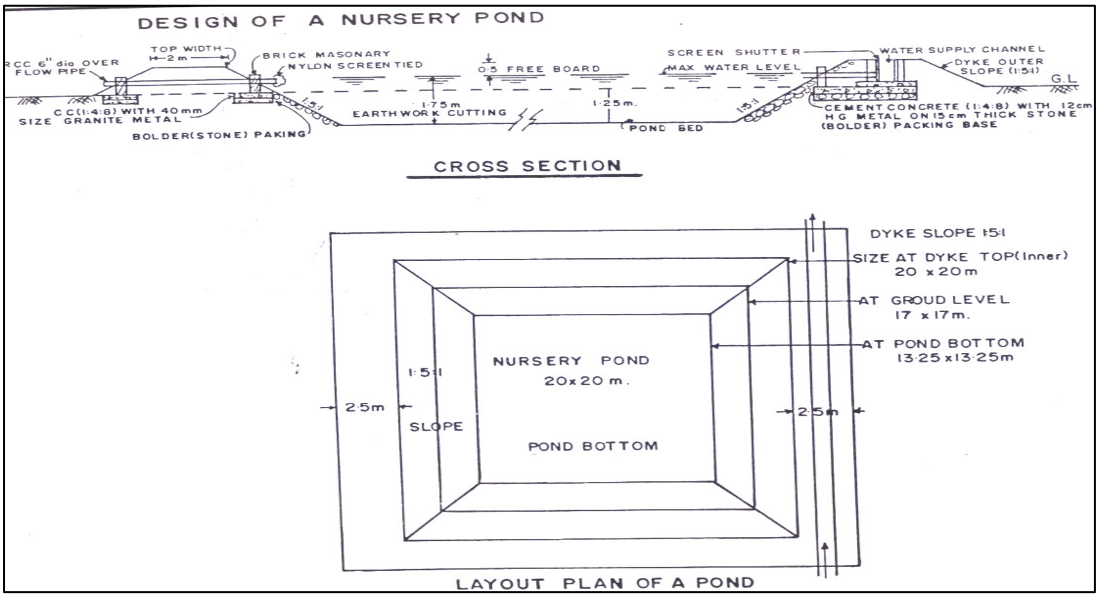


Fig. 4: Design of a nursery pond

3.2 Pond bed

For Aquaculture purpose the pond bed should be flat with an uniform slope. The pond bottom is provided with a slope between 1000:1 and 1000:5 towards the drainage outlet to facilitate the water flow during culture, harvest and drainage. The pond bottom may be designed above or below the ground water table as per the site condition, requirement and economic point of view, but it may be considered that, effective drying of pond bottom is essential for pond preparation. A well constructed pond is normally designed to drain out the water completely.

3.3 Pond depth and water level

Depth of a pond has an important bearing on the physical and chemical parameters of water. It is established that below 3-4 m water, there is not much photosynthetic activity to keep the deeper water oxygenated and water temperature is low containing less plankton. Therefore, 2-3 m water depth is desirable for larger ponds, while 1-2 m is suggested for small ponds which are used for nursery purposes. As per the present state of culture practices, suitable pond depths excluding free board are suggested below:

Ponds	Depth of pond (m) water logged/irrigated areas	Rainfed (plains and hills)
Small ponds (nurseries)	1.0-1.5	1.5-2.0
Large ponds (Grow-out/rearing/stocking)	2.0-3.0	2.5-3.5

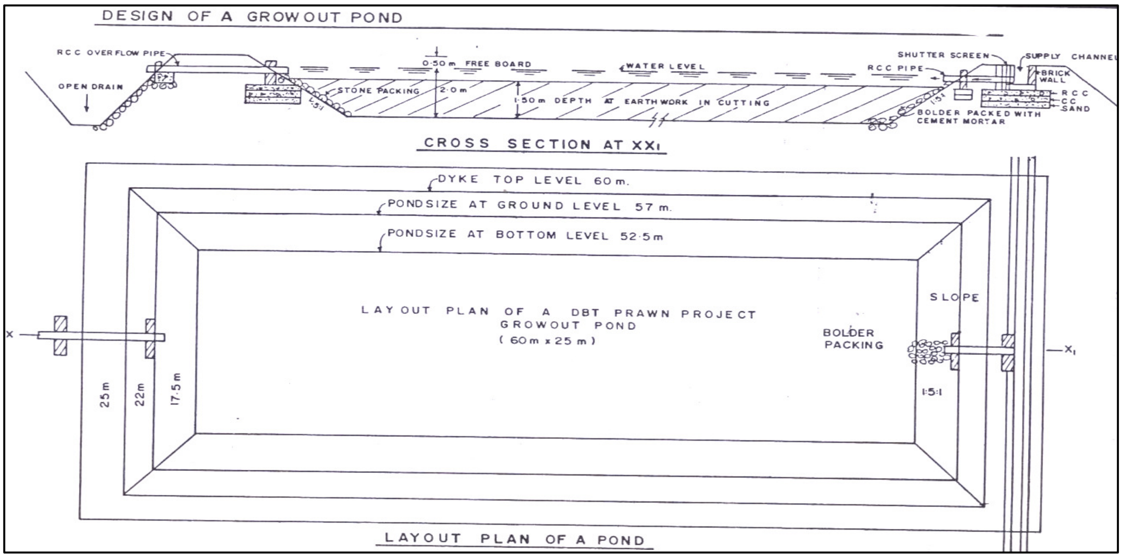


Fig. 5: Design of a growout pond

3.4 Free board

Free board is the additional height of the pond dyke above maximum water level. It is generally provided as safety factor to prevent overtopping from wave action, heavy rainfall and for other causes. It is the vertical distance between the elevation of the water surface in the pond at designed depth and the elevation of dyke/embankment after dyke settlement.

A free-board of 0.5-1.0 m is usually necessary to keep the carps/prawns safe from water management point of view. Therefore, in culture ponds at maximum water level an overflow or outlet arrangement is provided.

3.5 Pond dykes (Bundh)

The design of the dyke should be strong enough to hold the water upto the maximum level and be safe against hydraulic pressure. The stability of the dyke should be checked by drawing the hydraulic gradient line (slope of seepage line). The base should be sufficiently wide, so that the seepage line do not appear above the toe on the downstream side of dyke. It is desirable to have earth of about 0.3-1.0m above at downstream of the dyke to guard against any at percolation through the dyke. The base width at bottom of dyke on the depth of water in pond and top width depends on the type of soil. Approximate value of the slope of the seepage line are given below.

Type of soil	Slope of seepage line (horizontal/vertical)
Clayey soil	3.1
Sandy loam soil	5.1
Sandy soil	6.1

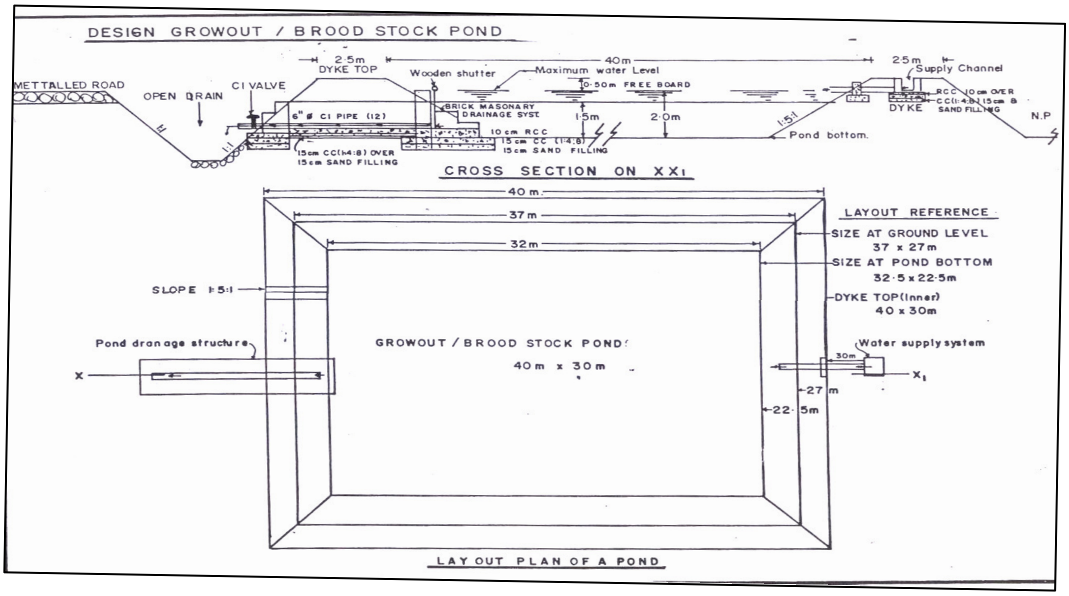


Fig. 6: Design of growout/brood stock pond

Berms are constructed at dyke base to provide additional stability to dyke or when there is excess soil. Pond dykes are generally constructed by using earth only. In some cases masonry, concrete or R. C.C. dykes are also constructed. Earth dykes with or without lining are most economical, though they occupy more space than concrete or R. C.C. The layout of the dyke and pond should be marked properly and a complete profile of the dyke section should be given at certain intervals at ground as per design to facilitate proper construction of the structure.

3.6 Dyke foundation

The top soil in the dyke profile at the ground level normally contains a large amount of vegetation and other organic materials which may be removed to a minimum depth of 10-15 cm to prove a good bond with the excavated and soil to be kept in the dyke bed. To construct a safe earthfill dyke, the foundation must be clayey or sandy clay impervious layer, if the foundation consists of pervious material, there is every chance of water seepage from pond to downstream side causing dyke failure and water loss in pond. In this case, a cutoff is required to join the impervious layer below ground level. A trench is cut along the centreline of the dyke bed, deep enough to extend well into the impervious layer. The bottom of the trench should not be less than 1.3 m wide and the sides should not be steeper than 1:1. the trench is filled with thin layer of impervious materials, and is compacted thoroughly at optimum moisture conditions before the next layer is placed. The most common kind of cutoff is made of compacted clayey material. The dyke or ground constructed with available porous material, a clay core or clay lining (Fig. 4) is provided to make the dyke water tight.

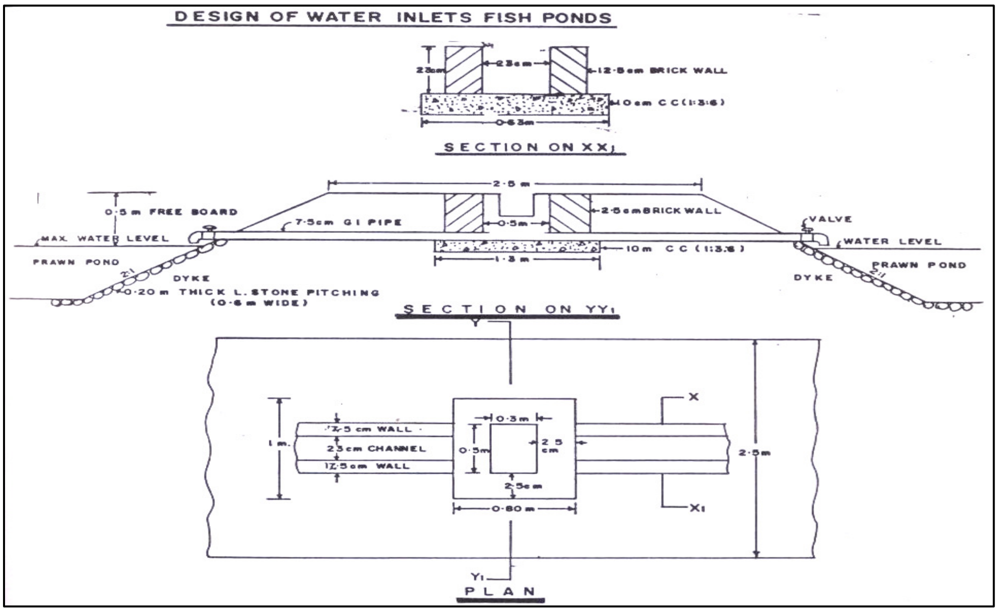


Fig. 7: Design of water inlets fish pond

3.7 Dyke top width

The dyke top (crest) width is decided by taking its uses into account. Generally 1.5-2.0 m is adopted. A much wider crest is required for the dyke which is used for the movement of vehicles. The wider crest enhances not only a comparatively larger area for dyke, but also an adequate volume of earth materials involving expenditure. The dyke less than2.0 m high, should have a minimum top width of 1.5 m. The top width vary as per the increasing height of the dyke. The recommended minimum top width for earth dyke/embankment is as given below:

Height of dyke/embankment (m)	Minimum top width (m)
Under 2.0	1.5
Under 2.5	2.0
2.5-5.0	3.0
5.0-8.0	4.0

3.8 Dyke side slope

The side slope of pond and dyke is necessary for stability of the dyke. The flatter the slope, the more stable it is. The outer and inner slope of the dyke depends on soil texture and site conditions. Usually, a slope between 1.5:1 and 2:1 is adopted in most of the cases for general purpose. It has been observed that, the dyke slope steeper than 1.5:1 has excessive erosion. As it depends on the class of soil, therefore, the minimum required slope for different soil textures is as follows:

Type of soil	Slide slope (horizontal/vertical)
Clay soil	1:1-1.5:1
Loamy soil	1.5:1-2:1
Sandy soil	2:1-3:1

3.9 Water supply and drainage system

Adopting an appropriate water supply and drainage system to culture ponds/farms is one of the most important considerations. Moreover, water change in a culture system is very much essential to reduce the byproducts of metabolites and to dilute disease causing agents. It is generally considered a good practice to exchange 10-25% of water at weekly/fortnightly intervals from the culture ponds. The detail design of supply and drainage system may be made as per the detail survey conducted in regards with existing source of water i.e. irrigation canal, river and natural water source and local drainage system.

WATER BUDGETING AND MANAGEMENT FOR FISH FARMING IN EARTHEN PONDS

K. K. Sharma*

Introduction

Indian aquaculture has demonstrated a six and half fold growth over the last two decades, with freshwater aquaculture contributing over 95 percent of the total aquaculture production. The production of carp in freshwater and shrimps in brackishwater form the major areas of activity. The three Indian major carps, namely catla (*Catla catla*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus mrigala*) contribute the bulk of production with over 1.8 million tonnes (FAO, 2005); followed by silver carp, grass carp and common carp forming a second important group. Average national production from still water ponds has increased from 0.6 tonnes/ha/year in 1974 to 2.2 tonnes/ha/year by 2001–2002 (Tripathi, 2003), with several farmers even demonstrating production levels as high as 8–12 tonnes/ha/year. The technologies of induced carp breeding and polyculture in static ponds and tanks virtually revolutionized the freshwater aquaculture sector and turned the sector into a fast growing industry.

Fish culture is a water-intensive endeavor and requires much more water than conventional agriculture (Boyd, 1982). The current expansion of freshwater aquaculture in the India may require large quantity of freshwater either groundwater or surface water. There already exists concern of adequate water supplies for traditional agriculture. Further, uncertainty in monsoon rain, scare and limited availability of freshwater resource has forced in rethinking wise-use of freshwater in aquaculture sector to increase water productivity. Now a day's water is increasingly becoming less available and costly to procure. World in general and India in particular, the freshwater supply and reserve is now under threat due to increased population following by increased demand of water in agriculture, aquaculture, industry and domestic sectors. Unplanned wasteful use of water in aquaculture is limiting further development of this sector.

Water budgeting is very important for estimating the total water requirements of ponds, flow through facilities, hatcheries etc. and also to estimate and predict the fish culture potential for different regions. This paper presents the consumptive water requirements for freshwater pond aquaculture at study site. Though the hydrology of pond is depending on local conditions, soil type, construction methods, seepage, evaporation, rainfall and other criteria. However the knowledge or protocols about estimating water use for pond aquaculture developed in this study could be applied in the same agro-climatic region of the country.

Experimental designs and hydrological measurements

The study was conducted in three numbers of rearing fishponds of 0.1 ha during year (2007-08) and in nine numbers of ponds of size 0.04 ha during 2008-09. The size of ponds was rectangular in shape. The depths of water in pond were maintained between 1.0m to 1.2m. The water level was maintained approximately 5 cm below the out flow pipes provided to each ponds.

*** Senior Scientist (SWCE), Central Soil & Water Conservation Research & Training Institute Research Centre, Chhalesar, Agra- 282006 (Agra)**

To measure water stages in ponds, a water level recorder was fabricated which consist of a stand pipe and glass cylinder with scale for measurement. The water level is measured inside the measuring cylinder to eliminate the effect of wind wave on stage. These instruments were installed inside the each ponds and data were taken daily between 7.30 to 8.00 hrs. Evaporation pan of class A was installed on dyke of pond for measurement of evaporation losses. Pond evaporation was estimated by calculating pan coefficient. The standard rain gauge was installed at metrological observatory centre at CIFA farm complex for recording of rainfall. For measurement of vertical and horizontal components of seepage losses, Seepage measuring device was fabricated to measure vertical seepage in ponds by installing it inside each pond.

Pond evaporation was estimated by using pan coefficient. The pan-pond coefficient was determined by measuring the stages in the RRC tank of 10 m x 5m of size and with 1.2m depths with effective water depth at around 1.0m available in the farm. A staff gauge was fixed inside the tank and the stage at the top of the gauge was fixed. The data on water stages were recorded on daily basis by maintaining the water level in the tank by adding the evaporation losses.

Regulated inflow and out flow from the ponds were measured by providing the inlet and outlet pipes of 15cm diameter of PVC materials. Flow meters were installed in these pipes for measuring the regulated flows.

Runoff was estimated by a curve number method of United State Soil Conservation service (1982).

The potential maximum retention was calculated for average condition using equation given below.

$$S = 25400/CN - 254 \qquad \ldots(i)$$

and then finally runoff was calculated using equation:

$$Q = (P-0.2S)^2/(P+0.8S) \qquad P > 0.2\,S$$

$$Q = 0 \qquad P \leq 0.2\,S$$

Where, Q = Runoff depth, mm
P = Rainfall depth, mm
S = Potential maximum retention, mm

Water budgets for each pond were calculated using modified hydrologic equations. The water budget of these ponds can typically be represented by the following equation.

$$\frac{dv}{dt} = Qi + P + R \pm S - E - Qo \qquad \ldots(ii)$$

V = Volume of water, Q_I= Regulated inflow, P = Precipitation, R = Runoff, S = Seepage, E = Evaporation

Q_o = Regulated outflow

The data as discussed above were collected regularly for one-year period starting from April to March. The pond-pan coefficient, pond evaporation and pond seepage were calculated as follows;

Pond-pan coefficient = Class A pan evaporation/Evaporation from RRC tank

$$\text{Pond - pan coefficient} = \frac{\text{Class A pan evaporation}}{\text{Evaporation from RRC tank}} \qquad \ldots(i)$$

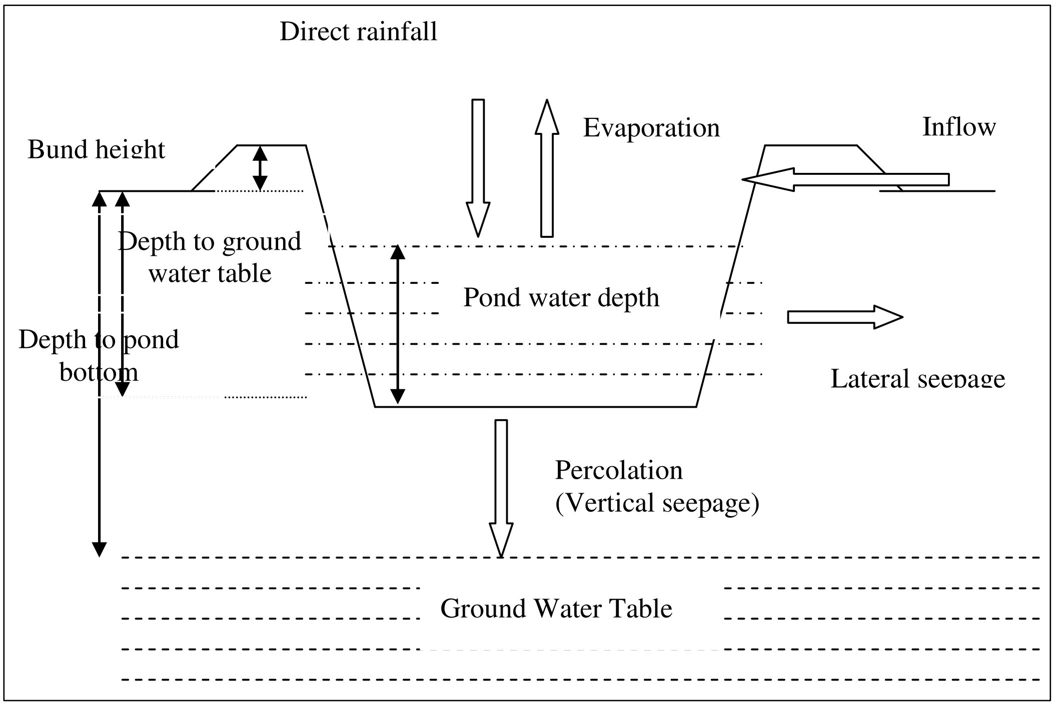
$$\text{Pond Evaporation} = (\text{Pond - pan coefficient x Class A pan evaporation}) \qquad \ldots(ii)$$

Pond Seepage:

Case 1: When there is no rainfall
Pond seepage = {(Stage at time 1 – Stage at time 2) - Pond evaporation} …(iii)

Case 2: When there is rainfall
Pond seepage = [{(Stage at time 1 + Rainfall + Runoff) – Stage at time 2} - Pond evaporation}], …(iv)

Case 3: When there is heavy rain and overflow
Pond seepage = [{(Stage at time 1 + Rainfall + Runoff - Overflow) – Stage at time 2} - Pond evaporation}], …(v)



Fishpond water-budget components

Water budgets for pond aquaculture

The average water budgets have been prepared and summarized in Table 1. From table it is evident that in almost all the months during the year, water had to be added to meet the requirement of water losses from fishponds except during rainy season where in water losses were compensated by gain in ponds either directly from rain or ground water contribution. The monthly average gain was highest in the month of June and lowest in April. Whereas inflow was quite higher in the month of April and lower in July. Total water gain, pond evaporation, seepage and water addition for a year is 1761.8±5.84 1498.3± 8.61,1182.60±10.16 and 2431.2±15.47 mm for the present study.

The detail of contribution of different components in term of percentage is given below:

Water gain: 35.55% (Rainfall + Run off and Ground inflow)
(Rainfall: 75%; Run off 2-.3%; Ground inflow 22-23%)
Regulated inflow: 64.45%
Evaporation: 51.25% and
Seepage loss: 48.75%

Table 1: Mean monthly water budgets of fishponds at CIFA farm

Months	Water gain (Rain +Run-off + ground water), mm	Pond Evaporation (mm)	Pond seepage, (mm)	Water addition (mm)
April	9.0± 1.2	181.3± 12.6	237.6± 21.4	230.0± 18.6
May	0.80± 0.2	139.3± 6.5	160.9± 15.6	300.1± 20.5
June	35.5± 2.3	110.7± 8.1	169.2± 18.5	444.5± 32.5
July	546.3± 19.8	50.7± 7.3	42.0± 5.8	20.40± 2.0
August	434.0± 15.2	63.5± 6.2	38.5± 4.5	207.5± 16.8
September	453.0± 14.5	36.6± 4.5	35.8± 4.2	60.0± 7.4
October	201.0± 10.2	161.8± 9.1	53.5± 5.8	15.20± 2.4
November	44.0± 3.5	111.1± 7.8	38.8± 7.6	106.0± 12.6
December	34.0± 2.2	132.2± 8.4	85.3± 8.9	237.2± 17.9
January	0.60± 0.1	161.0± 10.2	93.2± 9.7	257.5± 15.5
February	0.45± 0.1	170.0± 10.5	102.0± 9.8	243.2± 18.3
March	5.0± 0.8	179.9± 12.3	125.5± 10.2	345.2± 21.2

System associated water use in freshwater aquaculture

The system associated water use in freshwater aquaculture includes evaporation loss, seepage loss and water exchange for water quality management. In the present study it was assumed that there is no need for water exchange, as the water quality of fishpond did not deteriorate because of extensive aquaculture practices. The on an average the evaporation loss from the pond is 1498.3 mm/year and seepage loss per year is about 1182.60 mm/year. Consequently, the water requirements for the production of Indian Major Carps are presented in Table-2. The water requirement for a production target of 3-4 ton/ha/year comes to 7650 litre or 7.6 m^3 of water per Kg of fish production and water requirement decreases with the intensification of aquaculture or increase of production (Table 2). If seepage losses are considered to be green water (Verdegem et al. 2009) then total water consumption is about 4.1 m^3 per Kg of fish production. About 850,000 ha pond area is under carp cultivation in India (Ayyappan, 2006) and hence water requirement is very high for freshwater aquaculture sector.

Table 2: Water requirements of Indian Major Carps for production of one kilogram fish under different production technologies

Production (Ton/ha/year)	Water requirement at CIFA Study Site in m^3/kg & (litres/kg)
3-4	7.65 (7650)
6-8	3.82 (3820)
10-12	2.43 (2430)

Feed associated water use in aquaculture

The water use associated with the production of bone or blood meal, fishmeal and fish oil can be considered negligible. Animals fed formulated diets indirectly consume large quantities of water. Globally, about 1.2 m^3 of water is needed to produce 1 kg of grain used in animal feeds. Fish or crustaceans require less than 2 kg of grain concentrate for each kg produced, making them the most efficiently producing animals in terms of feed-associated water use (Verdegem et al., 2006). This means 2.4 m^3 of water is also being consumed to produce 1 Kg of fish if the feed is being used above that of 4.1m3 system associated water requirement. Hence, total water used to produce 1 Kg fish is 6.5 m^3 if the seepage losses are considered as green water. Otherwise the total water used would be about 10.3 m^3 per Kg of fish produced in the present study.

Freshwater resources availability and utilization in India

The average annual precipitation of the country is about 400Mham. However the utilizable surface water resources and ground water resources are about 70 Mham and 35 Mham respectively. Additionally 2.36 Mha areas of ponds and tanks are also available to be used for various purposes such as domestic use, irrigation, aquaculture etc. The future requirements of water resources have been predicted to meet the growing demand by different sector (Irrigation Commission, 1972). About 70% of total water requirement would be going for agriculture through irrigation in 2025. The total utilizable resources are about 105 Mham and 2.36 Mha areas of ponds and tanks after full development of groundwater as well as surface water resources for utilization, but about 77 Mham would be supplied to irrigated agriculture only to feed the growing population. In consequence, the future growth of agriculture including freshwater aquaculture would be constrained by the freshwater availability (Verdegem and Bosma, 2009). For development of freshwater aquaculture other water resources like Canal, reservoirs and Oxbow lakes & derelict waters should be fully exploited.

Comparison of water requirement of freshwater aquaculture with crops

The water productivity for freshwater aquaculture, which has been estimated in the present study, was compared with the other crops water productivity Table (3). It is clear from the table that the freshwater aquaculture needs more water to produce same amount of fish than the grains. Among the crops compared rice is the least water productive with water productivity 3.7 Kg/ha/mm and Freshwater aquaculture is even lesser water rice also having 1.50 Kg/ha/mm water productivity.

Table 3. Water productivity for different crops including freshwater aquaculture

Crops (New Strains	Water requirements cm	Yield Kg/ha	Productivity of water Kg/ha/mm
Rice	120	4,500	3.7
Sorghum	50	4,500	9.0
Pearl millet	50	4,000	8.0
Maize	65.5	5,000	8.0
Wheat	40.0	5,000	12.5
Freshwater aquaculture (Carp culture)	268	4,000	1.50

Options to reduce the use of water in freshwater aquaculture

The water use (7.6 m^3) per Kg of fish production was very high in case of semi-intensive pond culture where production of fish was 3-4 ton/ha/year. If the intensive pond culture with supplementary feeding and aeration, the production of 10–15 tonnes/ha/yr (Ayyappan, S., 2006) could be achieved, the water productivity would be almost doubled. The focus should be on using intensive and super intensive culture practices for aquaculture production. The main water consumption in pond aquaculture is in the form of evaporation and seepage losses. Hence our efforts should be such that these losses are minimized during the process. The seepage loss may be controlled by adopting different control measures in pond aquaculture (Jayanthi et al. 2004). In intensive or super intensive culture systems, focus should be on assuring the treatment of effluent water and reuse so that these should no longer be considered as a loss. RAS have got very good potential for increasing water productivity very high; they should be tried wherever possible.

On farm water management should also be practiced to reduce the water wastage and make available more water for aquaculture. Water storage capacity of ponds with extensive areas of shallow water can be improved if they are drained and deepened. The shallowest area in a pond should be at least three feet deep. This depth of water will slow growth of aquatic plants, which can take up a large amount of pond volume, effectively reducing the water storage capacity of the pond. To conserve water and reduce energy costs of pumping water in the pond, maintain water levels below the maximum allowed to the standpipe. This practice allows rainfall to be collected in the ponds. How much below maximum level the pond is filled depends upon season, weather patterns, evaporation rates, location, and water holding capacity of the pond, size of the fish in the pond and weight of fish.

Studies on water requirements for different fish culture systems

A. Seed production in Hatchery

Data available: (June-July)
(i) Depth of water in breeding pool = 1.5m
(ii) 3.5 kg brood stock require 1 m^3 of water
(iii) 0.7 to 0.8 million spawn = 1 cubic meter water (72 hrs)
(iv) Spawning time 90-120 hrs

B. Production of carp fry

Data available: (July-Aug.)
Nursery rearing = 72-96 hrs old spawn
Rearing period 15-20 days
Pond size =400 sq m
Stocking density 10 million/ha
Season= monsoon
Depth of water in pond=0.7-1m
Survival = 50 %
Size of final product = 4-6mg
Powder feed = 200 % (Initial 5 days) after that 400 % of body weight

C. Fingerling rearing

Data available: (Aug.-Oct)
Fingerling rearing period= 2-3 months
Pond size =0.02-0.1ha
Stocking density 0.1-0.3 million in earthen ponds
Season= monsoon
Depth of water in pond=1-1.5m
Survival = 50 %
Size of final product = 10g
Power/small pellet feed = 10 % body weight

Water budgets for different aquaculture practices

A. Seed production in Hatchery
WR = 230-240 m^3/million of spawn
B. Production of carp fry
WR = 2400-2500 m^3/million of fry (4-6mg)
C. Fingerling rearing
One million of fingerlings (10g), WR = 80,000 m^3)

Water Management in Fish ponds

Pond aeration

The level of dissolved oxygen (DO) present in aquaculture farm ponds is one of the most important factors for maintaining the water quality. Aeration is the addition of oxygen or air containing oxygen to water body. Low DO level in water affects growth, feed efficiency, disease and ultimately production of fish. The major factor affecting the DO concentration in the pond is temperature. During day light the aquatic plants growing in the pond produce oxygen by photosynthesis, this raises DO concentration in water above saturation and declines during night time due to respiration by organization ponds.

Photosynthesis occurs most rapidly in the surface layer of pond. DO concentration declines with depth due to less availability of light. The DO concentration at the bottom of the pond with water depth more than 1.5 m is low and fall considerably during night specially during early hours. To overcome DO depletion during night, pond aerators are introduced to maintain DO at desirable level. Aeration device or aerator increases the rate of oxygen diffusion in water. Paddle wheel aerators, propeller-aspirator-pump aerators are commonly used.

The pond where initial stocking rate is high, it is very much essential to aerate the pond water by installing a number of aerators as few the volume and size of water area. For a pond of 500 m^3 where the initial stocking is high, say 100 nos. of fish seed/m^3, it may become essential to provide each such pond with at least one aerator.

Seepage in fishponds

Seepage in fish ponds may be defined as water which by the action of capillary attraction passes underground from the pond surface, through close soils by general diffusion. Sometimes ponds or farms are constructed fully or partly in porous soil causing water loss by seepage through dyke and basin. In that case sealing/lining of the surface of dyke and bed is felt essential. Lining the pond with impervious material or treating the soil mechanically or chemically is practiced to prevent excessive water loss. This practice is applied where the loss of water in pond is too much, that it affects the complete filling of the pond. Few methods are described here for control of seepage in fish farm ponds.

Pond sealing by compaction is relatively inexpensive. However, its use is limited to soils having a wide range of particle sizes, capable of affecting a suitable seal. Sandy and silty loam type of soils are suitable for compaction. In addition to normal compaction of dyke during construction, a layer of 15-20 cm of surface soil of pond bed and dyke is required to be compacted properly by manual and hand roller with minimum moisture content. The pond surface soil should be mixed with good clay soil before compaction. Some chemicals such as tetrasodium pyrophospahte, sodium tripolyphosphate, sodium hexametaphosphate and sodium carbonate are mixed to the top soil and compacted to a 15 cm thick layer for a water depth of 2.5 m. The chemical treatment is not effective if the soil is of coarse grade. Application of cow dung and cement in clayey soil are mixed properly with 15-20 cm of bottom soil, it reduces loss of water considerably. Clay percentage is increased when pond soil contains more sand. Where there is deficiency of clay soil, one per cent cement and 1-5 per cent cow dung is mixed with the pond surface soil and is rolled with watering.

Where the clay percent is very low, it is said to be purely sandy soil at the pond base which is not at all suitable for retaining water constantly. The farm can sustain only by constant irrigation water supply system.

To avoid the excess seepage that to 100% in a particular soil condition, it is suggested that 80mm thick cement concrete (1:2:4) with 12 mm size stone chip with proper expansion and contraction joints may be provided on the pond bottom and on dyke up to maximum water level. The concreting work is required to be done after providing 100 mm thick sand layer with due watering and compaction.

The pond's base and slope may be provided with locally available stone with 1:6 cement mortars after 100 mm sand layer. The thickness of the stone masonry should be minimum 150mm.

The ponds with moderate seepage, Bentonite clay can be used to arrest the same. Bentonite is a fine texture colloidal clay which absorbs water several times its own weight and at complete saturation swells 8 to 20 times its original volume. The betonite is mixed with soil to a depth of 15 cm and the mixture is purely compacted and saturated. The particles of bentonite fill the pores in the soil and makes in nearly impervious. Bentonite powder should be applied at the rate of 5-15 kg per square meter of area depending on the quality of soil. Bentonite when dried, return to its original volume and leave cracks in the pond area.

Bentonite can also be applied when there is water in the pond. A coarse grade is suitable to use in this condition and it is applied uniformly to the water surface which settles to the bottom, swells and forms a seal.

The pond with comparatively less seepage may be provided with a layer of clayey soil at the pond's bottom and slope and compacted properly. The clayey soil may be brought from the nearest possible site and applied to a thickness of 200-300mm.

Plastic lining

- In coarse textured soils flexible membranes of polyethylene, vinyl and butyl rubber can be used to prevent excessive seepage losses. Thin films of these materials are structurally weak, however, if kept intact, they are almost completely watertight. Polyethylene films are least expensive and have better aging properties than vinyl, but they are difficult to join or patch (if damaged) since repair must be performed by heat sealing.
- The area to be lined should be drained and dried until the surface is firm enough to support the people and equipment to be used during the lining installation. Generally, the native soil sub grade should be disturbed as little as possible in the excavation operation to provide adequate structural bearing support. In addition, the area to be lined should be cleared of all vegetation. It is recommended to sterilize the areas to be covered with vinyl or polyethylene, since certain plants with high penetrating power can damage these thin membranes.
- Membrane linings should be supplied in sections as large as can be handled by the available equipment. Field splices should use a minimum overlap of 0.05 m. Splices on the side slopes should be oriented perpendicular to the water surface when ever practical. This orientation reduces stress on the joint.

- All thin films, such as polyethylene and vinyl membranes, must be protected from mechanical damage with a cover of soil or soil and gravel. This is also required to protect these plastic materials from atmospheric weathering. The cover should be at least 0.15 m thick for protection from atmospheric weathering. However, they must be protected against mechanical damage, especially in the areas where they are likely to be damaged.
- The bottom 0.07 m of the cover, which is in contact with the membrane, should be no coarser than silty sand. In general, cover material should be placed beginning at the bottom of the pond and proceeding toward the top of all slopes.
- The top edges of the lining should be anchored in a trench which is at least 0.15 m deep and about 0.25 m wide. The trench should be excavated at the elevation of the top of the lining around the entire area to be lined.
- All banks, side slopes and fills within the area to be lined should be uniformly sloped no steeper than 3:1 for covered linings. On steeper slopes there is a danger of the cover material sliding on the membrane. The distance between the maximum high water in the pond and the top of the embankment is called the freeboard. The lined freeboard should be at least 0.3 m above the maximum water level in ponds with surface areas of less than 0.4 ha. Additional freeboard is required in larger ponds to prevent overtopping and erosion by wind-generated waves.

STREAM BANK AND RIVER STABILIZATION TO IMPROVE WATER QUALITY AND BIODIVERSITY

P.R. Ojasvi*

Freshwater resources such as rivers, lakes, reservoirs and wetlands are suffering from various problems amongst them pollution originated from point and non-point sources; shore erosion and habitat lose due to construction and other unsustainable human activities and unsustainable practices. To stop and advert this trend there is a need to develop proper planning and management approaches within the context of Integrated Water Resource Management (IWRM).

Restoring the ecological integrity of the stream system means enhancing the biological diversity and natural instream processes. The new dimension of this philosophy has been provided by the concept of Ecohydrology which suggests the use of ecosystem properties as a management tool toward enhancement of the resilience and resistance of stream ecosystem to stress. Thus, ecohydrology may be proposed as a new tool for implementation for the Integrated Water Resources Management (IWRM). With the restoration of key stream processes such as flow patterns, patterns of sediment erosion and deposition, nutrient cycling, and species succession water quality can be enhanced. The first step in stream restoration, then, is to restore the natural stream morphology as a basic element of water quality and fishery improvement. Thus, Ecohydrology together with the application of bio-engineering practices is the key to successful IWRM.

Physical stream structure

In order to improve the quality of stream water and enhance its native biota, it is necessary to restore the natural complexity of the stream channel structure. Rehabilitation of the natural stream channel structure will restore the proper functioning of stream ecosystem.

Stream biota depends upon the structural complexity of the stream habitat. Thus, biota may be an essential indicator of the status of the stream ecosystem. The higher trophic level organisms, such as fish, may provide an integrated assessment of watershed conditions. Further, this means that fish communities can serve as a sensitive indicator of the relative health of its aquatic ecosystem and its surrounding watershed.

Therefore, the main aim of restoring stream channel structural complexity is to reintroduce the diversity of main channel features, such as depth, flow, substrate, and cover - both instream and riparian - that provide fish habitat and that comprise the physical attributes of the riverine ecosystem.

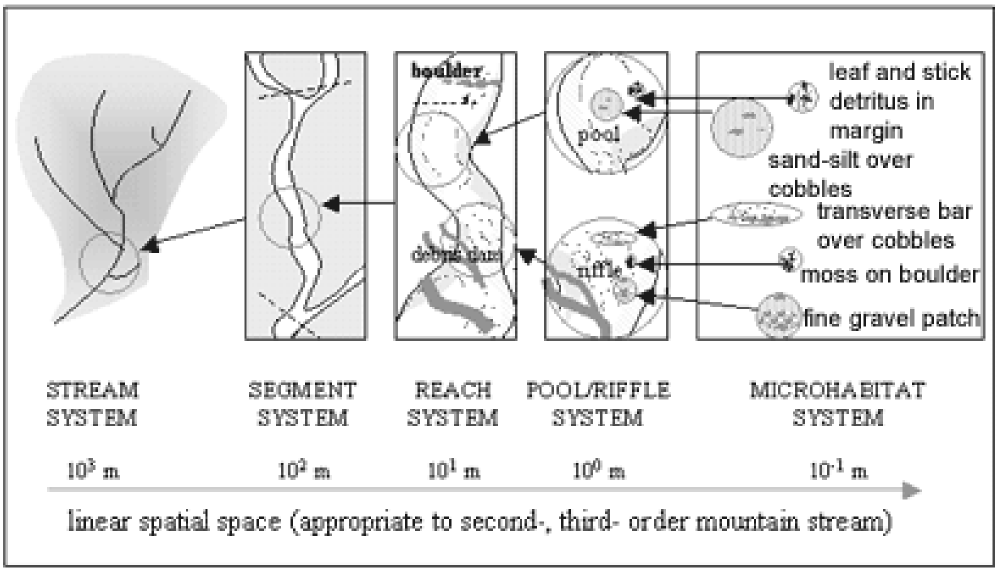
(i) Restoration of a pool-riffle-run sequence

The influence of habitat type on the fish community parameters - estimated as biomass and diversity - in small upland and lowland rivers showed that pools and riffles on both stream types maintained higher levels of fish biomass and fish diversity then the transition zones, or runs, situated between the pools and riffles. The pools provide a diversified depth gradient, while riffles offer diversified substrate sizes.

*** Principal Scientist (SWCE), Central Soil & Water Conservation Research & Training Institute, Dehradun-284 195 (Uttarakhand)**

(ii) Instream cover by large woody debris

Large woody debris (LWD), through its impact on physical processes within the stream ecosystem (e.g., hydrological, hydraulic, sedimentological, and morphological processes), plays a critical role in enhancing and maintaining habitat for biota.



Hierarchical organisation of stream systems and their habitat subsystems

(iii) Stream bank vegetation cover

The natural characteristics and ecological health of streams are linked to the landscape by the biotic and physicochemical properties of the riparian zone. The functions of riparian vegetation with respect to aquatic ecosystems is summarised in following Table.

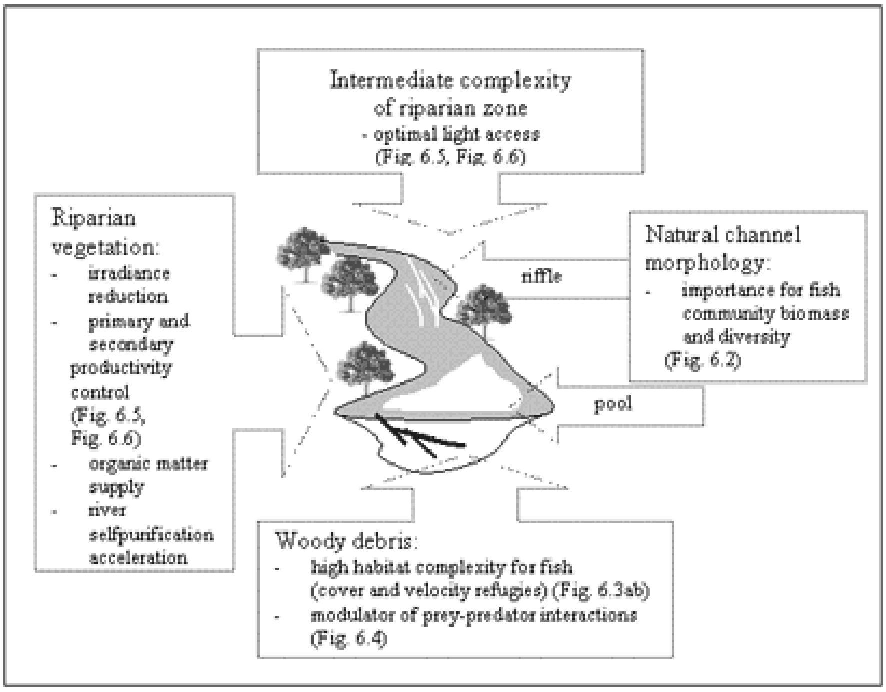
The functions of riparian vegetation in aquatic ecosystems

Sites	Components	Functions
Aboveground/ above channel	Canopy and stems	• shade controls in-stream temperature and primary production • source of large and fine plant detritus • wildlife habitat
In channel	Large debris derived from riparian vegetation	• controls routing of water and sediment • shapes habitat: pools, riffles, runs, and cover
Streambanks	Roots	• increases bank stability • creates overhanging banks, and cover • takes up nutrients from ground and stream water
Floodplain	Stems and low-lying canopy	• retards movement of sediment, water and floated organic debris during floods

Riparian vegetation largely determines the input of solar energy to a river by directly influencing the primary productivity of algae and macrophytes, and by indirectly influencing the productivity of higher trophic levels like invertebrates and fish. In the case of primary production, the opening of dense canopies over stream habitats may create better conditions for cyanophyte communities while disadvantaging diatom communities. This shift in algal populations can influence water quality. Cyanophytes have a higher capacity to buffer the stream from pollutants than do the diatoms community. This results in a higher absorption capacity for the stream ecosystem.

For small-sized rivers, fish biomass and diversity with riparian vegetation may be up to three times higher than in habitats with higher or lower levels of light input.

The proper restoration and management of streams for fishery enhancement purposes should include the conservation or reconstruction of the natural channel morphology and its riparian zone structure. By restoring the pool-riffle-run sequences, together with the optimal degree of canopy cover by the riparian vegetation, the habitat carrying capacity of the stream for biota can be maintained, and the river self-purification ratio could be accelerated.

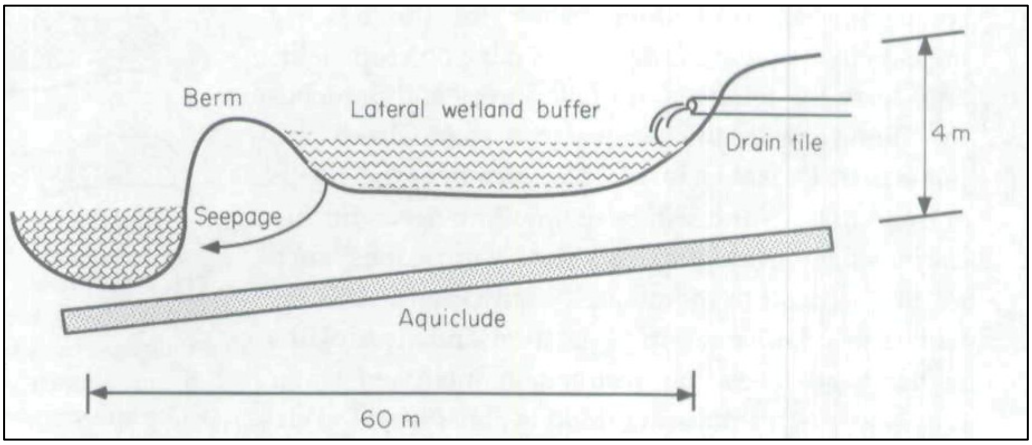


The importance of the channel morphology and riparian vegetation structure for riverine fish communities

Riparian vegetated buffer strips in water-quality restoration and stream management

Riparian zones link the stream with its terrestrial catchment, they can modify, incorporate, dilute, or concentrate substances. In small to mid-size streams forested riparian zones can moderate temperatures, reduce sediment inputs, provide important sources of organic matter, and stabilize stream banks. Both the forested and grass VBS can reduce nitrate-N concentrations in shallow groundwater. On an annual basis the forested VBS is found to be more effective at reducing concentrations of nitrate-N than the grass VBS, but was less efficient at retaining total and dissolved P.

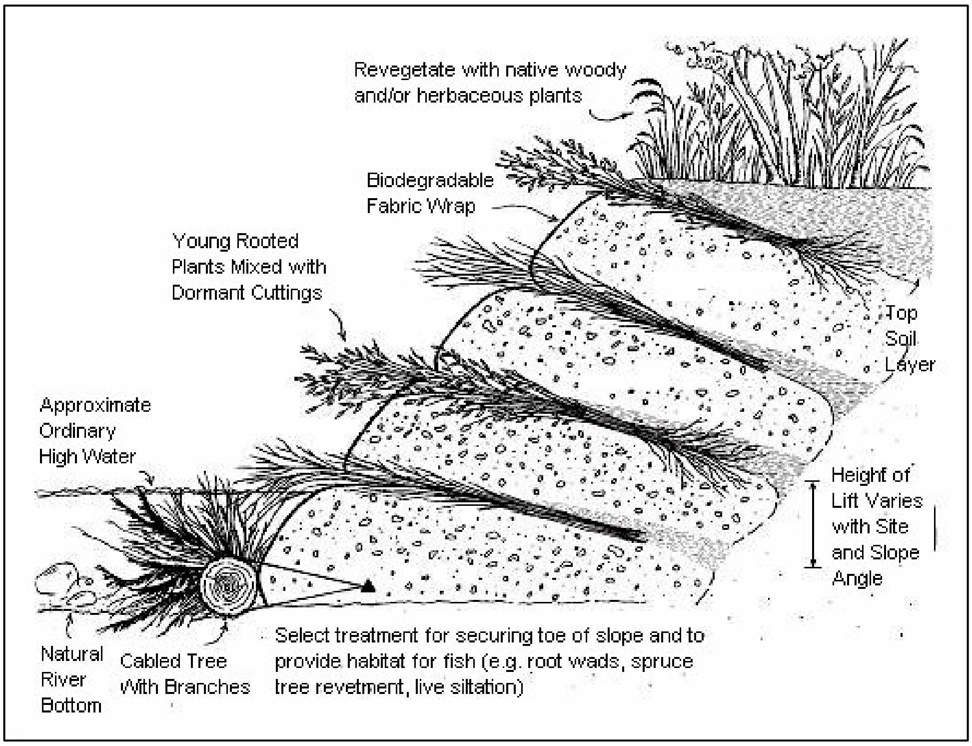
VBSs are not as effective in agriculture areas with tile drained fields. Also where sewage disposal outlets are directly draining in to river system, alternative restoration practices such as discharging drain tiles into wetlands constructed parallel to the stream channel may prove to be a more effective means of controlling non-point-source agricultural inputs of nutrients in such areas.



Stream bank stabilization measures

1. Brush layer

This is a form of soil bioengineering which uses live branch cuttings laid flat into small benches excavated in the slope face perpendicular to the slope contour. Brush layers act as live fences to capture debris moving down the slope.

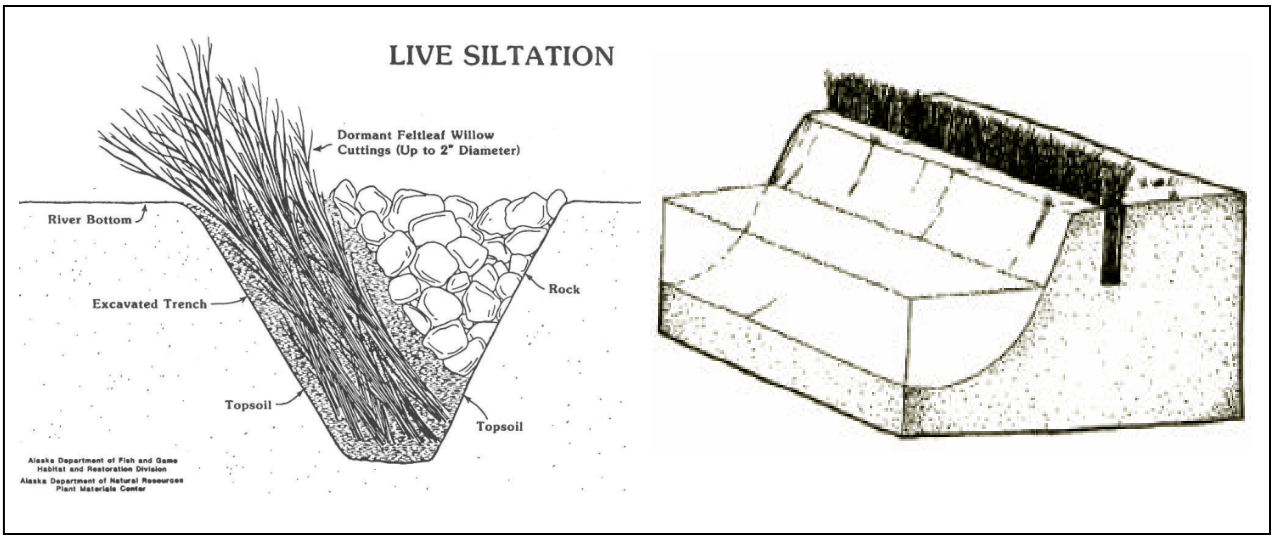


2. Brush mattress

A brush mattress is a layer (mattress) of interlaced live branches placed on a bank face, often with a live fascine and/or rock at the base. Together with the sprouting plants, the brush mattress develops a strong network of interlocking roots and plant stems.

3. Brush trench

Bundles of tree cuttings are buried in a trench stabilizing the eroding streambank. The sprouting cuttings will create a fence to filter sediment and storm runoff eroding into the stream while the roots will develop and stabilize the streambank.



4. Filter strips

Filter Strips are areas of grass or other permanent vegetation that intercept runoff before it enters a water body. Filter strips collect sediment, nutrients and organic materials, and provide wildlife habitat. The purpose of a filter strip is to provide a buffer between possible contamination sources and water bodies.

Bank strengthening

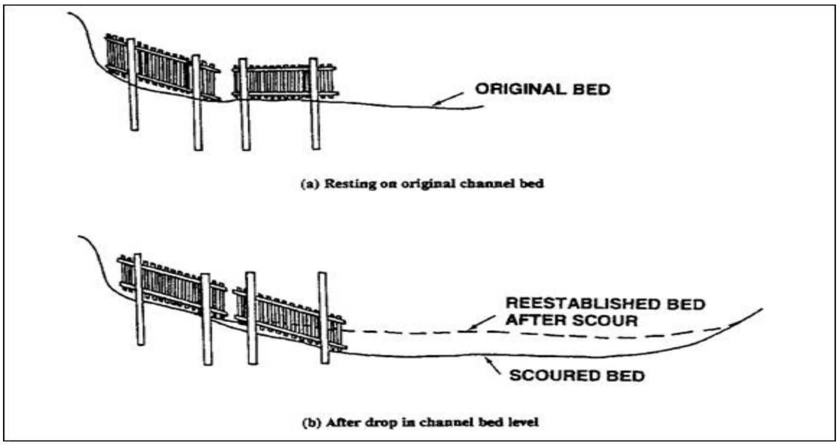
5. Riprap

Riprap consists of a layer of angular stone designed to protect and stabilize areas subject to erosion, slopes subject to seepage, or areas with poor soil structure. Riprap is used on streambanks where stream velocities are too great to successfully establish vegetative cover, on channel bottoms and slopes, stormwater structure inlets and outlets, slope drains, and shorelines.

6. Cribs and gabions

Cribs are timber boxes built outward from the river bank and filled with sand and gravel. The boxes can be stacked along the bank and fastened together as building blocks in the construction of hardened streambank protections. Cribs are preferred where stone is not available or timber is cheap, and is typically used on smaller streams.

Where stone is available on larger streams, gabions are often preferred. These are wire boxes into which stones may be placed, and are situated similarly to cribs. Gabions are a common substitute for riprap where smaller stones are available.



Flow obstruction and guiding

7. Pile dikes

Similar to rock spur dikes, but using timber pilings lashed together and driven into the streambed from the bank outward. They are permeable, allowing for flow between piles. Eroded banks can be rebuilt with the sediment that collects behind them. They are better suited for sandy-bottomed streams than coarse, steep rivers where rock dikes are more appropriate.

8. Spur dikes

Rock piles extending from shore into the stream, usually used in series, with the first at the greatest downstream angle and the latter ones more perpendicular to the bank. Spur dikes extend further into the stream and deflect flows well away from the bank.

Some Water Quality Control Measures for Fish Farm Ponds

Control of clay turbidity in ponds

Turbidity caused by clay particles is generally undesirable because it keeps light from penetrating the water, and light is required for algal growth. At very high concentrations, clay particles can also clog fish gills or mother fish eggs. Muddy water tends to have a lower average concentration of dissolved oxygen than water with a green phytoplankton bloom. Clay turbidity can sometimes develop quite suddenly, as when heavy storm runoff enters the pond or high bottom soils to be resuspended. In such cases, oxygen may decline to critically low levels and make it necessary to aerate the pond. Not much algae can grow in muddy water because clay particles limit the penetration of light into water.

Flocculation and coagulation

Flocculation is a way of controlling clay turbidity by adding substances to water. Metal salts make good flocculants, depending on pH. These hydrolyzed metal compounds destabilize colloids by shrinking the layer of positively charged ions surrounding clay particles, which increases the attraction of one particle to another (coagulation). Hydrolyzed metals also can be adsorbed onto the surfaces of clay particles and create bridges to other particles (flocculation). The sodium (Na^+) in sodium chloride (NaCl) is not a very effective coagulant. The calcium (Ca^{2+}) in gypsum ($CaSO_4$) is more effective because it carries a +2 charge. The aluminum (Al^{3+}) in alum and the ferric-iron (Fe^{3+}) in ferric sulfate are more effective yet because they carry a +3 charge. Some companies now manufacture various synthetic "polyelectrolytes," which are large, long-chained molecules with even more charge than the metal salt coagulants listed here.

One of the most effective coagulants is alum, or aluminum sulfate, which has been used to clarify muddy waters. A dose of 15 to 25 mg/L (150 to 250 pounds per acre) should be sufficient to remove the turbidity from most waters. Use the lower concentration for moderately turbid (less than 12-inch visibility) waters and the higher concentration for highly turbid (less than 6-inch visibility) waters. Alum makes water more acidic. In ponds with low alkalinity (less than 20 mg/L as $CaCO_3$) it can reduce water pH to levels that may affect fish growth and survival. In low alkalinity ponds, add 1/2 part hydrated lime for every part of alum applied in order to maintain proper pH.

Although not nearly as effective as alum, gypsum also can be used to control turbidity but without the loss of alkalinity. Gypsum must be added to achieve a concentration of 100 to 300 mg/L for effective turbidity control. For most ponds, gypsum application rates will range from about 1,000 to 2,000 pounds per acre In hard-water ponds (calcium hardness greater than 50 mg/L), the water is nearly saturated with calcium and gypsum may be ineffective. In that situation, alum will be the only effective coagulant.

All the coagulants mentioned can remove phosphorus from water. As phosphorus is an essential plant nutrient, it may be necessary to fertilize the pond after treating it for turbidity. On occasion, phytoplankton and clay can mutually coagulate, so fertilizing to start a phytoplankton bloom may also clear water of suspended clay particles. Organic matter such as chopped hay or cottonseed meal can reduce clay turbidity in farm ponds. However, large amounts of material must be added to the pond, which may deplete the dissolved oxygen as the organic matter decomposes. It may also be difficult and costly to transport and uniformly distribute large amounts of organic matter.

Nitrite in fishponds

Nitrite enters a fish culture system after feed is digested by fish and the excess nitrogen is converted into ammonia, which is then excreted as waste into the water. Nitrite enters the bloodstream through the gills and turns the blood to a chocolate-brown color. This accounts for the gasping behavior often observed in fish with brown blood disease, even when oxygen levels are relatively high. Nitrite problems are typically more likely in closed, intensive culture systems due to insufficient, inefficient, or malfunctioning filtration systems.

Since this is a nitrogen-related problem, the most obvious preventive measure is to reduce or minimize the amount of nitrogen incorporated into the system by reducing feeding rates. However, in modern intensive pond or closed system fish culture with high densities and rapid growout, longterm feed reduction is not considered by most farmers as a viable option. Luckily, although we often cannot prevent the occurrence of high nitrite, its effects can be minimized or neutralized safely and economically. Sodium chloride (common salt, NaCl) is used to "treat" brown blood disease. Calcium chloride can also be used but is typically more expensive. The chloride portion of salt competes with nitrite for absorption through the gills. Maintaining at least a 10 to 1 ratio of chloride to nitrite in a pond effectively prevents nitrite from entering catfish. As a general rule, maintain at least 100 ppm chloride in pond waters as "insurance" against high spikes of nitrite concentration.

Liming ponds

The acidity of pond soils can be neutralized and the productivity of the pond improved by liming. "Liming" refers to the application of various acid-neutralizing compounds of calcium or calcium and magnesium. Liming ponds has three important benefits: 1) Liming may enhance the effect of fertilization. 2) Liming helps prevent wide swings in pH. 3) Liming also adds calcium and magnesium, which are important in animal physiology.

The effect of liming on fertilization

Both recreational and commercial ponds are often fertilized to improve fish production. Fertilizers containing nitrogen phosphorus and potassium (especially phosphorus) stimulate the growth of microscopic plants (phytoplankton) and animals (zooplankton), which, in turn, serve as food for animals in the aquatic food chain. In ponds used for commercial production of juvenile fish, plankton is the primary food source. Healthy phytoplankton blooms also absorb toxic nitrogen wastes and raise daytime dissolved oxygen concentrations, so they are important to water quality. Perhaps the most common reason to lime ponds is to improve the response to fertilization. In ponds built on acidic soils and filled with fresh water of low mineral content, much of the phosphorus added in fertilizers becomes tightly bound in pond sediment where it is not available to support phytoplankton growth. Proper liming can improve phosphorus availability and greatly enhance pond productivity.

Most aquatic organisms can tolerate a broad range of calcium hardness concentrations, but a desirable range is 75 to 250 mg/L with a minimum concentration of 20 mg/L. Adding liming materials or gypsum increases hardness.

Deciding whether to lime a pond

To determine whether a pond needs to be limed, first check total alkalinity. If the total alkalinity of the water sample is less than 20 mg/L, the pond may benefit from liming. The amount of lime needed depends on the chemical characteristics of the bottom sediment. Materials such as agricultural limestone, basic slag, slaked lime, quick lime and liquid lime have been used to lime ponds. While all these compounds neutralize soil acidity, some are more practical or effective than others. It is not advisable to use quick lime (CaO) or slaked lime ($Ca(OH)2$). They are more expensive and can cause pH to rise rapidly to levels that can harm aquatic life.

SUMMARY

- Bio-engineering measures based on ecohydrology provide an effective and efficient mechanism for the restoration of degraded environments.
- Traditional sewage treatment plants, providing BOD and nutrient load reduction benefits to river systems and freshwater reservoirs, but continue to reduce the quality of water resources.
- Extending the technical, sewage treatment system by constructing wetlands results in a more efficient reduction in pollutant loads and generates additional societal benefits.
- Moreover, plantations within wetland fringe can provide alternative sources of energy (bioenergy) that can help to reduce CO_2 emissions from burning fossil fuels. The resultant ash can be used to fertilise the forested plantations. Producing bioenergy and timber also generates new employment opportunities and revenue flows while reducing capital outflows for fossil fuel use.
- The use of ecohydrology concepts, therefore, results not only in a good quality environment, but also can help to elevate the economic status and level of sustainable development in local communities.

AQUACULTURE AND AQUACULTURE SYSTEMS

M. Muruganandam*

Introduction

Aquaculture, farming of aquatic organisms including fish, prawn, shrimps, crabs etc. is one of the oldest farming activities after agriculture and animal husbandry. For long, it has been carried out in isolation without much integration with watershed management programmes. It has greater potential in watershed management programmes and Natural Resource Management (NRM) as both complement each other. The overwhelming importance with huge financial outlay and physical targets for Integrated Watershed Management (IWM) towards Natural Resource Management (NRM) and rural development placed in the whole country gives great scope for creation of water resources, Water Harvesting (WH) and Water Harvesting Structures (WHS) as one of the prime interventions with potential for accommodative fish culture along with other indented purposes. The polyculture or composite carp culture besides monoculture of indigenous and exotic carps, prawn, catfish and cognate technologies are some of the package of practices suitable for watershed management. Practice of composite culture would be most suitable for WHS.

Composite carp culture refers to culture of hardy and fast growing fish species with compatible feeding habits, mainly 3 Indian and 3-4 exotic carps that occupy varied ecological niches of bottom, column and surface zones utilizing maximum feed and space available in pond eco-system effectively for fuller and multiple utilization of developed/available water resources and pond's productivity towards socio-economic benefits. Both composite carp culture towards table size fish production and raising fish fingerlings/yearlings from fries either simultaneously or subsequently depending on demands can be practiced in WHS. Composite carp culture yields an average of 4.5 t fish.ha-1 yr-1 (4.0 - 5.5 t ha-1 yr-1). Net profit of about Rs. 1,00,000 to 1,10,000 ha-1 yr-1 can be obtained out of composite carp culture with the Benefit Cost (B: C) ratio of 1.9:1. The following details give fish farming in WHS and farm ponds.

Aquaculture resources and technologies

Generally, the aquacultural potential from surface water depends on the utilizable quantum of inland waters, river flows and coastal waters and the extent to which regulation is possible with the help of storages. The aquaculture can be practiced by introducing location specific and demand based fisheries technologies including development of ponds/impoundments, fish culture, shrimp farming, stream stabilization, fish ranching in lakes, streams, reservoirs, coastal waters, Oceans and the like. Diversified aquatic species (Table 1) are available especially in tropical countries like India to suit varying agro-climatic and ecological situations of farming. Similarly, various water resources, culture systems like ponds, WHS and production technologies (Table 2) do exist suiting varied natural environments and farmers' capacity to invest. Almost in every region and ecosystem one or more suitable fisheries technologies are available that can be practiced.

*** Senior Scientist (Fisheries), Central Soil & Water Conservation Research & Training Institute, Dehradun-284 195 (Uttarakhand)**

Though fish productivity would be high in nutrient rich and agriculturally productive lands fish culture can be competitively practiced in degraded land-water masses. Flood prone areas can be suitability used for seasonal and economical fish culture. Degraded lands resulted from salinisation of soils, alkalinization, water logging, water erosion, torrents, flooding, mining, undulating terrain, intensive farming and faulty cultivation of lands can also be suitably improved and put for fisheries and aquaculture exploitations according to prevailing agro-climatic conditions. Impoundments created as a result of mining activities (e.g. lime quarrying, stone mining, mineral mining), salt extracting saltpans and brick-kiln can be suitably improved and used for fish culture if water source exist. Semi-digested sewage and processed polluted water forms potential for culture of air breathing fishes, catfishes, carps, mussel farming, seaweeds, Spirulina culture etc. for ecological and socio-economical benefits. Fish culture in various flood protection devices such as reservoirs, water detention basins, flood water diversion embankments, channels and drainage systems can be undertaken suitably to enhance fish protein availability locally.

Globally, irrigation network is the biggest consumer of freshwater resources. On a global level, irrigation accounts for 72% of average per capita diversions of water resources. A renewed understanding of competition and complementarity between multiple use of water resources and irrigation demands have brought aquaculture in to irrigation networks, especially in Asian countries like China. Besides, various programmes of water quality monitoring, fish rescue and relocation, aquatic habitat restoration, fish habitat protection, stream/ecological stabilization, fisheries monitoring and aquaculture activities can promote water-based enterprises, economic utilization of degraded, and unproductive water resources realizing higher Water Use Efficiency (WUE).

Table 1: Aquaculture candidates

World - Widely used aquaculture spp. - 292; Rarely used aquaculture spp. - 281 (FAO)

India (at various levels of standardization and culture practices)

COLD FRESH WATER

1. **Finfishes**

a. Trouts - *Salmo trutta fario* (brown trout)*, *Raimmas bola* (Indian trout), *Schizothorax plagiostomus* (=*S. richardsonii), S. kumaonensis, Schizothoraichthys esocinus, S. progastus, S. longipinnis, S. niger, S. micropogon, S. curvifrons* (snow trout), *Oncorhynchus mykiss* (rainbow trout)*, *O. nerka**, *S. gairdneri gairdneri* (rainbow trout).

b. Mahseer-*Tor putitora* (golden mahseer), *T.tor* (tor/deep bodied mahseer), *T. khudree* (deccan mahseer), *T.mosal* (copper mahseer), *T. mussullah* (high backed mahseer), *Acrossocheilus hexagonolepis* (chocolate mahseer).

c. Common carp- *Cyprinus carpio communis* (mirror carp)*, *C. carpio specularis* (scale carp)*, *C. carpio nudes* (leather carp)*.

d. Others- *Barilius bendelisis* (lesser brails), *Labeo dero, L. dyocheilus* (minor carps), *Garra gotyla* (sucker head), *Glyptothorax pectnopterus, G. garhwali* (sisorids), *Nemacheilus* spp. (loaches).

WARM FRESH WATER

1. Finfish: a. Carps

Catla catla (catla), *Labeo rohita* (rohu), *Cirrhinus mrigala* (mrigal), *C. cirrhosa, C. reba, Labeo calbasu* (kalbasu), *L. fimbriatus* (peninsular carp), *L. bata, L. gonius, Ctenopharyngodon idella* (grass carp)*, *Hypophthalmichthys molitrix* (silver carp)*, *Cyprinus carpio* (common carp)*, *Aristichthis nobilis* (bighead carp), *Puntius pulchellus, P. ticto, P.* k*olus, P. sarana*, other minor carps.

b. Air breathing/live fishes

Clartius batrachus, Heteropneustes fossilis, Anabas testudineus, Channa striatus (snake head murrel), *C. punctatus, C. marulius, C. gachua.*

c. Catfishes (non-air breathing)

Mystus aor, M. seenghala, Wallago attu (fresh water shark), *Pangassius pangassius, Silondia childreni, Bagarius bagarius.*

d. Miscellaneous spp.

Oreochromis mossambica (java tilapia), *O. aureus (O. mossambica x O. niloticus* hybrid - red tilapia), *Ompok bimaculatus, O. pabda (*catfish*), Anguilla nebulosa nebulosa, A. bicolor bicolor* (eel), *Gambusia affinis* (mosquito fish)*, *Osphronemus goramy* (gourami - weed fish), *Etropiichthys vacha.*

e. Ornamental fish: i. Barbs- *Barbus arulis, B. conchonius, B. filamentosis.*

ii. Loaches- *Botia striata, B. almorhae, B. dario, Noemacheilus evezardi, N. anguilla.*

iii. Catfishes- *Ailia coila, A. punctata, Conta conta, Gagata cenia.*

iv. Others- *Petrophyllum scalare* (angel fish), *Syngnathus kalyanensis* (pipe fish), *Dania devario* (zebro fish), *Canda ranga* (glass fish), *Macropodus cupanus* (paradise fish), *Ctenops nobilis* (noble fish).

2. **Shellfish: i. Non-penaeid prawns-** *Macrobrachium rosenbergii* (giant freshwater prawn), *M. malcomsoni, M. rude, M. idella, M. scarbiculum, M. lamarrei, M. choprai.*

ii. Molluscs- *Lamellidens* spp. (freshwater pearls), *Pila globosa* (snail).

iii. Amphibians- Frog.

3. **Aquatic plants and algae -** *Euryale ferox* (machana), *Trapa bispinosa* (water chestnut), *Spirulina splendens, S. fusiformis* (Single Cell Protein), *Azolla* spp., (bio-fertiliser), *Lemna* spp. (Duckweeds), *Spirodela* spp. (Duckweeds), *Wolffia* spp. (Duckweeds).

4. **Probiotics and others -** *Daphnia pulex*, *Moina* spp.,*Oscillatoria, Anabaena, Ulothrix, Spirogira*.

BRACKISH WATER and coastal ecosystems

1. **Finfishes -** *Chanos chanos* (milkfish), *Mugil cephalus* (mullets*), M. cunnesius, Rhinomugil corsula, Valamugil sehela, Liza parsia, L. macrolepis, L. tade, Etroplus suratensis* (pearlspot), *E. maculatus, Lates calcarifer* (bekti, seabass), *Hilsa ilisha* (Indian shad), *Epinephelus tauvina* (grouper), *E. melabricus* (malabar ray cod), *Sillago sihama* (sand whiting), *Siganus canaliculatus, Megalops cyprinoides* (ox-eye herring), *Elops machnata, E. saurus, Polynemus tetradactylus, P. indicus, Sparus sabra* (sea bream*), Acanthopagrus berda, A. latus, A. bifasciatus* (sea bream*), Setipinna phasa, Eleutheranema tetradactylum* (thread fin - Indian salmon).

2.Prawn (penaeid) - *Penaeus monodon* (tiger prawn), *P. indicus* (white prawn), *P. semisulcatus, P. merguiensis, Metapenaeus dopsoni, M. monoceros, M. affinis, M. brevicornis, Parapenaeopsis stylifera.*

3. Crabs - *Scylla serrata* (mud crab), *S. tranquebarica, Portunus pelagicus, P. sanguinolentus.*

4. King crabs - *Carcinoscorpius rotundicauda, Tachypleus gigas.*

5. Molluscs – *Perna indica, P. viridis* (mussels), *Crassostrea madrasensis, C. grephoides* (edible oysters), *Pinctada fucata, P. margaritifera* (pearl oysters*), Meretix meretix, M. casta* (clams).

* exotic species to India

Table 2: Aquaculture systems and technologies

1. *As per land cover and intensity of management*

Satellite farming, large-, medium-, small-scale farming systems, fertilization- and feed-based systems.

2. *As per intensity of seed stocking and management*
   - **(i) Traditional and Extensive –** Both traditional and extensive aquaculture are practiced in relatively larger water bodies. Here, only stocking of fish species carried out and the harvest is determined by the utilisation of natural productivity of waters.
   - **(ii) Semi-intensive -** Intensive, elements of fertilization, feeding, management of water, pond and biomass are introduced to sustain and support natural productivity.
   - **(iii) Intensive system** - Supplementary feeding is almost the only means of sustaining production.
   - **(iv) Super-intensive systems -** Employ the use of balanced diet together with intensive aeration, water replenishment and intensive management.
3. *As per integration*
   - (i) Monoculture (single species), polyculture (mixed culture of prawns and molluscs, small and large fish etc.), composite culture (Indian and exotic carps).
   - (ii) Bio-gas slurry based, waste water based, aquatic weed based.
   - (iii) Integrated Farming Systems (IFSs).
     - a- Agriculture based systems - fish, paddy, oil crops, vegetables,...
     - b- Livestock based systems - fish, duck, chicken, pig, and cattle.
     - c- Agri-horti-livestock based - Fish, cattle, goat, rabbit, sheep, vegetables, fruits, food crops...
4. *As per culture area/environment*
   - (i) **Water based -** open Sea/reservoir farming, cage (floating, submerged – on-bottom, off-bottom water), pen, net (floating, fixed, moored), raft, rack and rope culture systems…
   - (ii) **Land based -** Tanks and ponds (earthen, concrete, dugout, embankment, drainable, non-drainable, lined,…locational (Watershed/farm/village ponds, homestead ponds, irrigation ponds, spill ponds, rock ponds, inter-tidal ponds etc.)).
5. *According to the environment temperature*

   Cold water (upland), warm water aquaculture systems.
6. *As per salinity and geography*
   - (i) Inland systems – freshwater ponds, tanks, reservoirs, rivers, lakes, ox-bowls aquaculture,..
   - (ii) Coastal systems - lagoon, estuarine, backwater, brackish water aquaculture, ...
   - (iii) Marine systems – Marine (mariculture), inter-tidal, sub-tidal, pelagic, marine mid-water, bottom water aquaculture...
7. *As per nature of water supply and movement of water*
   - (i.) Spring, rainwater, river water aquaculture.
   - (ii.) Running (lotic) water aquaculture, stagnant (lentic/confined) water aquaculture, flow-through culture/recycling system (partial, closed system).
8. *According to species*
   - **(i) Crustaceans culture -** prawn culture, lobster culture, crabs culture,…
   - **(ii) Molluscan culture** - Mussel culture, pearl culture, edible oyster culture, clam culture, abalone culture, scallop culture,….
   - **(iii) Fish culture** – Carp culture, sea bass culture, catfish culture, air-breathing fish culture, ornamental fish culture etc.
   - **(iv) Others -** Seaweed culture, holothurian culture (sea cucumber), gorgonids culture, *Spirulina* culture etc.

In a way, fisheries and aquacultural technologies can very well be imposed successfully in surface and subsurface water resources, irrigation networks, flood-protection devices, degraded lands and unproductive water that are otherwise less potential for other sectoral developments or lie unused. Thus, promotion of aquaculture would reduce poverty, unemployment, income disparity, fallow-lands or water bodies and improve personal, rural, national and global economy at large.

Aquaculture systems and technologies

Aquaculture systems must be considered in relation to natural resource systems and human development circumstances within which they exist. The mix of culture systems, species, farming systems and different phases of culture create an extreme diverse collection of aquaculture systems and technologies.

Grossly, water-based systems (cages and pens - both inshore/offshore), land-based systems (rain-fed ponds, irrigated or flow- through systems, tanks and raceways), recycling systems (highly controlled enclosed systems, open pond-based re-circulation) are major aquaculture systems.

Overall, various facts and dimensions of fisheries and aquaculture are being researched by different agencies world over during the past five decades. Major achievements and technological developments fitted to Natural Resource Management (NRM), water management, rural development, soil-water conservation and other related fields can be briefed as follows.

1. Carp culture system – Poly culture of Indian Major Carps (IMC, catla, rohu, mrigal) alone (mixed farming) or Indian and exotic carps (silver carp, common carp, grass carp) together (composite carp culture)
    a. Fertilization and feed based system,
    b. Waste water based system,
    c. Biogas slurry based system,
    d. Aquatic weed based system,
    e. Agriculture/horticulture based system,
    f. Livestock based integrated farming system.
2. Subsistence carp farming in ponds originated through various initiatives and methods, v*iz.*
    a. WHS meant for integrated water use including life-saving irrigation, animal watering, ground water recharge, etc.
    b. Impoundments resulted from brick-kilns, mining, etc.
    c. Ponds, tanks, raceways, running water systems, re-circulatory/filtering systems (open/closed), pens, racks, cages, off-stream ponds, sub-surface water collection/diversion tanks suitable for integrated water uses.
    d. Exclusive fishponds.
    e. Fish farming in other irrigation facilities
3. Integrated fish farming, rice-fish culture, sewage-fed aquaculture, etc.
4. Integration of fish farming with irrigation tanks, channels, canals, *ghuls*, etc. and along with multipurpose River Valley Projects (RVPs), microhydral projects, micro-irrigation projects of agriculture, environment and tourism development.
5. Mono- and poly-sex culture of tilapia.
6. Mono- and poly-culture of catfish and air-breathing fish culture.
7. Mono- and poly-culture of freshwater prawn, shrimp farming, mussel farming, oyster culture, pearl culture, crab culture etc.

Various carp culture in inland water for local consumption and shrimp culture in coastal/brackish water for export are the two major aquaculture practices adopted widely in India. To a lesser extent, tilapia, catfishes, freshwater prawn and pearl culture in inland waters, milkfish, sea bass, grouper, crabs, pearl and edible oysters, clam and seaweed culture in coastal/brackish water, trout and mahseer culture in coldwater environments are in practice in India. Besides these, broad categorization of aquaculture and aquaculture systems are given in Table 2. Glossary of aquaculture and aquaculture systems related terms are given in Annexure 1 for reference.

Indian Major Carps (IMC, catla, rohu, mrigal) and exotic carps (silver carp, grass carp and common carp) are widely suited and cultivated species among freshwater finfishes in India as a whole. As regard to hilly ecosystems, Indian Major Carps are suitable only in lower hills, but in upper hills and beyond middle Himalayas exotic carps only found to give economic returns. Various culture techniques, feeds, fish seed attributes, fertilization, liming etc. regarding carp culture is extensively researched in plains. But in Himalayan perspectives and in hill ecosystems, many of the underlining principles on these culture techniques are yet to be studied in detail. Similarly, on other aquaculture species like trout and mahseer and their culture technologies in mountain ecosystems still require extensive research efforts in order to enhance productivity.

Integrated Farming Systems (IFSs)

Aquaculture can be integrated with almost all farming activities that are associated with water and ponds. Of the many kinds of integration, paddy-cum-fish culture and fish-poultry-piggery-agriculture are very common in many parts of the Globe. Strategic integration of various farming activities including agriculture, animal husbandry, agro-forestry and agroestology along with aquaculture in fishponds, farm ponds and WHS would bring-in multifarious prosperity for any given landscape through synergetic effects.

Integrated Farming System (IFS) has many inherent advantages over monoculture systems. The output of one integrated sector becomes input for others, providing augmented profit and reduced wastes. It would be broad-based and reduce inter-sectoral conflicts too. However, while establishing strategic farming integrations with existing farming practices, basic farming principles and connecting modes with the understanding of their needs and limitations need to be born in mind.

Beginning aquaculture, its requirements and stages

Prior to begin aquaculture in a large and commercial scale proper planning and studies on various feasibilities (economic, biological, technical and legal) are essential. Subsequently, a hands-on training for water management, basic fish biology and fish culture is necessary to start aquaculture in a small-scale for pilot testing so as to initiate commercial operation later.

Proper planning, market survey, selection of suitable species, their inputs' availability including technologies, site selection, appropriate design and construction of farming systems and facilities are to be made so as to avoid later stage costly mistakes and losses.

Like in any farming enterprise, aquaculture yield (Y) depends on quantity of production (Q), prevailing price (P) and cost of production. While yield depends on stocking densities and management intensities, price is influenced by demand and market situations. Cost of production depends on price and availability of inputs such as fish seed, feed, medicines, chemicals, labour and interest on capital or lease amount. Thus, the yield potential is expressed as $Y = Q \times P - C$. All efforts to enhance Q and P and reduce C by different ways and means need to be undertaken to realise maximum benefits.

While the prime necessities for watershed-based low-input fish farming are land, pond and water as in any fish farming system, it also requires active participation and confidence of farmers, Watershed Development Associations (WDAs) and other stakeholders of local land-water resources. They basically are to be developed as essentials of Integrated Watershed Management (IWM). In fact, essential needs of fish farming (Table 3 and 4) are generally enshrined in the programs of watershed management. Overall critical needs for aquaculture are as follows:

1. Land-water and pond
2. Fish/aquaculture seed
3. Fish/aquaculture feed
4. Labour
5. Demand and market
6. Institutional capacities for financial support and dissemination of culture and technical know-how.

Table 3: General requirements for fish farming under watershed management.

Sl. No.	Requirements	Specifications
1.	Land-water	• 7 - 30 ha watershed/catchment for 1 ha-m water • Volume runoff/Pond Volume: Humid = 3 Semiarid = 4 • (E + S) -P = 25 cm/yr (E= Pan evaporation* 0.7; S = Seepage; P = Precipitation) • Rainfall seasonality (consecutive days without significant rainfall) = 5 - 25 days (more days is acceptable, if alternate source water available) • Vegetative cover in watersheds = 70 - 100 % (Less cover is permissible, if conservation measures are established) • Depth to water table = > 75 cm • Water source: surface, sub-surface water harvesting, snow and spring fed streams and runoff.
2.	Suitable species and fish seed rate	• 0.5 - 4 Seeds/m^3 stocking density. • Seed price - Rs.75 - 125/1000 seeds. • Species - Indian and exotic carps (catla, rohu, mrigal, silver carps, grass carps, common carps), air-breathing fish (live fish), catfish (magur, etc.) prawns, shrimps and cold water species like mahseer, trout, *Schizothroax* spp.
3.	Feed	• Natural food maintenance through pond and water management. • Artificial/supplementary feed arrangement. • Potential feed ingredients – rice bran, wheat flour, oil cake, tapioca powder, fishmeal, agricultural, slaughter (for carnivores like magur and *Channa* spp.) and household wastes. Normally, rice barn and oil cakes, 1:1 ratio would suffice supplementary feed for carps in composite culture. • Local preparation at pond itself as there is no any commercially prepared pellet feed for freshwater fishes in most areas.
4.	Labor	• For feeding, soil and water testing, watch and warding, harvesting and marketing. Of course, if watershed ponds are located far-off from local settlement, chance or intuition for poaching may be remote. Further, through the participation of villagers and other stakeholders, social fencing needs be created to ward-off socio-cultural problems and control or regulate through norms of penalty for violators.
5.	Fish farming techniques most suited	• Low management-minimum intensive, extensive type of carp, prawn, shrimp, catfish and live fish farming.

Table 4: Primary and secondary needs for fish culture

Sl. No.	Categories	Items
I.	**Prime Needs**	Land-water (ponds)
	i)	Seeds
	ii)	Feeds
	iii)	Labour
II.	**Secondary Needs**	
	i)	Feeding troughs/trays
	ii)	Nursery tanks/ponds
	iii)	Fertiliser/cow dung soaking pits
	iv)	Inorganic and organic fertilisers, chemicals like lime, potassium, permanganate (KM_nO_4), copper sulphate, antibiotics etc.
	v)	Boats, ropes, buckets, etc.
	vi)	Water quality testing kits, equipments and accessories
	vii)	Watch shed, store
	viii)	Records
	ix)	Sampling, holding and harvesting nets, pits/tanks

Organized fish farming involves various activities including pond-water preparation, management, seed-feed management, harvesting and marketing (Table 5). All the stages need to be managed scientifically and are invariably important for successful culture operations.

Table 5: AQUACULTURE - Production phases

PRE-PROJECT

- *SURVEY AND PREPARATION (soil, land, species survey and selection based on soil qualities, topography, water availability, approachability, production potentials etc.)*
- *ANALYSIS AND EVALUATION*
- *IMPLEMENTATION AND FARM DEVELOPMENT*

CULTURE

- ***HATCHERY/SEED DEVELOPMENT***

⇒ Brood stock/seed collection/production

⇒ Probiotics and seed production through bio, physical and chemical manipulations

- ***FEED PRODUCTION***

⇒ Raw material production

⇒ Feed preparation through bio, physical and chemical treatments

- ***GROW-OUT PHASE***

⇒ Pond preparation, water preparation, stocking, soil and water management, protection from stresses, farm management, stock management through bio, physical and chemical manipulations

HARVEST AND POST- HARVEST

- *SCIENTIFIC HARVESTING*
- *VALUE ADDITION*
- *MARKETING/EXPORT*

Fish culture, calendar, management and package of practices

The polyculture or composite culture besides monoculture of indigenous and exotic carps, prawn, catfish and cognate technologies are some of the package of practices suitable for watershed management and integrated micro-irrigation programs. Practice of composite culture would be most suitable for WHS. Here, composite culture means, culture of various species together in a system that occupy different ecological niches utilizing complete eco-system effectively.

Stocking of bottom, column and surface feeders would utilize all the feed and space available in ponds. For example, composite carp culture of three or six species combination (Table - 6) comprising catla, rohu, mrigal, silver, common and grass carps together is advocated in WHS/fishponds. However, suitable species combination and their combination ratios are to be standardized precisely through experience for given locations.

Table 6: Approximate species combination for composite carp culture

Feeding niche	**Species combination**			
	Three	**%**	**Six**	**%**
Pond surface	Catla	40	Catla and silver carp	30 and 15
Pond column	Rohu	30	Rohu and grass carp	20 and 10
Pond bottom	Mrigal	30	Mrigal and common carp	15 and 10

About 0.5-8 fish seeds/m^3 stocking is preferred for modest level of management. Good quality seeds are to be transported quickly with least stress from hatcheries and stocked in pond during cool hours after a brief acclimatization. Initially, seeds may be acclimatized in a secondary pond (2x2x1.2 m or 3x3x1.2 m) near main pond or small happa (1.5x1.5x1.5 m or 2x2x2 m) erected in main culture pond itself to impose close monitoring and slow weaning before being released into culture ponds so as to increase initial survivability.

Knowing initial survivability is a precursor to calculate biomass, feed requirement and other yield related parameters subsequently. Regular feeding, periodic netting for biomass health checks, growth assessment and appropriate feed adjustments accordingly are paramount efforts for win-win farming. Pond and water preparation, periodic renovation of pond, soil-water quality management, scientific fish farming, programmed harvest and post-harvest management, input-output planning, store management and record keeping are essential for successful fish farming in watershed/fishponds.

All basic input requirements in quality and quantity, their procuring schedule and means are to be identified in advance so as to avoid unexpected problems latter during culture. Appropriate store for feed materials, lime, fertilizer etc. is to be managed to set aside storage dependent problems.

Stocking during March-July and harvesting during Dec. - Feb. may be the ideal calendar of fish production in most hill regions. For coastal shrimp farming, two crops per year are possible. The first crop is from March to June and the second from Aug. – Nov. As regards to carps, normally, one crop per year is harvested widely either from March/April or July to December. Stocking is influenced by availability of adequate water and quality seeds. Some of the major fish/shellfish culture duration and their average production potentials are given in the following Table 7.

Fish growth rate is relatively faster in summer and poorer in winter. Hence, exclude winter months from culture or maintain with minimum feeding and pond management, as there may not be appreciable growth due to poor energy trapping in pond and sluggish fish physiological functions during winter. Harvesting may be proposed depending on climate, growth rate, existing biomass in ponds, market situations, demand for fish and profit potentials. Best time for harvest could be Dec. - Feb. during low growth rate and good price exist.

Table 7: Major fish/shellfish culture technologies, their duration and average production potentials

Sl. No.	Aquaculture technologies	Duration (months)	Stocking density	Production potential
1.	Brackish water shrimp farming	3 – 4	1 – 10 Post Larva/m^2	3 – 6 t/ha/crop
2.	Freshwater prawn culture	5 – 8	1 – 10 Post Larva /m^2	1.5–2 t/ha/crop
3.	Polyculture of carps with prawn	8 –12	5 fish, 5 –10 prawn /m^2	3 – 4 fish, 0.3 – 0.5 prawn t/ha/year
4.	Composite carp culture in fishponds	5 – 12	0.5 – 10/m^2	3 – 7 t/ha/year
5.	Composite carp culture in watershed ponds	5 – 8	0.5 – 8 fish/m^2	2.5 – 4 t/ha/year
6.	Sewage-fed fish culture	5 – 12	0.5 – 4 fish/m^2	3 – 5 t/ha/year
7.	Weed-based carp polyculture	5 – 12	0.5 – 6 fish/m^2	3 – 4 t/ha/year
8.	Biogas-slurry based fish culture	5 – 12	0.5 – 5 fish/m^2	3 – 5 t/ha/year
9.	Integrated fish farming with poultry, pigs, ducks, horticulture etc.	5 – 12	2 – 4 fish/m^2	3 – 5 t/ha/year
10.	Intensive fish culture with supplementary feeding and aeration	5 – 12	8 – 20 fish/m^2	10 – 15 t/ha/year
11.	Pen culture	4 - 7	3 – 6 fish/m^2	3 – 5 t/ha/year
12.	Cage culture			10 – 15 kg/m^2/year
13.	Running-water fish culture			20 – 50 kg/m^2/year
14.	Paddy-cum-fish culture	4 – 6	0.5 – 2 fish/m^2	1 t fish/ha/year and 5 – 6 t paddy/ha/year
15.	Cage culture in irrigation channels for fish seed nursing	3 – 6	1000 – 1500 fish seeds/m^3	Rs.10,000 in 3 months from 100 cages in 1 km canal
16.	Culture of air-breathing fishes and catfishes	6 -10	15 – 20 fish/m^2	3 – 6 t/ha/year

Water management and fish production techniques in watershed/fishponds

Although aquaculture is a non-consumptive enterprise/farming, it has specific water requirements in respect of water depth, velocity, water quality, water supply reliability and duration especially in irrigation systems and watershed ponds.

Watershed-based aquaculture may be managed through minimum input for additional benefits. The general requirements for fish farming in watershed ponds are given in Table 3 and 4. Parameters to assess runoff (water) for production potentials that need to be born in mind while aiming for runoff-fed aquaculture are listed in Table 8. Low-input extensive types of fish farming, composite carp culture and polyculture of fish and prawn are some of the suitable fish production techniques under watershed mission.

The Watershed:Pond Ratio (WPR) should be properly matched to harvest potential water yield for productive and conservative use. Normally, 7 - 30 ha watershed may provide 1 ha-m water depending on the features of watershed, rainfall and climate. If water yield is more, series of ponds may also be proposed to harvest potential water for augmented and conservative production. For effective pond and production management under watershed development, appropriate design, orientation, size, shape and capacity of ponds accounting quantity, quality, period of availability, demands and losses of water are indispensable.

Any intensive disturbance in watershed would eventually affect water quality in watershed ponds and reflect in productivity. Hence, effective watershed treatment and management are essential to reduce problems like eroded soil reaching pond causing turbidity, reduction of pond capacity, light entry and primary productivity in watershed ponds. Further, screening with suitable mesh at inlets and outlets is essential to screen out weed species, sediments and other allochanthous materials and to prevent the escape of stocked fish biomass respectively to avoid latter stage problems and production losses.

Despite many inherent benefits of aquaculture in watershed ponds, stringent water management may not be possible as water source to ponds is mainly from limited rainfall-runoff. Water level may go down below critical level of 1.0 m during summer or low rainfall period limiting aquacultural productivity. However, during water scarcity periods, conjunctive use of ground water or irrigation canal water if available can be established to evade the problem greatly.

Integrated use of water for life-saving irrigation or others need to strike a compromise to accommodate aquaculture as it would require a minimum water level of 1.0 m or more according to species, density, biomass and location. In fact, a co-ordination and compromise between agriculture use and aquacultural need are to be arrived to maintain a minimum dead level in ponds to favour optimum production from both.

Table 8: Runoff (water) assessment parameters for aquaculture considerations

Runoff quality - Turbidity, colour, odour, nutrient load, heavy metal concentration, pesticide levels.

Runoff quantity - Adequacy for fish culture and other demands, temporal variation and its influence on runoff quality, runoff loss and management details.

Ecological and physico - chemical parameters - pH, temperature, E^h, dissolved oxygen, BOD, alkalinity, organic matter, ammonia, total suspended solids, depth, etc.

Biological diversity - Qualitative and quantitative phyto- and zooplankton composition, microbial load, other macro-organisms and vegetation, prey-predator relationship, temporal variation and influence on productivity.

Productivity - Primary productivity, culture practices and yields, pond performance and biomass behavior.

Tips to pond management

1. Water entering pond need to be checked for nutrient levels so as to program external fertilization or to prevent entry of excessive nutrients from runoff.
2. Divert excess water when possible, around rather than through pond to prevent loss of added nutrients. Nutrients maintain plankton bloom that shades out less desirable plant species and forms food for fish.
3. Regulate water levels, if needed, through drains for better control of weeds, pond bottom spoilage, fish populations and for easy access to repair or renovate pond.
4. Trees or other woody vegetation should never be allowed to grow on dam, because roots would eventually penetrate the core and cause pond to leak. Additionally, un-cleared roots, stems and vegetation would hamper future fish culture activities especially during netting and harvesting.
5. Fields next to ponds should have sod-border as buffering zone. Hence, maintain sod or grass strips 50 - 100 feet wide between field and pond to reduce soil erosion and pesticide contamination that can cause fish kills.

Water quality management

By and large water quality determines the success or failure of fish farming operations. Fish perform all their bodily functions in water. Since fish are totally dependent upon water to breathe, feed, grow, excrete wastes, maintain a salt balance, and reproduce, understanding the physical and chemical qualities of water and basic fish biology are critical for successful aquaculture.

Water quality is important for fish farming and roughly can be determined/monitored by observing watercolor, transparency (alternatively white and dark colored (seechi) disc's disappearance level to find turbidity), testing water pH, temperature, dissolved oxygen, carbon-di-oxide, alkalinity, hardness, ammonia and other pollutants etc.

Prediction of water quality problems to propose timely corrective measures must be regularized for assured production. Water testing kit with all necessary chemicals and tools are prerequisite for frequent monitoring of water quality. Desired water quality parameters for optimum fish production in freshwater and brackish water environments are given in Table 9.

Water quality problems may be more severe in watershed ponds than in levee ponds because of various problems. Greater depths of watershed ponds experience summer stratification and contribute to water quality restrictions. Surface water warms during summer decreasing its density and resulting in a layer of oxygenated water 4 to 6 feet deep floating over an extended layer of cooler, denser and oxygen-less water. This stratification may last for few days to months. Turbid/muddy incoming water tends to flow along bottom because of higher density than top cleaner water of pond. Problems arise when these two layers mix due to wind, rain etc. as “turnover” takes place.

Bottom water of the pond accumulates decaying plant materials and other organic loads especially during warm weather. Consequently low oxygen levels occur that cause water sediment to release phosphorous into water often beyond the need. Thus, bottom water exchange at times becomes essential in runoff-fed ponds to eliminate cooler, oxygen-less, muddy, silt-loaded water and organic settlements. Discharging bottom water would provide remaining clear surface water for production.

Sediment control is best achieved by preventing erosion in the watershed, supported with sediment-traps and bottom water exchange. Adequate dissolved oxygen (> 3.5 parts per million (ppm)) in pond water is important for fish culture and it depends on temperature, atmospheric oxygen (O_2), rate of oxygen dissolution, photosynthesis (primary productivity), respiration of aquatic organisms and sediments in pond. Normally during daytime O_2 level in ponds may rise due to photosynthesis and in night decrease due to respirations.

At times, dissolved O_2 demand in pond may rise due to oxidation of bottom organic matter, sediments and dissolved metals, death and decay of algae that may ultimately deplete available O_2. Thus, pond water aeration may be necessary to avoid low O_2 level below 3.5 ppm especially in early mornings when O_2 deletion might occur proving detrimental to fish biomass due to asphyxia condition developed. This problem may not be severe in levee ponds.

Table 9: Ideal values of various water quality parameters for aquaculture in two types of water environments.

Sl. No.	Parameters	Freshwater	Brackish water
1.	Colour (Colour units)	Clear water with greenish hue < 100 colour unit	Clear water with greenish hue < 100 colour units
2.	Transparency (cm)	20-35	26-35
3.	Clay turbidity (mg^{-1})	< 30	< 30
4.	Solids ($mg1^{-1}$)		
a)	Total	< 500	< 500
b)	Suspended	30-200	25-200
5.	Temperature (°C)		
a)	Tropical climate	25-32	25-32
b)	Temperate climate	10-12	10-12
6.	pH	6.7-9.5	7.0-8.7
7.	Hardness ($mg1^{-1}$)	30-180	> 50
8.	Alkalinity ($mg1^{-1}$)	50-300	> 50
9.	Chlorides ($mg1^{-1}$)	31-50	> 500
10.	Salinity (ppt)	< 0.5	10-25
11.	Dissolved oxygen ($mg1^{-1}$)	5-10	5-10
12.	Total dissolved free carbon dioxide ($mg1^{-1}$)	< 3	< 3
13.	Ammonia nitrogen (NH_3-N) ($mg1^{-1}$)		
a)	Unionized (NH_3)	0-0.1	0-1.0
b)	Ionized (NH_4^+)	0-1.0	0-1.0
14.	Nitrite Nitrogen (NO_2-N), ($mg1^{-1}$)	0-0.5	0-0.5
15.	Nitrate nitrogen (NO_3-N) ($mg1^{-1}$)	0.1-3	0.1-3
16.	Total nitrogen ($mg1^{-1}$)	0.5-4.5	0.5-4.5
17.	Total phosphorus (mgl^{-1})	0.05-0.4	0.05-0.5
18.	Potassium ($mg1^{-1}$)	0.5-10	> 0.5
19.	Calcium ($mg1^{-1}$)	75-150	> 75
20.	Magnesium ($mg1^{-1}$)	20-200	200-1350
21.	Sulphate ($mg1^{-1}$)	20-200	200-885
22.	Silica ($mg1^{-1}$)	4 -16	> 5
23.	Iron ($mg1^{-1}$)	0.01-0.3	0.01-0.3
24.	Biochemical Oxygen Demand (B.O.D.) ($mg1^{-1}$)	< 10	< 15
25.	Chemical Oxygen Demand (C.O.D) ($mg1^{-1}$)	< 50	< 70
26.	Hydrogen sulphide ($mg1^{-1}$)	< 0.002	< 0.003
27.	Residual chlorine ($mg1^{-1}$)	< 0.003	< 0.003
28.	Primary productivity (mg C/m^3/day)	1000-3000	1000-2500
29.	Chlorophyll - a ($\mu g1^{-1}$)	20-275	20-250

Source: CIFE (1997). Training Manual - Recent Advances in Management of Water Quality Parameters in Aquaculture. P 183.

Pond aeration can be effected through aerators or recirculating and agitating pond water by operating two small 2 Horse Power (HP) pumps kept diagonally on pond dykes. If aeration is not possible and fish surfacing due to oxygen depletion occurs simple agitation of water with wooden poles and subsequently thinning of fish biomass by partial harvesting and/or water exchange may be advocated. Equipping watershed ponds with electricity and aeration may prove expensive.

Fish species, seed attributes, selection and stocking for culture

While selecting species for culture, few defining parameters like growth rate, acceptance of artificial feed, compatibility with other species, suitability to the environment, existence of good taste and demand, local availability of inputs such as seed, feed, technical know-how; involvement of limited/no risks and such others (Table – 10 and 11) are to be considered critically for the successful farming. Largely, species availability is not a constraining issue in most tropical countries like India as fish diversity here is one of the richest in world.

Fish seed quality is an important attribute that needs to be paid greater attention to ensure expected yields. Disease free- and healthy-seeds would consume feed actively and resist against diseases or stressing agents registering good survivability, growth rate and hence total ultimate yield. Poor quality seeds would be problematic right from beginning to last extent that low survivability, disease or risk proneness, soil and water contamination due to excessive mortality or non-feeding may be experienced.

Good quality seeds are identified through observing for activeness to stimuli, bright body color, uniform size, lack of discoloration, rotting or body soar, and body mutilation. Fish seeds can be normally collected from two sources such as wild environments like streams, rivers, estuaries, mangroves and creeks or hatcheries. Seed availability from wild environment is generally poor, inadequate, uncertain and most often stands as poor quality because of non-uniform sizes.

Table 10: Principles of species selection for aquaculture.

Sl. No.	Species qualifications
1.	Rapid growth potential and short life cycle in given agro-climate.
2.	Ability to use natural/accept artificial feed with high Feed Conversion Efficiency (FCE).
3.	Culture inputs and requirements are easily available.
4.	Hardy, resistant to disease and infections, tolerant for crowding and high-density conditions.
5.	Have high fecundity.
6.	Prolonged or multiple breeding frequency. Easy to bred in pond/captivity or amenable for artificial propagation to have adequate seed supply.
7.	Exhibit high survival rate.
8.	Non-predaceous, non-cannibalistic, non-territorial and preferably planktophagous and herbivorous.
9.	Be easy to handle, harvest and transport.
10.	Compatible with other species and adoptability to wide range of culture systems.
11.	Small head, high body profile, thick back, and have good dress-out weight values.
12.	Low bone to flesh ratio, good cutability and easy to process.
13.	Have long shelf-life.
14.	Palatable with high nutritive values and healthy appearance with agreeable colors.
15.	Possess adequate demand and markets.

Table 11: General guidelines for stocking

Sl. No.	Pond situation/ecosystem	Emphasis while stocking/Stocking principles
1.	Scientific stocking	The stocking should emphasis trophic strata of the ecosystem in terms of shared, unshared and vacant ecological niches
2.	If the pond is eutrophicated and weed infested	More of grass carps to be stroked
3.	If the pond is deep	More of column feeders *i.e.* rohu and grass carps to be stroked
4.	If the pond is managed under external feeding	More of fast growing and demanded species like catla and rohu to be stroked
5.	If colder region	More of exotic carps to be stroked
6.	If warmer water	All species in suitable proportion according to demand to be stroked
7.	If turbid and polluted water	Air-breathing and catfishes, instead of carps to be stroked
8.	If soil-water is poor in nutrients and productivity	Adequate lime and fertilizers to be applied
9.	If water shortage exists	Production of fish fingerlings may only be taken up rather than grow out culture

Presently, in India and elsewhere, seed supplies from hatcheries are not appreciable throughout the country baring limited pockets for few species like shrimps and carps. Even for widely cultured species, seed availability problems do exist almost in the entire country. Hence, development of local fish seed hatcheries, nurseries and seed-banks becomes imperative for reliable, timely, uniform sized and adequately qualified seeds.

Stocking rates are determined by cost of fish/aquaculture seeds and the risk that farmers are willing to assume. As stocking rates increase, feeding rates also increase leading to more accumulation of aquaculture wastes, increased oxygen demand and due risks. Low risk stocking densities are less than 10,000 fish per ha to achieve an average yield 3 – 5 t/ha/year with harvestable size of 0.5 - 1.0 kg/fish. Risks increase as standing crop and biomass increase. Dependable aeration and use of good management enable most producers to reach a standing fish crop of 3 - 6 t/ha.

Pond and water preparation (Liming, fertilization etc.) and management

Prior to water letting in for stocking, pond is to be prepared through established ways of renovation and conditioning. General features and requirements of fishponds are given in Table 12, 13, 14 and 15. If ponds are found contaminated due to over-feeding during previous culture, organic load or with other pernicious materials, planned application of lime, spraying of disinfectants like chlorine and bleaching powder are advocated to prepare ponds for fish stocking.

Top bottom soils should be scraped out at least once in 8 years of culture or when more organic or any settled matter from many years of fish farming or other means have accumulated to endure high productivity of ponds. Otherwise, pond bottom with high organic content may be ploughed (shallow tillage) to expose soil so as to facilitate oxidation and then can be compacted.

Table 12: Features of ideal farm ponds for fish farming

Sl. No.	Features	Ideal specifications/needs
1.	Depth	1.5 - 2 m.
2.	Direction	East-west, windy and sunny direction.
3.	Shape	Rectangular, square or round.
4.	Size	0.1– 2.0 ha in general. 0.02 ha (200 m^2) for rolling terrain and hills.
5.	Inlet	With net liners (filters), adequate sediment detention structures.
6.	Outlet	With net liners (filters), varied shutters for regulated water release/exchange.

Table 13: Preferred critical water quality parameters for composite carp culture

Sl. No.	Critical parameters	Preferred range	Limiting level	Possible correction measures
1.	Dissolved oxygen (ppm)	5 - 10	< 3.5 > 15	Reduce fish density, aerate water, exchange water Exchange water
2.	Free CO_2 (ppm)	< 3	> 20	Aerate water, exchange water
3.	pH	6.7 - 9.5	< 6.5 > 10	Application of lime Application of gypsum/water exchange, if possible
4.	Temperature (^{o} C)	25 - 32	< 15 > 40	Reduce other stressing factors, maintain on minimum feed, harvest fish stock,
5.	Water hardness (ppm)	30 - 180	< 20 > 500	Liming Water exchange
6.	Transparency (Secchi disc visibility, cm)	20 - 40	< 15 > 120	Manual harvesting by net/cloth or killing of plankton by diluted dose of mild chemicals like formalin, water exchange. Liming and fertilization
7.	Color	Clear with greenish hue, < 100 color unit	Dark, brownish, intense greenish Colorless, light color	Manual harvesting by net/cloth or killing of plankton by diluted dose of mild chemicals like formalin, water exchange. Liming and fertilization

Table 14: Runoff-influx associated changes observed in the pond during peak monsoon

Sl. No.	Variables	Ranges during peak monsoon (Change from normal)	Probable causes	Implications
1.	Water level	4 - 4.5 m (Increase)	Heavy runoff influx	Various stratification, poor fish feeding
2.	Physical and Physico-chemical stratifications	Varies (Increase)	Increase in water depth	Physiological stress in fish
3.	Silt turbidity	Highly turbid (Increase)	Heavy sand and silt influx	Poor light entry, photosynthesis and primary productivity, gill choke in fish, siltation, pond capacity reduction
4.	Transparency	0 - 5 cm (Decrease)	High turbid-laden water due to incoming sands and silts	Do
5.	Dissolved oxygen (O_2)	4 - 5 ppm (Decrease)	Less O_2 production through photosynthesis than consumption for respiration of organisms and oxidation of sediments	Prevalence of sub-standard environment for fish
6.	Carbon-di-oxide (CO_2)	3 - 6 ppm (Decrease)	Influx of acidic rainwater	Preferred, but may give poor buffering capacity in pond water
7.	pH	6 - 6.5 (Decrease)	Influx of acidic rainwater	Poor buffering capacity in pond water
8.	Fish feeding	Gradually reduced (Decrease)	More turbidity, more water depth and less primary productivity	Poor growth and less yield

Before stocking, water preparation is invariably indispensable to improve water quality and make water amenable for fish culture. Water preparation may include liming, fertilization, sterilization and eradication of unwanted or unproductive weed fish and other aquatic fauna by netting out or by application of mahua oil cakes, nicotine powder, bleaching powder etc.

Water sterilization with chlorine, bleaching power, potassium permanganate, lime and others may be advised if only the source or pond water are observed to be seriously contaminated with physical, chemical and biological stressing agents. Normally, their use is costly and may not be necessary. Water disinfectants and weed fish killers may be applied in reduced water level to minimize application quantity and enhance desired results.

All these would improve water quality and avoid unproductive competition by weed fish for space, dissolved oxygen and feed so as to provide enhanced fish yields. Most of these applications may not be possible, if watershed pond depends mainly on limited runoff.

Table 15: Favorable range of land-soil parameters for aquaculture

Sl. No.	Specifications
1.	Soil texture: sandy - clay - loam (Sand: 40%, Silt: 30%, Clay: 30%)
2.	Soil colour: blackish brown
3.	pH : 6.5 - 8.5
4.	Water retention capacity: > 40%.
5.	Total nitrogen: > 50 mg/100 gm (0.05%) of soil sample.
6.	Phosphate: > 6 mg/100 gm of soil sample.
7.	Potassium: > 25 mg/100 gm of soil sample.
8.	Organic carbon: > 0.5%.
9.	Electrical conductivity: < 16 millimhos/cm.
10.	Depth to sulfidic or sulfuric layer = >100 cm
11.	Thickness of organic soil material = < 10 cm
12.	Depth to rock = >150 cm
13.	Exchangeable acidity = < 20 %
14.	Lime requirement = < 2 t/ha
15.	Terrain slope = < 2 - 6 %

Liming and fertilization

Regular liming, fertilization and monitoring of water quality during culture are very necessary for organized fish farming. Monitoring water quality by turbidity levels to characterize watercolor, suspended materials including phytoplankton, zooplankton, solids and clay particles are a critical need. If transparency is low due to more suspended solids, alum (aluminium sulphate) or gypsum with care for pH change can be applied to minimize turbidity. Abrupt pH changes may stress fish and affect fish growth.

Liming would maintain buffering capacity of pond preventing sudden pH change. Liming can be done with calcium carbonate (CaCO3), calcium oxide (CaO), calcium hydroxide (Ca(OH)2) and dolomite (CaMg(CO3)2) essentially to increase pH (if acidic), buffering capacity and sterilization of water. Initially, 300-400 kg of CaCO3 or CaMg(CO3)2 or 100-150 kg CaO or 200-250 kg $Ca(OH)_2$ per ha and subsequently 50 kg/ha according to need may be applied. Lime needs to be dissolved with water prior to application in ponds.

Fertilization with organic fertilizers like cow-dung, Farm Yard Manure (FYM) and inorganic fertilizers such as urea and super phosphate can be practiced to improve primary producers, the phytoplankton, optimally so as to produce sufficient live food for zooplankton, fish and fish seedlings. The inorganic fertilizers may be applied at the rate of 150 kg/ha initially and subsequently 50 - 75 kg/ha on need. Organic fertilizers at the rate of 500 kg/ha initially and 100 - 150 kg/ha periodically would suffice to induce primary producers and decomposers. Fertilizers may be dissolved with water and sprayed over pond uniformly to facilitate equal distribution.

If the source runoff comes through nutrients-rich agricultural fields, the water may carry adequate nutrients to the extent that external application of fertilizers may not be necessary. Similarly, in raceways or ponds that have excessive seepage, application of fertilizers and others may not be useful, as they would be washed out without contributing much to pond fertility and productivity.

Water pH, temperature and dissolved oxygen are normally measured twice a day in early morning around 6 A. M. and evening 3 P. M. to monitor and correct the diurnal variation in acid-base state, buffering capacity, temperature and dissolved oxygen contents of water if needed. However, water quality of watershed ponds may not change abruptly until heavy runoff comes in and abrupt climatic changes occur.

Turbidity and its control

Suspended solids including silts, clay and microscopic organisms such as pytoplankton and zooplankton cause turbidity meaning cloudiness or muddiness of water. Thus, turbidity may be of two kinds, clay turbidity or plankton turbidity. Clay turbidity in the pond might arise either out of incoming turbid runoff from over grazed and erosive watersheds or pond bank erosion from wave action and certain bottom dwelling fish such as common carps. Plankton turbidity would be the result of plankton bloom.

Generally, plankton turbidity to certain level (20 - 60 cm transparencies) is desirable for pond productivity and fish culture. However, often, suffocation of benthic organisms by the settlement of solids, off-flavour in fish due to plankton crash and other related problems may result out of turbidity.

Clay turbidity problems are more in soft and poorly buffered (low alkalinity) waters. Turbidity reduces the aesthetic value of ponds. Muddy water tends to have lower dissolved oxygen than water with plankton turbidity. Suspended solids in ponds would have profound effect in reducing the light penetration and thereby limiting pond productivity, enhancing absorption of heat from sunlight raising water temperature and increasing the risk of de-oxygenation in pond water.

Further, clay turbidity would limit photosynthesis and respiration. Hence, wider diurnal fluctuations in dissolved oxygen content that arises out of inadequate photosynthesis during day and reduced oxygen availability due to excessive respiration in night would be experienced. If sudden turbidity occurs, low oxygen level might prevail necessitating aeration or water exchange in addition to water treatment with lime. In most watershed ponds, the possibility for water exchange is remote.

High-suspended solids beyond 20,000 ppm might cause behavioral disturbance. However, turbidity level up to 20,000 ppm may not affect fish population and often, even muddy water would have less than 2000 ppm suspended solids.

In a way muddy water would pose severe damage to overall aquatic productivity in terms of loss in phytoplankton, photosynthesis and dissolved oxygen content, and enhanced bottom sedimentation. Fish gill tissues are the most susceptible for turbidity impacts. Gill damages through excessive mucus production or clogging and bacterial gill diseases are common responses to high-suspended solids in water.

If excessive soil working in catchment happens over sedimentation in down-stream ponds would occur. Subsequently, the accumulated sediments and organic materials would undergo oxidation in pond that would eventually lower dissolved oxygen level in pond water especially during night when only oxygen consumption (respiration) and no generation occurs.

With the principle of prevention is better than cure, arresting the source of clay, sediments and turbidity through proper watershed management and control structures like silt fences, sediment basins and Sediment Detention Structures (SDSs) both in watersheds and at inlets as preventive measures would prove beneficial. If the watershed is erosion prone and ponds witness turbidity problems, its control requires both watershed and pond management.

Clay turbidity can be controlled by adding metal salt substances like alum (aluminium sulphate) and gypsum at the rate of 25 - 45 kg ha^{-1} and 1,000 -3,000 kg ha^{-1} respectively according to turbidity levels that facilitate flocculation, coagulation and settlement.

However, application of alum or gypsum might lower water pH. At low alkalinity (< 20 ppm as $CaCO_3$), alum can reduce water pH to levels that would affect fish growth and survival. Hence, in low alkalinity water, addition of half part hydrated lime for every part of alum applied may be necessary. Further, as these coagulants may remove potential plant nutrients especially phosphorus from water, phosphorus fertilization should essentially follow turbidity treatments. Besides, treatments to reduce turbidity including alum or gypsum application would add to production cost and reduce profit potentials ultimately.

Depending on water pH, turbidity and water depth levels, alum application needs standardization through experimentation using buckets-full pond water in order to economize effective treatment. Often, fertilization and resultant phytoplankton blooms as such might reduce suspended particles. Besides these, some stray reports reveal that organic matter such as chopped hay (15 - 25 squares bale of hay/surface ha) or cottonseed meal can reduce clay turbidity in ponds.

All these treatments must prelude to arrest of the cause of turbidity problems by watershed management, pond protection and soil conservation practices including SDSs, buffer strips, balanced grazing and deepening pond edges to minimize scouring edges by wave action. Periodic cleaning, conditioning and de-silting of ponds at least once in 8 years would contain severity of turbidity in the conserved water.

Fish-feed and feeding

Fish feed accounts for almost 40 – 60 % of investment costs in most fish farming efforts. Normally, fish feeds include natural (live foods) and supplemental or artificial feeds. Natural fish foods for different species include phytoplankton, zooplankton, benthos, aquatic insects, other small organisms, microphytes, peripytons, macrophytes and detritus mass. Natural foods can be induced through liming, external fertilization and water management.

Natural (Live) foods

Most fish species mainly depend on live foods particularly during their initial stages such as fry, fingerlings and small fish seedlings. So, maintaining adequate live foods in pond is very important at least to improve initial survivability, subsequent growth rate and water quality.

Light green to green and light brownish watercolors are observed to contain necessary blue-green, green and brown algae and other live foods in adequate quantity. Red, dark brownish, black and clear (colorless) water are poor quality and unsuitable for fish culture. Ponds/systems with such water do require water culture/exchange besides harvesting of excessively unwanted phytoplankton growth if any or liming and fertilization in clear water to induce appropriate color through desired phytoplankton bloom.

Artificial (supplementary) feeds and feeding

Supplementary or prepared/artificial pellet/dough feeds are available in markets for certain species like shrimps and carps. However, their uniform availability throughout any region is doubtful. Virtually, shortage or non-availability of prepared feeds in markets hampers motivation of innovative farmers towards aquaculture. Good quality commercial feeds are essential to produce fish in large-scale. So, mass-scale feed production may help popularization of fish farming in IWM.

Besides ready-made feeds, local feed formulations can also be prepared at pond site itself using locally available materials; agricultural and household wastes along with few other essential feed additives like vitamin and mineral mix on need basis for high density and intensive production management. Local fish feed ingredients may include rice bran, oil cakes (groundnut, mustard, or any edible oil-cakes), wheat flour, tapioca powder, fishmeal, soybean powder and household wastes. These local ingredients can be prepared into pellets or small dough using water for feeding.

Largely, to carps, a mixture of oil-cakes and rice or wheat bran in 1:1 proportion can be used successfully. The mixture can preferably be cooked prior to pelletize using hand-held, commercial, household or mechanized pelletizer with suitable dies. The pellet feeds should be air-dried before feeding for good results in ponds. Good smell, taste, color, consistence and buoyancy of feeds are important to attract fish, stand in water at least for few minutes to facilitate feeding and sink slowly to be available to bottom living fishes.

Right feeding according to fish survivability and 2 - 4 % of fish biomass in ponds would improve fish production and its economics. Under-feeding would attract high competition for feed and induce size variations among fishes as the vigorous ones pick-up feeds fast and grow regularly leaving the un-fed weak and ultimately as dead due to cannibalism (if cannibalistic) or infection. On the other hand, over-feeding would not only enhance input costs for no benefit, it would also deteriorate pond bottom and water quality due to continuous accumulation of un-fed feeds inviting disease problems and yield loss.

Normally, feed is distributed uniformly over pond areas for effective feeding. Otherwise, feeding at specified locations constantly is also practiced particularly in carp culture to avoid feed wastages. Tray feeding (Fig. 1) to check feed consumption rate of fish and boat feeding to feed in defined feeding zones earmarked with ropes tied over water surfaces would avoid excess feeding and production losses. These practices would help in exacting needed feed increments and minimize feeding in non-feeding zones in ponds under semi-intensive and intensive-culture.

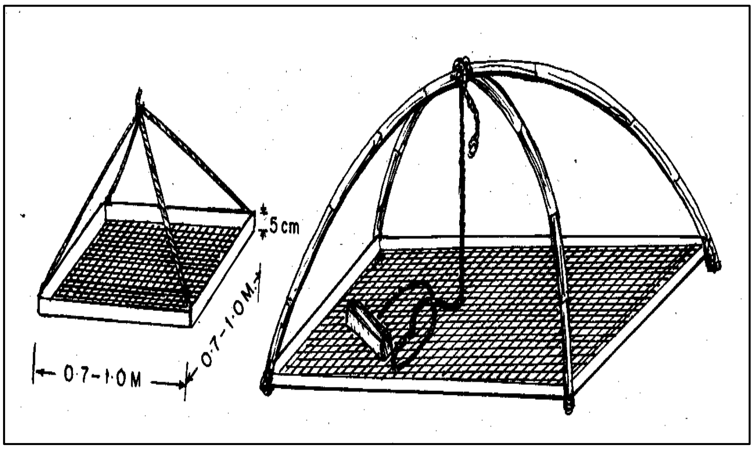


Fig. 1: Fish feeding trays

Feeding only from a short dam may restrict feeding activity resulting in slower and differential growth rates. A better way to feed fish in watershed pond is by a boat to spread feed over large areas especially when high fish density exists. Boats or barges should be equipped with hoppers for bulk feeding over extended areas.

High depth ponds may develop thermocline, oxycline and chemocline layers causing temperature/dissolved O_2 shock to fish and harvesting problems. Since most culture species would avoid deeper zones, preferably, no or minimized feed should be applied in deeper water. Otherwise, floating feeds can be used in deeper ponds. Feeding of contaminated feeds would only promote infection and stock degradation. Hence, demand based preparation of feeds and cares to preserve prepared feeds may be practical to avoid such problems.

Surveillance of fish diseases and fish health management

Fish disease is the culmination of an interaction between the susceptible fish, pathogen and the environment. If the equilibrium between them is disturbed, conducive conditions for an outbreak of disease occur causing death in case of extreme or behavioral changes, reduced growth, Feed Conversion Efficiency (FCE) etc. under sub-lethal levels.

Stress is the overall cause of disease outbreaks and is a reaction to unusual conditions that include chemical, physical, biological and procedural stressors like temperature extremities, rapid pH changes, high ammonia, nitrite concentration, low oxygen, high carbon-di-oxide, excessive handling, extreme turbidity and poor nutrition.

Control of stress needs good management starting with proper stocking of good quality seeds, feeding, careful handling and water quality management for successful harvests. A coordinated effort through appropriate liming and fertilization are indispensable to induce adequate primary productivity and phytoplankton so as to ensure required natural fish foods, appropriate dissolved oxygen level of 4 – 8 ppm, a negligible level (0 – 2 ppm) of free CO_2 in water and ideal stress-free environment. Also, timely identification of problems, stresses and diseases and implementation of required measures including water exchange, thinning of biomass, medication through water treatment or feed according to infections may evade production losses greatly.

Fish disease can be of both infectious and non-infectious nature according to the cause agents. The root causes for infectious diseases are mainly parasitic (protozoan), bacterial, viral or fungal agents that cause irritation, damages in gills, skin, weight loss, systemic failures, and ultimately death.

Infectious diseases can be controlled by the application of formalin, copper sulphate, potassium permanganate in water and others like anti-bacterial/viral agents through feeds in suitable concentration depending on the intensity of infection in the presence of a trained technical person. Chemical treatment may be needed to correct or improve water quality of ponds. Treatment of pond water according to water volume in right quantities without giving rooms for under or over treatment is to be practiced, strictly on demand.

Non-infectious diseases are primarily caused by environmental problems, nutritional deficiencies and genetic abnormalities. Hence, they can be avoided by providing suitable culture environments to the healthy and genetically superior seeds. If an outbreak is severe, water exchange can be proposed to eliminate/dilute concentration of stressors.

During minimum rainfall and water scarce year, drying and scrapping of all settled matter may be proposed regularly to endure high productivity. If the pond and catchment are in integrated use, dependence on pesticide for pest control in agricultural fields should be kept at very minimum. This would help to reduce problems due to residual effects of pesticides reaching ponds. Fish seeds, fingerlings, micro-plants and plankton are more susceptible for synergetic pesticide effects.

At high temperature and low dissolved oxygen condition, most fishes pumping more water and hence more pesticide over their gills exasperating damages. In high turbidity, the toxicity and effect of pesticide pollution may be diminished as most pesticides are easily bound to the large amount of organic matter present in such environment.

Overall, maintaining healthy pond ecosystems and resorting to Best Management Practices (BMPs) are essential to prevent disease outbreaks. Treatment for disease or premature harvest imposed due to severe outbreaks would enhance production costs and reduce productivity and overall profits. Hence, follow strict preventive and prophylactic measures timely to avoid disease causalities. Pick out or weed out the sick or abnormal ones if encountered to avoid further spread of disease.

The diseased or stressed fish with poor health can be noticed from behavioral changes like splashing, surfacing, whiling, rubbing its body against pond banks, non- or sluggish-feeding, resting in corners or shallow areas, discoloration, filmy coloring on skin, spotting on body, pale, white or red spotted gills, excess slime secretion, external mutilation, plankton or fungal settlements on body, abnormal movements and appearance. Healthy fish can be observed through normal color conditions with bright appearance, activeness and behavior, clear red colored gills and escape and defense reflex for disturbances.

Harvesting, economics and record keeping

Watershed ponds should be devoid of all stumps, rocks and trash so that a seine can be used for harvest. Lowering water to 3 - 4 feet deep through drain is the easiest way to harvest. Complete draining may be practical for total harvesting.

Harvesting can be either partial during culture period itself or complete final harvesting after total de-watering of pond. Partial harvesting is normally effected to thin out crowded fish biomass thereby to achieve good pond condition or to meet out pressing local demands for fish. Normally, multiple stocking and harvesting can be practiced in WHS to enhance overall fish production.

Harvested produce can generally be sold at pond site itself depending on demand. Otherwise, packed in baskets or trucks and transported as head-loads or by motors to nearby markets for sale. If the market is in far-off places, icing may be necessary to preserve and improve shelf-life of harvested fish.

In case poor demands exist, the produce can be salted and dried for future use or value added products can also be prepared for higher sale and margin. Record keeping for inputs and outputs during and after every culture period is must to monitor and correct the progress of farming as in any other investments.

Major risks associated with aquaculture

Although aquaculture is often said to be of minimum risk-prone proposition, at times it is constrained by following risks and failures (Table 16).

1. Disease washout – Protozoan, fungal, bacterial, viral and feed related,
2. Poaching and human interferences,
3. Natural calamities like floods and earth quake,
4. Uncertainness in market state,
5. Inadequate supply of quality fish seed and feed.

Table 16: Major problems pxperienced

Sl. No.	Problems observed	Possible remedies proposed
1.	Poor growth rate and high demand during winter	Maintenance of yearlings, hence a need for nursery pond near main pond proposed.
2.	Water shortage during summer, i.e. during potential growth period	About 600 –700 m3 of supplemental water addition during summer needed.
3.	Menace due to aquatic birds' and snakes	Birds' strong scaring devices need to be installed. Weed out snake, if any found.

Applications of biotechnology in aquaculture

The comparison of antiquity and modernity brings the high level advancements of biotechnology and today it offers valuable applications beyond our imagination. At this context, principles of biotechnology have thrown enormous light on the improvement of natural resources. Aquaculture and biotechnology have close links and hold potentials to improve production of food, marine biomedical compounds, marine toxins, marine industrial chemicals, bioactive compounds and management of aquatic environment and pollution.

In a strict sense and according to broad definition of biotechnology as application of biological and engineering principles to receive goods and services from biological agents for mankind, recent day's aquaculture itself is a bio-technical advancement. Production of transgenic fish, super fish, super salmon and raising fast growing fish through hormonal manipulations and genetic engineering are becoming very popular in Global fisheries developments.

However, real bio-technological studies on aquaculture species have been seriously neglected till last decade, and the concept of effective bio-technological research in this field and marine science is quite recent. Hence as with other forms of agriculture, aquaculture endeavor is also to be motivated to feel the impact of biotechnology in years to come.

In this stream, biotechnology finds immense hope in production of transgenic fish/prawn/molluscs with promoted growth, increased nutritional value, flavor and aroma, disease/stress resistance through manipulation of growth hormone (GH) genes, hormonal controls, feeding application of bio-energetic techniques and optimal feed regime, improving Feed Conversion Ratio and Efficiency (FCR and FCE), developing strains of improved probiotics and value addition to the produces.

Further, development of new diagnostic agents/methods like attenuated- and DNA-vaccine, monoclonal antibody (Mab) production and generation of genetically improved and domesticated stock through established techniques and modern advancements are some of the main frontiers of bio-technological areas in aquaculture.

Various technologies and strategies used for aquacultural biotechnology based on scientific and bio-engineering principles include r-DNA technology, gene transfer, protoplast fusion, hybridoma, tissue/cell culture, gene probe (DNA probe), germplasm development, embryo transfer technologies, enzyme and protein engineering, micro-injection, fermentation, ployplodization, hybridization and chromosomal engineering.

Conclusion

In all, fisheries and aquacultural technologies have potential for management of land-water resources including degraded masses. In fact, they can add value to degraded or unproductive land-water resources. Water development, WHS and aquaculture in them along with related activities to minimize wastes and maximize profits in integrated modes are potential interventions for development of watersheds and their resources. Fish farming in WHS requires bare minimum extra resources and energy as most basic resources like pond, water, labour and agricultural waste-inputs are generated that can be integrated with least expenses. Shortly, fish farming in watershed management tasks can be an incentive for resource conservation as it yields extra benefits. Presently, inclusion of fish farming in integrated watershed management efforts is very subsistence in nature and this needs reorientation of watershed programs and policy matters to promote fisheries through this new approach. Both the concepts of watershed management and aquaculture needs appropriate interaction to augment environmental and social prosperity.

Sustainability of natural resources requires inter-disciplinary development including fisheries and aquaculture. Towards this, targeted training, out-reach programmes and awareness campaigns along with programmed and co-coordinated research to characterize the interface between aquaculture and other agricultural sub-sectors under watershed mission are need of the hour.

Mobilization of private resources and entrepreneurs in addition to public investments need to be achieved in order to establish more farm ponds or WHS those can be integrated for development. These would bring-in greater opportunities for self-help and income-generating groups through fisheries and aquaculture-related economic ventures. Automatic and induced participation of farmers in all the farming integration and avenues are very essential to make a balance between development and resource exploitation. If watershed based fish farming is adopted, every watershed will have self-sufficiency to balance nutrition, employment opportunities, purchasing capacities and overall socio-economic wellbeing.

Photo 1: Fish Farming - A viable Venture under Watershed Management Programs

Photo 2: Fish Harvest from a watershed pond - An Incentive for Resource Conservation

Photo - 3 Pig-Fish-Agroforestry Integration

Photo - 4: An Integrated Farming Unit of Fish - Poultry - Agriculture.

SOIL MANAGEMENT TECHNIQUES TO REDUCE AGRICULTURAL NON-POINT SOURCES OF POLLUTION AND IMPROVE AQUATIC ECOSYSTEMS

Debashis Mandal*

1. Introduction

Rapid population growths, land development along river basin, urbanisation and industrialisation have subjected the rivers to increase stress, giving rise to water pollution and environmental deterioration (Sumok 2001). The surface water pollution issue has been enlisted as one of the most serious problems in developing countries. Most of the rivers in the urban areas of the developing world are the end point of effluents discharged from the industries (Phiri et al. 2005). In India, urban runoff and sewerage disposal in river catchments areas is the major problem of river water quality maintenance. The wastewater from urban runoff and industrial discharges contributes to water resources degradations, reduces agriculture production and affects public health. According to Kaushik et al. (2009), in India, where most of the developmental activities are still dependent upon rivers for cleaning as well as disposal purposes, it becomes very important to systemically study the status of pollution of the rivers in relation to various anthropogenic activities, since river water has been used as drinking water and irrigation water for agriculture and for fish culture throughout the history of mankind

A range of pollutants can be introduced to the environment from agricultural fields including nutrients, pathogens, particulate matter, ammonia, and antibiotic or hormone residues. The extent to which an individual farm contributes pollutants is dependent upon a wide range of physical factors, including soils, landscape, climate, the type of animals, and farm management. It is well known that agriculture is the single largest user of freshwater resources, using a global average of 70% of all surface water supplies. Except for water lost through evapotranspiration, agricultural water is recycled back to surface water and/or groundwater. However, agriculture is both cause and victim of water pollution. It is a cause through its discharge of pollutants and sediment to surface and/or groundwater, through net loss of soil by poor agricultural practices, and through salinization and waterlogging of irrigated land. It is a victim through use of wastewater and polluted surface and groundwater which contaminate crops and transmit disease to consumers and farm workers. Agriculture exists within a symbiosis of land and water and, as FAO (1990a) makes quite clear, "*... appropriate steps must be taken to ensure that agricultural activities do not adversely affect water quality so that subsequent uses of water for different purposes are not impaired.*"

This article deals specifically with the role of agriculture in the field of freshwater quality. Categories of non-point source impacts - specifically sediment, pesticides, nutrients, and pathogens - are identified together with their ecological, public health and, as appropriate, legal consequences. Recommendations are made on evaluation techniques and control measures.

*** Senior Scientist (Soils), Central Soil & Water Conservation Research & Training Institute, Dehradun-284 195 (Uttarakhand)**

1.1 The Importance of soil and its effect on water resources

Soil serves a vital function in nature, providing a medium for plant growth as well as nutrients for plants, and habitat for millions of micro and macro organisms. Healthy soil allows them to flourish, release oxygen, hold water and diminish destructive storm runoff, break down waste materials, bind and breakdown pollutants.

The disturbance, compaction and degradation of soils impact the soil structure and reduce its ability to provide these functions. Preserving native soils as much as possible and adding organic amendments such as compost to disturbed soils (prevalent in the urban environment), offer a strategy that allow soils to do their job.

1.2 Healthy soil functions in relation to water

Soil Health is the capacity of a soil to function, to sustain plant and animal productivity and to maintain or improve water quality. A healthy functioning soil will:

I. Reduce nutrient leaching into groundwater
II. Minimize runoff and erosion so water infiltrates into the soil and doesn't runoff into surface
III. water
IV. Filter pollutants
V. Provide a healthy plant rooting environment
VI. Create the proper habitat for plants, animals, and microbes that live in and above the soil

Soil health is worth quantifying because soils and their biota provide ecosystems functions that benefit humans. These ecosystem services can be of considerable value (Costanza et al., 1997) and include soil functions of storing and releasing water, decomposing plant and animal residues, transforming and recycling nutrients, sequestering and detoxifying organic toxicants, and promoting plant health by suppressing plant-pathogenic microbes and phytophagous fauna. It is often possible and desirable to measure soil function directly. In contrast, direct measurements of some soil functions may be too expensive (for example, direct measurements of nutrient transformations) or require observations across too much time (for example, the capacity of a soil to supply water for plant growth during a drought may be observable only during rare drought years). In such cases, rather than measuring the soil function directly, it may be preferable to measure surrogates or proxies that are well correlated with the soil function. Soil organisms meet this criterion, because the abundance and diversity of soil organisms often are well correlated with many beneficial soil functions (Pankhurst et al., 1997). However, care is needed in selecting which organism or which community parameter to use as a proxy for soil function (Bengtsson, 1998).

In major roles of soil in relation to water can be broadly classified as:

Store water and nutrients: Much like a giant sponge, healthy soil acts as a storehouse for water and nutrients. The slow release helps plants absorb the correct amount. As a storage reservoir for both water and nutrients, healthy soil has a greater holding capacity than soils that lack sufficient organisms, organic matter and pore spaces.

Water flow regulation: Like the on/off function of a faucet, healthy soil regulates and partitions water flow, naturally maintaining the water cycle by slowly discharging to streams, lakes and recharging aquifers.

Neutralization of pollutants: Healthy soil is the site of intensive physical, chemical and biological activity, thus it can prevent water and air pollution. Soil rich in organic matter contains microorganisms that can immobilize or degrade pollutants.

1.3 Human impact on soil and water

Soil disturbance from human activity cause dramatic changes to soils from compaction, erosion and development and can lead to the degradation of soil quality. When native soils are removed or eroded, soil organic matter content is reduced, soil structure declines and diversity of soil organisms are lost. Likewise as heavy machinery moves across soil, the pores and channels within a soil profile collapse. As these spaces are reduced, the organisms that thrive there are killed. The heavy use of certain pesticides reduces the numbers of beneficial organisms. With the loss of these organisms, many of the soils vital functions are lost:

- Decline in organic matter inhibits the soil's ability to hold water, depletes nutrients, suppress' plant growth and inhibits the breakdown of toxins
- Decreased biological activity in soil limits nutrient availability to plants
- Soil compaction inhibits water infiltration and contributes to water runoff
- Soil erosion clogs and contaminates waterways

Soils in poor condition from improper management have a reduced ability to function like a healthy native soil. Instead of absorbing water, supplying nutrients and breaking down toxins, surface water runoff increases which can contribute to negative impacts in the watershed hydrology and the salmon habitat including:

1.3.1 Changes in water volumes and flows from surface water runoff

Alterations of sites by development exposes bare soils to rainfall which increases erosion. When sediment enters streams and deposits itself in spawning beds, it inhibits oxygen from getting to fish eggs, suffocating them and causing them to die.

1.3.2 Increased chemicals and pollutant levels from runoff and erosion

Landscapes on poor soils may require more fertilizer and pesticides. Poor soils are also less effective at binding and breaking down pesticides, fertilizers, hydrocarbons, and other urban pollutants. These toxins significantly degrade water quality and damage fish health in the short and long term, as well as reducing populations of the organisms that they eat.

1.3.3 Increases in water temperature from surface water runoff

Fish need cool water temperatures to thrive and reproduce. Warmer temperature variations occur when groundwater infiltration is diminished resulting from increased runoff and damage water quality.

A goal of Soils for fish is for local governments to develop Best Management Practices that conserve native soils and improve disturbed soils.

- Soil degradation and water pollution are widely recognized as major environmental problems;
- Healthy soils directly contribute to healthier water resources and thus indirectly support aquaculture
- Steps taken to improve soils lead to improved water quality and quantity that will result in healthier fish habitat;
- Increased use for compost helps close the recycling loop through beneficial use of organic materials.

1.4 Soil quality vis-a vis water quality

Soils are often the interface between human activities and the hydrosphere and the atmosphere in the environment and serve as s source or sink for various constituents in water and air. Both point and non-point source pollution may result in contaminated soils. Soil quality affects water quality both directly and indirectly. Direct effects of soil quality and water quality are attributed to inherent soil characteristics, e.g. parent material, texture and structure (Table 1). Land use and soil quality also affect water quality through the effects of soil quality. Important soil management practices that affect water quality include tillage, application of fertilizers, pesticides and soil amendments, drainage, and farming system. If the quantity, timing, and method of manure application are not carefully managed with respect to crop need and site characteristics, excess nutrients may accumulate in the soil. The result may be nitrate leaching through the soil to contaminate groundwater or phosphorus moving in surface runoff, leading to eutrophication of surface waters. Pathogens and antibiotic or hormone residues in manure runoff can also contaminate water bodies and threaten human health

Table 1. Relation between soil quality and water quality

Soil properties/ processes	Water quality characteristics
A. Direct effects	
1. Parent materials	1. Salt concentration, softness-hardness
2. Organic matter content	2. Colour
3. Soil structure and erodibility	3. Turbidity
4. Cation exchange capacity	4. Dissolved load
5. Anaerobiosis	5. BOD and COD
6. Texture	6. Suspended load
B. Indirect effects	
1. Tillage methods	1. Sediment concentration and suspended load
2. Chemical inputs	2. Dissolved load, eutrophication
3. Farming system	3. Dissolved load

2.0. Key processes

The major characteristic of non-point source pollution is that the primary transfer mechanisms from land to water are driven by those hydrological processes that lead to runoff of nutrients, sediment, and pesticides. This is important, not only to understand the nature of agricultural pollution, but also the hydrological processes by which agriculturalists estimate and predict agricultural runoff and aquatic impacts. Except where agricultural chemicals are dumped directly into watercourses, almost all other non-point source control techniques in agriculture involve control or modification of runoff processes through various land and animal (manure) management techniques.

In large parts of the world, precipitation is in the form of rain. Therefore, focus will be on the relationships between rainfall and runoff. While the practice of hydrology can be quite theoretical, the principal concepts are easily understood (Fig. 1).

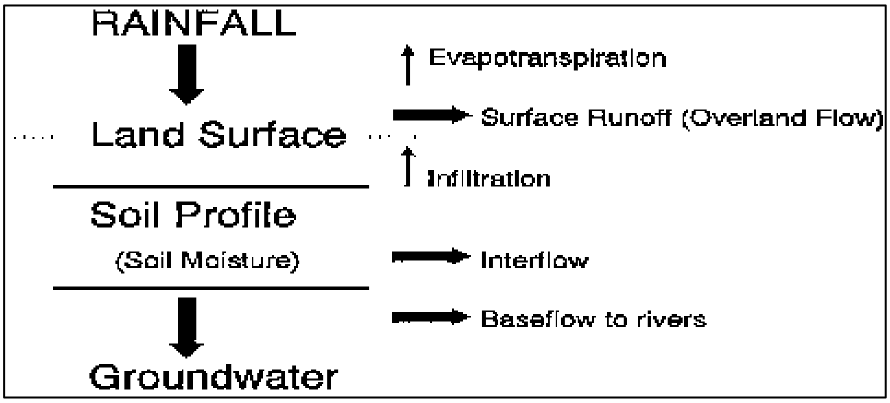


Fig.1. Schematic diagram showing the major processes that link rainfall and runoff

Rainfall: The primary controlling factor is the rate (intensity) of rainfall. This controls the amount of water available at the ground surface, and is closely related to measures of energy that are used in many mathematical formulations to calculate soil detachment by rain drops. Soil detachment makes soil particles available for sediment runoff.

Soil Permeability: Permeability is a physical characteristic of a soil and is a measure of the ability of the soil to pass water, under saturated conditions, through the natural voids that exist in the soil. Permeability is a function of soil texture, mineral and organic composition, etc.. In contrast, "porosity" is the measure of the amount of void space in a soil; however, permeability refers to the extent to which the porosity is made up of interconnecting voids that allow water to pass through the soil.

Infiltration: Infiltration rate, the rate at which surface water passes into the soil (cm/hr), is one of the most common terms in hydrologic equations for calculating surface runoff. Infiltration is not identical to permeability; it is mainly controlled by capillary forces in the soil which, in turn, reflect the prevailing conditions of soil moisture, soil texture, degree of surface compaction, etc. Infiltration will vary between and within rainfall events, depending upon factors such as antecedent soil moisture, nature of vegetation, etc. In general, infiltration rate begins at a high value during a precipitation event, and decreases to a small value when the soil has become saturated.

Surface runoff: This is the amount of water available at the surface after all losses have been accounted for. Losses include evapotranspiration by plants, water that is stored in surface depressions caused by irregularity in the soil surface, and water that infiltrates into the soil. The interaction between infiltration rate and precipitation rate mainly governs the amount of surface runoff. Intense rainstorms tend to produce much surface runoff because the rate of precipitation greatly exceeds the infiltration rate. Similarly, in areas of monsoonal rain and tropical storms, the length and intensity of precipitation frequently exceeds infiltration capacity. Destruction of protective surface vegetation and compaction of the soil, especially in tropical environments, leads to major erosional phenomena due to the amount of surface runoff. Except for nitrogen which is usually found in groundwater in agricultural areas, surface runoff is the primary contributor of agricultural chemicals, animal wastes, and sediment to river channels.

Interflow: (sometimes called "throughflow") Because soil horizons have different levels of permeability not all water in the soil will move downward into the groundwater. The residual water in the soil will move along the soil horizons, parallel to the ground surface. Interflow usually emerges near the bottom of slopes and in valley bottoms. Therefore, identification of these hydrologically active zones is an important part of agricultural non-point source control measures. Interflow is the mechanism which has also been linked to soil piping, a potentially destructive characteristic in some soils by which shallow "pipes" form naturally in the soil and are enlarged by interflow to the point where they collapse causing gullies in the agricultural surface. Soil processes affecting water quality is given in Table 2.

Table 2: Soil processes affecting water quality

Soil process	Impact on water quality
Soil erosion	Transport of dissolved and suspended sediments in surface runoff
Leaching	Movement of nutrients, agricultural chemicals and dissolved organic carbon in percolating water
Macro pore flow	Rapid transport of water and pollutants from surface to subsurface and into drainage system
Mineralization of humus	Release of readily soluble compounds that are easily washed away or leached out

3.0 Water quality as a global issue

Agriculture, as the single largest user of freshwater on a global basis and as a major cause of degradation of surface and groundwater resources through erosion and chemical runoff, has cause to be concerned about the global implications of water quality. The associated agrofood-processing industry is also a significant source of organic pollution in most countries. Aquaculture is now recognised as a major problem in freshwater, estuarine and coastal environments, leading to eutrophication and ecosystem damage.

Experts predict that, because pollution can no longer be remedied by dilution (i.e. the flow regime is fully utilized) in many countries, freshwater quality will become the principal limitation for sustainable development in these countries early in the next century. This "crisis" is predicted to have the following global dimensions:

- Decline in sustainable food resources (e.g. freshwater and coastal fisheries) due to pollution.
- Cumulative effect of poor water resource management decisions because of inadequate water quality data in many countries.
- Many countries can no longer manage pollution by dilution, leading to higher levels of aquatic pollution.
- Escalating cost of remediation and potential loss of "creditworthiness".

Although agriculture contributes to a wide range of water quality problems, anthropogenic erosion and sedimentation is a global issue that tends to be primarily associated with agriculture. While there are no global figures, it is probable that agriculture, in the broadest context, is responsible for much of the global sediment supply to rivers, lakes, estuaries and finally into the world's oceans.

Pollution by sediment has two major dimensions.

One is the PHYSICAL DIMENSION - top soil loss and land degradation by gullying and sheet erosion and which leads both to excessive levels of turbidity in receiving waters, and to off-site ecological and physical impacts from deposition in river and lake beds.

The other is a CHEMICAL DIMENSION - the silt and clay fraction (<63μ m fraction), is a primary carrier of adsorbed chemicals, especially phosphorus, chlorinated pesticides and most metals, which are transported by sediment into the aquatic system.

Non-point source water pollution, once known as "diffuse" source pollution, arises from a broad group of human activities for which the pollutants have no obvious point of entry into receiving watercourses. In contrast, **point source** pollution represents those activities where wastewater is routed directly into receiving water bodies by, for example, discharge pipes, where they can be easily measured and controlled. Obviously, non-point source pollution is much more difficult to identify, measure and control than point sources. Non-point source pollutants, irrespective of source, are transported overland and through the soil by rainwater and melting snow. These pollutants ultimately find their way into groundwater, wetlands, rivers and lakes and, finally, to oceans in the form of sediment and chemical loads carried by rivers. As discussed below, the ecological impact of these pollutants range from simple nuisance substances to severe ecological impacts involving fish, birds and mammals, and on human health. The range and relative complexity of agricultural non-point source pollution are illustrated in Figure

Although agriculture contributes to a wide range of water quality problems, anthropogenic erosion and sedimentation is a global issue that tends to be primarily associated with agriculture (Table 3). While there are no global figures, it is probable that agriculture, in the broadest context, is responsible for much of the global sediment supply to rivers, lakes, estuaries and finally into the world's oceans.

Table 3: Classes of non-point source pollution

Source	Mechanism	Type of pollution
Agriculture		
Animal feedlots Irrigation Cultivation Pastures Dairy farming Orchards Aquaculture	Runoff from all categories of agriculture leading to surface and groundwater pollution. In northern climates, runoff from cultivated field is a major problem, especially where manure is spread during the summer. Growth of aquaculture is becoming a major polluting activity in many countries. Irrigation return flows carry salts, nutrients and pesticides.	Phosphorus, nitrogen, metals, pathogens, sediment, pesticides, salt, BOD[1], trace elements (e.g. selenium).
Forest land	Increased runoff from disturbed land. Most damaging is forest clearing for urbanization.	Sediment, pesticides
Liquid waste disposal	Disposal of liquid wastes from municipal wastewater effluents, sewage sludge, industrial effluents and sludges, wastewater from home septic systems; especially disposal on agricultural land, and legal or illegal dumping in watercourses.	Pathogens, metals, organic compounds
Residential Commercial Industrial	Urban runoff from roofs, streets, parking lots, etc. leading to overloading of sewage plants from combined sewers, or polluted runoff routed directly to receiving waters; local industries and businesses may discharge wastes to street gutters and storm drains; street cleaning; road salting contributes to surface and groundwater pollution.	Fertilizers, greases and oils, faecal matter and pathogens, organic contaminants (e.g. PAHs[2]and PCBs[3]), heavy metals, pesticides, nutrients, sediment, salts, BOD, COD[4], etc.
Solid waste disposal	Contamination of surface and groundwater by leachates and gases. Hazardous wastes may be disposed of through underground disposal.	Nutrients, metals, pathogens, organic contaminants

[1] BOD =Biological Oxygen Demand

[2] PAH = Polycyclic Aromatic Hydrocarbons

[3] PCB = Polycyclic Chlorinated Bi-Phenyls

[4] COD = Chemical Oxygen Demand

4.0. Sediment as a physical pollutant

Global estimates of erosion and sediment transport in major rivers of the world vary widely, reflecting the difficulty in obtaining reliable values for sediment concentration and discharge in many countries, the assumptions that are made by different researchers, and the opposing effects of accelerated erosion due to human activities (deforestation, poor agricultural practices, road construction, etc.) relative to sediment storage by dam construction. Milliman and Syvitski (1992) estimate global sediment load to oceans in the mid-20th century at 20 thousand million t/yr, of which about 30% comes from rivers of southern Asia (including the Yangtze and Yellow Rivers of China). Significantly, they believe that almost 50% of the global total comes from erosion associated with high relief on islands of Oceania - a phenomenon which has been underestimated in previous estimates of global sediment production. While erosion on mountainous islands and in upland areas of continental rivers reflects natural topographic influences, Milliman and Syvitski suggest that human influences in Oceania and southern Asia cause disproportionately high sediment loads in these regions.

Sediment, as a physical pollutant, impacts receiving waters in the following principal ways:

- High levels of **turbidity** limit penetration of sunlight into the water column, thereby limiting or prohibiting growth of algae and rooted aquatic plants. In spawning rivers, gravel beds are blanketed with fine sediment which inhibits or prevents spawning of fish. In either case, the consequence is disruption of the aquatic ecosystem by destruction of habitat. Notwithstanding these undesirable effects, the hypertrophic (nutrient rich) status of many shallow lakes, especially in developing countries, would give rise to immense growth of algae and rooted plants were it not for the limiting effect of light extinction due to high turbidity. In this sense, high turbidity can be "beneficial" in highly eutrophic lakes; nevertheless, many countries recognise that this situation is undesirable for both aesthetic and economic reasons and are seeking means to reduce both turbidity and nutrient levels. Box 4 presents the impact of sediment on coral reefs.
- High levels of **sedimentation** in rivers lead to physical disruption of the hydraulic characteristics of the channel. This can have serious impacts on navigation through reduction in depth of the channel, and can lead to increased flooding because of reductions in capacity of the river channel to efficiently route water through the drainage basin. For example, calculations by the UFRGS (1991) of erosion and sediment transport in the Sao Francisco River Basin, a large drainage system in eastern Brazil, demonstrate that the central portion of the river basin is now dominated by sediment deposition. This has resulted in serious disruption of river transportation, and clogs hydraulic facilities that have been built to provide irrigation water from the main river channel. The sediment largely originates from rapidly eroding sub-basins due to poor agricultural practices.

BOX 1: SEDIMENT AND DESTRUCTION OF CORAL REEFS

Sediment has been identified as a major cause of decline and destruction of coral reefs, worldwide. Experts (M. Risk, pers. comm., 1995) estimate that percentages of reefs affected by siltation are:

Central America - 100%

Polynesia - 10%

Asia - nearly 100%

Worldwide - 60-70% of fringing reefs

Studies of coral reefs in the Australia indicate that terrestrial particulate organic carbon can be transported off-shore over distances of 110 km to reef locations (Risk *et al.,* 1994). Sediment is largely produced by agricultural activities and from erosion of deforested lands. Sediment production from intensive logging of the island of Madagascar has killed the fringing reefs. Observations from space described the transition of Madagascar from an island of green in a sea of blue, to an island of brown in a sea of red (sediment).

Box 2: Uncontrolled deforestation, forest-fires, over-grazing, improper methods of tillage, unwise agricultural practices and other activities are responsible for accelerated soil erosion. It has been estimated that about 6 billion tonnes of soil are eroded every year from cultivable lands, thereby causing a loss of 8.4 million tons of nutrients. If this nutrient loss is to be compensated by application of chemical fertilizers; a huge investment would be needed. Further, according to some studies, it is estimated that 2.2 billion tonnes of sediments is transported each year by the Ganga-Brahmaputra river systems into the Bay of Bengal. Central Water Commission (1991) found from an analysis of capacity survey data of 46 reservoirs in India that there was a wide variability in sedimentation rate of those reservoirs. The sedimentation rate is affected by multiple factors like hydrometeorology, physiography, climate etc. Considering these factors the whole country has been classified into seven regions. The sedimentation rates in region-wise reservoirs are given below:

Region	Sedimentation rate ha m 100 km^{-2} $year^{-1}$
Himalayan region (Indus, Ganga, Brahmputrta region)	Varies from 5.658 to 27.85
Indo Gangetic Plateau	Varies from 0.3 to 16.3
East flowing rivers excluding Ganga upto Godavari	6.08 in case of Hirakud Reservoir
Deccan Peninsular east-flowing rivers Including Godavari	Varies from 0.15 – 12.16
Narmada Tapti Basin	Varies from 3.64 – 7.16
West flowing rivers	Varies from 0.96 – 25.4

5.0. Sediment as a chemical pollutant

The role of sediment in chemical pollution is tied both to the particle size of sediment, and to the amount of particulate organic carbon associated with the sediment. The chemically active fraction of sediment is usually cited as that portion which is smaller than 63 µm (silt + clay) fraction. For phosphorus and metals, particle size is of primary importance due to the large surface area of very small particles. Phosphorus and metals tend to be highly attracted to ionic exchange sites that are associated with clay particles and with the iron and manganese coatings that commonly occur on these small particles. Many of the persistent, bioaccumulating and toxic organic contaminants, especially chlorinated compounds including many pesticides, are strongly associated with sediment and especially with the organic carbon that is transported as part of the sediment load in rivers. Measurement of phosphorus transport in North America and Europe indicate that as much as 90% of the total phosphorus flux in rivers can be in association with suspended sediment.

The affinity for particulate matter by an organic chemical is described by its octanol-water partitioning coefficient (K_{OW}). This partitioning coefficient is well known for most organic chemicals and is the basis for predicting the environmental fate of organic chemicals. Chemicals with low values of K_{OW} are readily soluble, whereas those with high values of K_{OW} are described as "hydrophobic" and tend to be associated with particulates. Chlorinated compounds such as DDT and other chlorinated pesticides are very hydrophobic and are not, therefore, easily analysed in water samples due to the very low solubility of the chemical. For organic chemicals, the most important component of the sediment load appears to be the particulate organic carbon fraction which is transported as part of the sediment. Scientists have further refined the partitioning coefficient to describe the association with the organic carbon fraction (K_{OC}).

Unlike phosphorus and metals, the transport and fate of sediment-associated organic chemicals is complicated by microbial degradation that occurs during sediment transport in rivers and in deposited sediment. Nevertheless, the role of sediment in the transport and fate of agricultural chemicals, both for nutrients, metals, and pesticides is well known and must be taken into account when monitoring for these chemicals.

Organic chemicals associated with sediment enter into the food chain in a variety of ways. Sediment is directly ingested by fish however, more commonly, fine sediment (especially the carbon fraction) is the food supply for benthic (bottom dwelling) organisms which, in turn, are the food source for high organisms. Ultimately, toxic compounds bioaccumulate in fish and other top predators. In this way, pesticides that are transported off the land as part of the runoff and erosion process, accumulate in top predators including man.

Box 3: Excessive amounts of sediment cause taste and odour problems for drinking water, block water supply intakes, foul treatment systems, and fill reservoirs. A high level of sediment adversely impacts aquatic life, reduces water clarity, and affects recreation. Even in relatively flat areas, such as the Mississippi Delta, considerable soil erosion can occur. Murphree and Mutchler (1981) reported a 5-year average sediment yield as high as 17.7t/ha.y from a flat watershed in the Mississippi Delta. Cooper and Knight (1990) found that suspended sediment loads generally exceeded 80 to 100 parts per million (maximum for optimal fish growth) during and immediately following storm events in two upland streams in Mississippi. Ritchie et al. (1979) found that one to three inches of fine sediments accumulated per year in natural lakes along Bear Creek, a drainage system in the Mississippi Delta where 75 percent of the land is in cultivation. Accumulated sediment has covered the bottom of many lakes and stream sections with fine silt (Ritchie et al., 1986).

6.0. Role of agriculture in eutrophication

"Eutrophication" is the enrichment of surface waters with plant nutrients. While eutrophication occurs naturally, it is normally associated with anthropogenic sources of nutrients. The "trophic status" of lakes is the central concept in lake management. It describes the relationship between nutrient status of a lake and the growth of organic matter in the lake. Eutrophication is the process of change from one trophic state to a higher trophic state by the addition of nutrient. Agriculture is a major factor in eutrophication of surface waters.

Although both nitrogen and phosphorus contribute to eutrophication, classification of trophic status usually focuses on that nutrient which is limiting. In the majority of cases, phosphorus is the limiting nutrient. While the effects of eutrophication such as algal blooms are readily visible, the process of eutrophication is complex and its measurement difficult. This is not the place for a major discussion on the science of eutrophication, however the factors noted in Table 4 indicate the types of variables that must be taken into account.

Table 4: Parameters for measuring and monitoring eutrophication

Resultant variables		Causal variables
Short-term variability: high	**Short-term variability: moderate-low**	
Phytoplankton biomass	Zooplankton standing crop	**Nutrient loadings**
Major algal groups and dominant species	Bottom fauna standing crop	Total phosphorus Ortho phosphates
Chlorophyll-a & other phytopigments	Epilimnetic □ P, □ N, □ Si (□ is difference between winter and summer concentrations)	Total nitrogen Mineral nitrogen (NO_3+NH_3) Kjeldahl nitrogen
Particulate organic carbon and N	Hypolimnetic O_2 and □ O_2	**Nutrient concentrations** Same as above
Daily primary production rates	Annual primary production	Reactive silica Others (e.g. micro-elements)

The symptoms and impacts of eutrophication are:

- Increase in production and biomass of phytoplankton, attached algae, and macrophytes.
- Shift in habitat characteristics due to change in assemblage of aquatic plants.
- Replacement of desirable fish (e.g. salmonids in western countries) by less desirable species.
- Production of toxins by certain algae.
- Increasing operating expenses of public water supplies, including taste and odour problems, especially during periods of algal blooms.
- Deoxygenation of water, especially after collapse of algal blooms, usually resulting in fish kills.
- Infilling and clogging of irrigation canals with aquatic weeds (water hyacinth is a problem of introduction, not necessarily of eutrophication).
- Loss of recreational use of water due to slime, weed infestation, and noxious odour from decaying algae.
- Impediments to navigation due to dense weed growth.
- Economic loss due to change in fish species, fish kills, etc.
- In their summary of water quality impacts of fertilizers, FAO/ECE (1991) cited the following problems:
- Fertilization of surface waters (eutrophication) results in, for example, explosive growth of algae which causes disruptive changes to the biological equilibrium [including fish kills]. This is true both for inland waters (ditches, river, lakes) and coastal waters. The huge increases in fertilizer use worldwide over the past several decades are well documented. However, fertilizer use (either mineral or organic) is not, of itself, the primary factor in downstream water quality. More important are the land management practices that are used in crop production.
- Groundwater is being polluted mainly by nitrates. In all countries groundwater is an important source of drinking water. In several areas the groundwater is polluted to an extent that it is no longer fit to be used as drinking water according to present standards.
- While these problems were primarily attributed to mineral fertilizers by FAO/ECE (1991), in some areas the problem is particularly associated with extensive and intensive application of organic fertilizers (manure).

The precise role of agriculture in eutrophication of surface water and contamination of groundwater is difficult to quantify. Where it is warranted, the use of environmental isotopes can aid in the diagnosis of pollutant pathways to and within groundwater (IAEA, pers. comm. 1996).

To increase crop production, fertilizers are extensively used worldwide. The wide spread use of fertilizer continues to be a major public concern because of possible human health risks and the eutrophication of surface water. Nitrate concentration is a parameter of particular concern because it has been linked with "blue baby" syndrome and formation of carcinogenic compounds (NCSU, 2000). Off-site transport of sediment and its transported pollutants from agricultural cropland has been classified as one of the major sources of water quality impairment and water quality would directly benefit if the amount of soil loss was reduced (NRCS, 1997). The impairment to surface water quality due to sediment and nutrient transport from agricultural cropland has been estimated to be about $9 billion per year (Ribaudo, 1992). Although more than $500 billion has been spent on water pollution control since the implementation of the Clean Water Act in 1972, the quality of the nation's water still remains largely unknown (Akobunbo and Riggs, 2000). In reducing soil erosion and solving nonpoint source water quality problems, regulatory agencies promote BMP adoption on areas most susceptible to NPS pollution to reduce sediment and pollutant losses from agricultural land areas.

7.0. Strategies and management techniques to control source of pollution

The recommendations reflect two very different scales which, in turn, reflect two different types of issues. At the small scale are the recommendations which apply at the farm level and which reflect actions to be taken by the individual farmer after considering the economic costs of his alternatives. At the large scale (river basin scale) are those issues that tend to reflect policy and investment needs of states. This includes issues such as determining the net contribution of agriculture to river pollution relative to other types of polluting sources.

7.1. Internalizing costs

Although the control of erosion at source in rain-fed agriculture is a major factor in improving downstream water quality and associated ecological impacts, implementation of control measures will only be successful if the farmer can determine that it is in his economic interest to undertake such measures. Therefore, the economic benefits such as maintenance of soil fertility, reduced energy consumption in minimum till situations, etc., relative to economic costs of excessive fertilizer usage and loss of productivity by "mining" of soil capital, must be clearly demonstrated. This implies that agricultural agencies must use a holistic approach to the economics of farming practices.

7.2. Erosion control

There are no unique solutions to erosion control. Control measures depend very much on the economic situation of the farmer, the degree of importance placed on sediment erosion by environmental authorities, availability of capital, and the state of development of the country. The following control measures are those classified and recommended by the US-EPA (1994). These categories are used in many parts of the world, including developing countries. These techniques also have beneficial effects for conservation of nitrogen and phosphorus in the soil.

CONSERVATION COVER	*Establish and maintain perennial vegetative cover to protect soil and -water resources on land retired from agricultural production.*
CONSERVATION CROPPING	*A sequence of crops designed to provide adequate organic residue for maintenance of soil tilth. This practice reduces erosion by increasing organic matter. It may also disrupt disease, insect and -weed reproduction cycles thereby reducing the need for pesticides. This may include grasses and legumes planted in rotation.*
CONSERVATION TILLAGE	*Also known as reduced tillage, this is a planting system that maintains at least 30% of the soil surface covered by residue after planting. Erosion is reduced by providing soil cover. Runoff is reduced and infiltration into groundwater is increased. No-till, common in North America, is a conservation tillage practice.*
CONTOUR FARMING	*Ploughing, planting, and other management practices that are carried out along land contours, thereby reducing erosion and runoff.*
COVER AND GREEN MANURE CROP	*A crop of close-growing grasses, legumes, or small grain grown primarily for seasonal protection and soil improvement. Usually it is grown for 1 year or less.*
CRITICAL AREA PLANTING	*Planting vegetation, such as trees, shrubs, vines, grasses or legumes, on highly erodible or eroding areas.*
CROP RESIDUE USE	*Using plant residues to protect cultivated fields during critical erosion periods.*
DELAYED SEEDBED PREPARATION	*Any cropping system in which all crop residue is maintained on the soil surface until shortly before the succeeding crop is planted. This reduces the period that the soil is susceptible to erosion.*
DIVERSIONS	*Channels constructed across the slope with a supporting ridge on the lower side. By controlling downslope runoff, erosion is reduced and infiltration into the groundwater is enhanced.*
FIELD BORDERS AND FILTER STRIPS	*A strip of perennial herbaceous vegetation along the edge of fields. This slows runoff and traps coarser sediment. This is not generally effective, however, for fine sediment and associated pollutants.*
GRASSED WATERWAYS	*A natural or constructed channel that is vegetated and is graded and shaped so as to inhibit channel erosion. The vegetation will also serve to trap sediment that is washed in from adjacent fields.*
SEDIMENT BASINS	*Basins constructed to collect and store sediment during runoff events. Also known as detention ponds. Sediment is deposited from runoff during impoundment in the sediment basin.*
STRIP CROPPING	*Growing crops in a systematic arrangement of strips or bands across the general slope (not on the contour) to reduce water erosion. Crops are arranged to that a strip of grass or close-growing crop is alternated with a clean-tilled crop or fallow.*
TERRACING	*Terraces are constructed earthen embankments that retard runoff and reduce erosion by breaking the slope into numerous flat surfaces separated by slopes that are protected with permanent vegetation or which are constructed from stone, etc. Terracing is carried out on very steep slopes, and on long gentle slopes where terraces are very broad.*

Note however, that in tropical areas a number of these measures may produce situations that enhance the breeding of disease vectors as a result of ponding of water or reducing of water velocity in waterways.

The reader is referred to Roose (FAO, 1994a) for a detailed analysis of the social, economic and physical consequences of erosion of agricultural land and of measures that should be taken to control erosion under different types of land use, especially in developing countries. Whereas Roose is mainly concerned with the impact of erosion on agriculture, this publication is primarily concerned with agricultural erosion from the perspective of its impacts on downstream water quality.

Erosion in tropical areas has a unique set of problems. Marginal agricultural practices such as slash and burn on highly erodible tropical soils and tillage on steep tropical slopes lead to highly unstable situations which erode quickly during rainy seasons. Similarly, deforestation in tropical lands, either for agriculture or for timber, tends to leave a highly erodible land surface. In many tropical countries erosion from deforested areas is having a devastating influence on coastal zones including destruction of coral reefs far offshore. Poor land management practices such as overgrazing, especially on hill lands, always leads to serious erosion problems which are difficult or impossible to remedy due to the scale of damage and cost of reconstructing hill-sides.

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Annexure I

Water is judged according to the following broad categories for its quality:

1.	Physical properties:	Color; temperature; turbidity, suspended solids, etc.
2.	Microbiological organisms:	Bacteria, Viruses, etc.
3.	Inorganic chemicals:	Alkalinity, dissolved oxygen, pH; total dissolved solids; hardness; and several specific inorganic ions including metal ions, etc.
4.	Organic chemicals:	Corbon- chloroform extract (CCE); oils and greases; phenols; cyanide; several individual pesticides etc. Radium-226; strontium-90; gross beta emitters, etc.
5.	Radioactivity:	Radium-226; strontium-90; gross beta emitters, etc.

Annexure II

Selected Water Quality Parameters according to CPCB

Parameter		Method of Analysis
A.	Physical 1. Temperature 2. Turbidity 3. Velocity of flow	Thermometric method visual method 1. Current meter 2. Float method 3. Chemical method
B.	Chemical 1. pH 2. Dissolved oxygen 3. Biochemical oxygen demand 4. Total Kjeldani nitrogen 5. Nitrogen (Nitrate+Nitrite) 6. Conductivity 7. Chloride 8. Hardness 9. Calcium 10. Magnesium 11. Alkalinity 12. Sulphate 13. Sodium 14. Chemical oxygen demand	Electrometric method Iodometric method Dilution method 1. Digestion 2. Distillation 3. Ammonia estimate by a. Titration method (mg/1) b. Nesslerization method (5mg/1) Amalgamated cadmium reduction method for reduction of Nitrate by diazotization method Conductometric method 1. Argentometric method 2. Mercurimetric method EDTA Titrimetric method EDTA Titrimetric method By difference of 8 & 9 1. Electrometric method 2. Visual titration method Turbidimetric method, Flame photometric method Flame photometric method Diohromate method
C.	Bacteriological	
	1. Total Coliform (MPN) 2. Fecal Coliform	Multiple Tube Dilution Technique Multiple Tube Dilution Technique

Annexure III

International Standards for Drinking Water according to WHO

Substance of characteristic	Highest desirable level
Substance causing discoloration	5 units (Platinum- cobalt)
Substances causing odours	Unobjectionable
Substances causing tastes	Unobjectionable
Suspended matter	5 units (of turbidity)
Total Solids	500 mg/1
pH range	7.0 to 8.5
Ammonia detergents	0.2 mg/1
Mineral oil	0.01 mg/1
Phenolic compounds (as phenol)	0.001 mg/1
Total hardness	100 mg/1 $CaCO_3$
Calcium (as Ca)	75 mg/1
Chloride (as CI)	200 mg/1
Copper (as Cu)	0.05 mg/1
Iron (total as Fe)	0.1 mg/1
Magnesium (as Mg)	Not more than 30 mg/1, if there are 250 mg/1 of sulfate; magnesium upto 150 mg/1 may be allowed
Magnesium (as Mn)	0.05 mg/1
Sulfate (as SO_4)	200 mg/1
Hydrogen sulfide (as H_2S)	
Zinc (as Zn)	5.0 mg/1
Nitrate (as NO_3)	
Ammonia (as NH_4)	
Free carbon dioxide (as CO_2)	
Dissolved oxygen	

Source: Twort AC/Hoather RC, Law FM, 'Water Supply' Cox and Wyman, 1974. 198-202

The water which has characteristics suited to a given requirement is called good quality water with reference to that requirement. The set of characteristics given in the table make the water excellent for drinking as per World Health Organization specifications

Annexure IV

Limitation ratings of source water for aquaculture

Property	Limitation rating			Restrictive feature	Site
	Slight	**Moderate**	**Severe**		
Total dissolved salts (TDS; mg/litre)	50-500 (F) 15000-25000(B)	500-2000 (F) 5000-15000(B)	>2000 (F) <5000 (B)	Osmoregulation	H,P
Salinity (ppt)	<0.5(F) 15-25(B)	0.5-2 (F) 25-35(B)	>2(F) >35(B)	Osmoregulation	H,P
pH	6.5-8.5	5.0-6.5 8.5-10.0	<5.0 >10.0	Low pH High pH	H,P
Total alkalinity (mg/liter as $CaCO_3$)	50-200	20-50 200-500	<20 >500	Low alkalinity High alkalinity	H,P
Secchi disk visibility# (cm)	30-60	15-30 60-120	<15 >120	Excessive Low	H,P
Turbidity (NTU)	0-25	25-100	>100	SEDIMENTATION, LOW LIGHT	H,P
Dissolved oxygen (mg/liter)	>5	2-5	<2	Low oxygen	H,P
Orthophosphate (µg/liter)	10-20 10-20	10-20 10-20	10-20 10-20	Excessive phytoplankton Insufficient phytoplankton	H,P
CO_2(mg/liter)	0-5	5-20	>20	CO_2 toxicity	H,P
COD ((mg/liter)	0-50	50-200	>200	Oxygen demand	
Toxic Materials	Low	Medium	High	Toxicity	

measurement of phytoplankton; F, freshwater; B, brackish-water; H, hatchery; P, pond.

Annexure V

Tolerance limits for industrial effluent discharged on land for irrigation purposes

1	Characteristics	Tolerance limit
2	pH value	5.5 to 9.0
3	Total dissolved solids (inorganic), mg/1, Max	2100 (See Note 1)
4	Sulphate (as SO_4), mg/1 Max	1000
5	Chloride (as CI) mg/1 Max	600
6	Percent Sodium, Max	60 (See Note 2)
7	Boron (as B), mg/1, Max	2
8	Biochemical oxygen demand (5 days at 0 C), mg/1, Max	500 (See Note 1 and 3)
9	Oils and grease, mg/1, Max	10
10	Alpha emitters, uc/1 Max	10^{-9}
11	Beta emitters, uc/m1 Max	10^{-8}

Note 1: Limit is subject to relaxation or tightening by the local authorities.

Note 2: Taking into account the nature of soil and the crop, the limit may be relaxed up to a maximum of 75 by the local authorities.

Note 3: It should be noted that BOD of even 500 mg/ can have adverse effect if the nature of the soil and application rates is not taken into account.

*Methods of sampling and test for industrial effluents.

Annexure VI

Primary water quality standards

	Designated best use				
Criterion	Class A	Class B	Class C	Class D	Class E
Dissolved Oxygen (mg/l) Maximum	6	5	4	4	-
BOD (mg/l) Maximum	2	3	3	-	-
Total coliform count (MPN/100 ml) Maximum	50	500	5000	-	-
pH acceptable range	6.5-8.5	6.5-8.5	09-juin	6.5-8.5	6.5-8.5
Free ammonia (mg/l)	-	-	-	1.2	
Condustivity	-	-	-	-	2.25
Sodium absorbtion ratio	-	-	-	-	26
Boron (mg/l)	-	-	-	-	2

Class A: Drinking water source without conventional treatment.
Class B: Water for outdoor bathing.
Class C:Drinking water with conventional treatment.
Class D: Water for wildlife and fisheries
Classe E: Water for recreation and aesthetics, irrigation and industrial cooling.

ASSESSMENT OF IMPACT OF FISHERIES INTERVENTIONS UNDER WATERSHED MANAGEMENT PROGRAMMES

B.L. Dhyani*

Fisheries sector plays a vital role in the socio-economic development of the country. It has been recognized as a powerful income and employment generator as it stimulates growth of a number of subsidiary industries. It is source of cheap and nutritious food besides being a foreign exchange earner. At the same time it is an instrument of livelihood for a large section of socio-economically backward population of the country. The Indian fisheries sector over a period of time has seen a virtual turnaround. The fish production has increased at the rate of 5.1% per year during 1980-2000, and now stands at 6.30 million tonnes with 44% share from marine and 56% share from inland fisheries, as compared to 0.75 million tonnes in 1950-51, 1.76 million tonnes in 1970-71 and 2.44 million tonnes in 1980-81.

There are different types of fisheries namely;

1. Marine fisheries – fisheries in sea
2. Brackish water fisheries
3. Fresh water fisheries :
   A) Natural : i) Revirine ii) Inland (Lake, Swamp)
   B) Manmade i) Reservoir ii) Pond

The present topic will cover man made reservoir or pond pisiculture under freshwater fisheries only.

Impact indicators

Impact indicators vary with the nature of programme being implemented and level of assessment. There are two types of benefits accrued from developmental interventions (i) tangible benefits, which can be measured precisely and we can assign monetary values to them as there exist some market for them, and (ii) intangible benefits, which cannot be either measured due to non-availability of measurement techniques or if measurable then cannot assign monetary value as they are non-tradable or if tradable but no market exist. The impact indicators will be different at farm, regional, national and global level. At the farm level, the direct beneficiaries are affected by adopting the watershed interventions. At higher level, the society and the environment are being influenced and measured. Important farm-level and regional/national-level indicators are listed in below:

Farm level impact indicators

- Efficiency :
  - Increase production/productivity
  - Unit cost reduction
  - Increase water/energy use

- Household food security
  - Nutritional security
  - Income augmentation
  - Poverty reduction
  - Employment generation

*** Principal Scientist (Agri. Eco.) & OIC (PME Cell), Central Soil & Water Conservation Research & Training Institute, Dehradun-284 195 (Uttarakhand)**

- Risk management
  - Reduction in soil erosion or loss of lives and property production
  - Improving yield, or income stability in the absence of insurance
  - Reduction in flood plain

- Equity
  - Social equity
  - Economic equity
  - Gender equity
  - Drudgery reduction

- Natural resource conservation
  - Increased fuel and fodder availability
  - Increased water perineality

The emphasis of the listed indicators would vary with the type of intervention outputs. It is not necessary that all indicators would be applicable for any kind of interventions change.

Regional / National-level impact indicators

- Fish production
- Food self-sufficiency
- Employment generation
- Equity issues
  - Inter-regional
  - Inter-personal
- Poverty reduction
- Increase in GDP
- Trade
  - Prices
  - Export and / or import substitution
- Inter-sectoral linkages
  - Forward linkages (like markets, transport, processing, etc.)
  - Backward linkages (like fish seed, pesticide industry, machinery, etc.)
- Sustainability of natural resources
  - Ecosystem services
  - Biodiversity
  - Intrinsic value

Measuring economic efficiency indicators

The important methods for assessing the economic efficiency benefits of project/intervention impact are:

Benefit Cost Analysis (BCA): This method compares the stream of benefits with that of stream of costs. Following are the indicators for the benefit-cost analysis:

Net Present Value (NPV): It is the present worth of the incremental net benefit stream.

Internal Rate of Return (IRR): It is the discount rate when net present worth of benefit and costs are equal to zero.

Pay-Back Period (PBP): It is the period during which the entire investment / fixed cost incurred is recovered from the project.

Following steps are to be followed to work out an Economics of a Water Harvesting System for pisiculture.

A) **Assumptions** : Explain the assumptions made before analysis e.g.
   i) Water Harvesting System is exclusively constructed for pisiculture,
   ii) Water Harvesting System is constructed in a area which was totally unproductive,
   iii) A minimum water depth of 1m is maintained in Water Harvesting System during fish growing period,
   iv) Water exchange or other facilities for aeration etc. are available without any extra cost,
   v) Water quality and site conditions meets the technical requirement for pisiculture, and
   vi) Seeding and harvesting is done at one time only as per technical prescription (explain in methodology). It may be more but explain them precisely.

B) **Period of analysis** : It refers to technical/economic life of the assets created. In present case it is life of Water Harvesting System and be determined by technical expert or evaluator.

C) **Estimate marginal costs and benefits :** Estimate stream of Costs (C_t) and Benefits (B_t) from the project for a period of analysis where t is time and prepare cash flow chart by taking constant prices of input used or output produced.

D) **Select appropriate discount rate(r)** : It is the rate of return likely to forego from next best alternative with equal degree of risk and calculate discount factor 'd', as $d = 1 / (1+r)^t$ where t is time period.

E) **Workout present value of costs and benefits**

F) **Workout economic efficiency indicators as described above**:

A Hypothetical example :

i) A RCC water harvesting tank of 1000 cum capacity was constructed having a depth of two meter for carp fish culture in a barren land.
ii) The cost of pond construction and other equipment required for pisiculture is Rs. 1,00,000/- only and incurred in first year.
iii) Construction of WHS was completed within a year
iv) Pisiculture was initiated from second year only and continued till 20th year without major repair of Water Harvesting System.
v) Fish stocking was done @ 2 fingerling / m^2
vi) Assumed mortality rate is 30%.
vii) The technical life of WHS is 20 yrs, (d) Discount rate 15%

Cash flow chart and economic analysis

Cash flow Chart			0.3617			Economic Analysis	
Year	**Additional**		0.1500	**Present value of**			**Cumulative**
(t)	**Cost**	**Benefits**	**D. Factor**	**Cost**	**Benefits**	**NPV**	**NPV**
0			1				
1	100000	0	0.869565	86956.5217	0.0000	-86956.5	-86956.5
2	40000	66000	0.756144	30245.7467	49905.4820	19659.7	-67296.8
3	50000	90000	0.657516	32875.8116	59176.4609	26300.6	-40996.1
4	50000	90000	0.571753	28587.6623	51457.7921	22870.1	-18126.0
5	50000	90000	0.497177	24858.8368	44745.9062	19887.1	**1761.1**
6	50000	90000	0.432328	21616.3798	38909.4836	17293.1	19054.2
7	50000	90000	0.375937	18796.8520	33834.3336	15037.5	34091.6
8	50000	90000	0.326902	16345.0887	29421.1596	13076.1	47167.7
9	50000	90000	0.284262	14213.1206	25583.6171	11370.5	58538.2
10	50000	90000	0.247185	12359.2353	22246.6236	9887.4	68425.6
11	50000	90000	0.214943	10747.1611	19344.8900	8597.7	77023.3
12	50000	90000	0.186907	9345.3575	16821.6435	7476.3	84499.6
13	50000	90000	0.162528	8126.3978	14627.5161	6501.1	91000.7
14	50000	90000	0.141329	7066.4329	12719.5792	5653.1	96653.9
15	50000	90000	0.122894	6144.7243	11060.5037	4915.8	101569.7
16	50000	90000	0.106865	5343.2385	9617.8293	4274.6	105844.3
17	50000	90000	0.092926	4646.2943	8363.3298	3717.0	109561.3
18	50000	90000	0.080805	4040.2559	7272.4607	3232.2	112793.5
19	50000	90000	0.070265	3513.2660	6323.8789	2810.6	115604.1
20	50000	90000	0.0611	3055.0139	5499.0251	2444.0	118048.1
				348883.3979	466931.515	118048.12	1028261.45

(20 years) B:C Ratio = 1.3383598

AGRO-ECOLOGICAL ANALYSIS FOR IDENTIFICATION AND PRIORITISATION OF FISH FARMING INTERVENTIONS IN WATERSHED MANAGEMENT PROGRAMMES

Bankey Bihari*

Watershed management is a holistic approach which aims at optimizing the use of land, water and vegetation in an area, to alleviate drought, moderate floods, prevent soil erosion, improve water availability and increase fuel, fodder, fish and agricultural production on a sustained basis. The issues relevant to watershed management include environmental issues, crop, fish, livestock production, social & cultural concerns and infrastructure planning.

Factors associated with success of watershed management

- People should be the focal point of watershed management programmes and innovations should be planned with their needs in mind.
- Involvement of farmers should be as stakeholders and not be limited only to problem identification. They should also be included in implementation and evaluation.
- Project workers should be accountable to the farmers who have contributed significant amounts of time, faith and resources.
- Watershed programmes need complete holistic approach and not only for certain components.
- Integration of farmers' wisdom with improved technologies can result in appropriate and long lasting solutions.
- Success indicators should relate to the watershed as a whole.
- Farmers should have access to credit for their consumption needs as well as for small income generating activities.
- Landless and marginal farmers should be given access to the increased bio-mass in the watershed viz; priority to harvest and sell or use grasses.
- Adequate priority should be given to the provision of upgrading of skills and other services required for the landless and marginal farmers.
- Gender relations to be more equitable which requires a sharp tilt towards women.
- Priority should be given to employ vulnerable groups living in the watershed.
- Priority should be given to vulnerable groups in watershed institutions like credit groups and watershed development associations.

Objectives of watershed development and management

- To promote economic development of village community dependent on watershed and

  to restore ecological balance in the village environment through:

  - Sustained community action for operation and maintenance of assets created.
  - Simple, easy and affordable solutions built upon local knowledge and available materials.

*** Senior Scientist (Agri. Extn.), Central Soil & Water Conservation Research & Training Institute, Dehradun-284 195 (Uttarakhand)**

- Emphasis to improve economic and social condition of the resource poor and disadvantaged section of the watershed community through.
  a. More equitable distribution of benefits of land and water resources development.
  b. Greater access to income generating opportunities and focus on their human resource development programmes.

Participatory approach, what is it?

Authenticity of information, what different agencies get from the farmers and farmers get from different agencies, counts much more in the research and development process. Conventional methods of surveys and information collection have certain loopholes. According to Robert chambers, in conventional surveys preference is given to factual information over people related information, poorer people are easily overlooked, labour and expense involved are not in proportion to results obtained and necessary information is elicited, analyzed and used most exclusively by outsiders. Dissatisfaction with results of such "Surveys" led to a search for more effective methods resulting in the emergence of participatory approaches viz; PALM, PAR, PRA, PRAP, PRM, PTD etc. depending upon nature of requirement like problem diagnosis, community empowerment, farmers-led research, health context, Watershed development and food security assessment.

In the areas like soil and water conservation, agroforestry, fishery, wildlife conservation, agriculture, poverty alleviation and emancipation, health and nutrition and village and district level planning, PRA (Participatory Rural Appraisal) is used more prominently.

Participatory Rural Appraisal (PRA) is a "Way of enabling local people analyze their living conditions, share outcomes and plan their activities. The outsider is a facilitator and convenor of processes within a community, prepared to alter their situation". It is a methodology that enhances the development agents understanding of the rural reality in planning and development of projects and a greater degree of ownership and responsibility by the farmers for achieving better results and social acceptance of the progromme.

Why participatory approach?

- It is necessary that users of resources are involved in analyzing the problem and identifying solutions since they know best of the benefits, constraints and initiatives for conservation and regeneration.
- It enables labourers, women and small farmers to analyze conditions giving them confidence to assert their priorities, to present proposals, to make demands and take action, leading to sustainable and effective programmes.
- It encourages and enables expression and exploitation of local diversity.
- It is helpful in identification of research priorities and initiating participatory research with scientists more receptive to local knowledge and farmers ability to design, carryout and evaluate their own experiments.

How to achieve participation?

- Farmers are more willing to participate in activities which meet their felt needs and priorities. The needs of all people should be taken into consideration, not just those who are accessible and co-operative.

- Farmer's idea must be taken into account to sustain their involvement.
- Farmers are more likely to participate if the actual benefits are directly tied to the participation.
- Farmers, specially those with low incomes, are more likely to participate and remain involved if the benefits are material, direct and immediate.

I. Institutional arrangements

Community Organization

The Project Implementing Agency (PIA) selects Watershed Development Team members of four disciplines Viz; plant science, engineering livestock and social sciences. They must be graduate in their field. During the course of various meetings with community members, the WDT members may identify village based social workers/motivators who can be involved in organizing the community. Wherever possible the youth clubs, mahila mandal, anganwadi members may also be involved in this process.

Kinds of groups to be constituted

Four types of groups are to be constituted at the village level namely: Self Help Group (SHG), User Group (UG), Watershed Association (WA) and Watershed Committee (WC). A proper sequence is required to be followed while organizing the groups. In order to minimize conflict among the community members, it is essential to form WC at the end after organizing the first three types of groups. This is contrary to the normal tendency where WC is formed at the beginning through a meeting of unorganized members of the gram sabha. Till the WC is organized and its office bearers like secretary and volunteers are identified, WDT may take the assistance of village level community organizers not only for organization of Self Help Group (SHG) and Users Group (UG) but also to facilitate Participatory Rural Appraisal (PRA) exercises for preparation of strategic/detailed action plan of the watershed. Organization of above three types of groups may be completed in about 8 to 10 months after the start of the project.

Self Help Groups (SHG)

By and large Self Help Groups (SHG) shall include those who are landless or have marginal size of land holding. Such community members may be motivated to get organized into small homogenous groups (preferably with 15 to 20 members in each case) based upon their livelihoods, social affinity, compatibility etc. Credit and thrift activity may be used for organizing them into groups. Preference may be given to groups with women members of the households as they have been found to be highly successful in management of credit and thrift activity.

Self Help Groups may be organized with the help of village level community organizers. These organizers should be thoroughly trained in the concept of SHG, management of credit and thrift activity, group dynamics and maintenance of records through focused exposure visits to successful examples as well as through skill oriented training programmes. Such visits and trainings may be arranged also for representative members of the proposed SHG. The expenses towards visits and skill development courses may be met out of funds under training component. The expenses towards honorarium for community organizers may however be charged out of the funds under community organization component. The above honorarium may be provided against specific jobs to be carried out by the organizers, namely; facilitation of monthly meetings on a fixed day, preparation of proceedings, maintenance of records for credit and thrift activity, training of group representatives regarding the above aspects etc.

The primary purpose of organizing the SHGs is not only to involve them in the implementation of the project activity but also to strengthen them as a social and functional unit in order that they may effectively manage their own need based activities (even if these are not within the framework of watershed project). Hence, at a micro level the basis for formation of these groups need be both common interest or activity and also social affinity and compatibility.

User Groups (UG)

User Groups shall include those members who are land owners within the identified watershed area. Such land-owning community may also be motivated to get organized into small homogenous groups. Like SHG, the UG may also be organized around credit and thrift activity with the help of locally available trained community organizers. These groups may be of women members or men members or both depending upon their availability, willingness etc. As in the case of SHG, the expenses for exposure visit and training of community organizers/group representatives may be met out of the training budget whereas honorarium to the community organizers may be provided out of the community organization budget.

Experience indicates that it is preferable to organize UG also as per their social affinity and compatibility even if they are to manage a particular community asset. Such members learn the value of group work and would be able to manage the community structures through occasional meetings of concerned members as and when the need arises.

Watershed Association

After the organization of SHGs/UGs, the WDT shall call for a General Body meeting of all members of the above groups and also other participants representing the households within the watershed area, who have not yet become member of the SHG and UG. The watershed Association will be the General Body comprising all members of the watershed Community who agree to participate in the watershed development project. This body would be formally registered under Societies Registration Act. The WA shall evolve its own working procedures after electing its President. It will meet preferably once in a month, to discharge the functions entrusted to it as per the guidelines. All decision making power would vest with the WA. The WA would not only approve the Strategic Plan and Annual Action Plan but also carry out review of progress during implementation phase.

Watershed Committee

The WA shall in its first General Body meeting, nominate four representatives from the Self Help Groups and five from the User Groups as members of the Watershed Committee. The Gram Panchayat and the WDT will be requested to nominate one each of their members as representatives. While making nominations, it will be ensured that the Watershed Committee (WC) has at least two women members and the SC/ST community is adequately represented. The WA will decide on its own procedures for nomination of the members of the WDT by rotation, which shall be simple and easy. However, members of the WDT shall be present during the meeting of the General Body of WA in which nominations to the WC are approved. The President of the WA may also be Chairperson of the WC. The WC shall perform all the functions that are entrusted to it in the guidelines for which it will work out its own procedures in consultation with the WDT. The Watershed Committee shall act as the executive body of the WA and carry out the day-to-day activities of the watershed development project subject to overall supervision and control of Watershed Association.

Functioning of WC and WA improves significantly if its members belong to mature UG and SHG. Hence, it is useful to stagger formation of WC/WA until the UG/SHG is suitably organized. It may be appropriate if membership of WA is given to all those persons who are direct participants in the watershed programme so that decision-making process is influenced by these members. This may include members of UG and SHG and other land owners whose land is covered under the identified watershed. It may be desirable if a nominal annual membership fee is charged from the WA member so that their involvement becomes active.

Watershed Secretary and Volunteers

After its constitution, the WC with the assistance of the project leader of the WDT, shall identify one secretary and 2 to 3 volunteers residing within the village on honorary basis/contract basis, who shall be able to carry out the required jobs. Watershed Secretary should preferably be a graduate from the same village or at least from some nearby village and he should agree to live in the watershed village during project period. The WC shall fix the honorarium to be paid to the watershed secretary and volunteers, as well as the manner in which these should be paid – either on a fixed monthly basis or linked to performance of specific duties. The Watershed Secretary is primarily responsible for maintaining records related to physical and financial progress, disbursement of wages to the labourer, purchase of material, supervision of the work of volunteers, maintaining the measurement book etc. The volunteers are expected to initiate implementation of works, provide markings at the site, supervise the quality, measure its progress, maintain measurement book, maintain register regarding use of materials, employment of labourers etc., besides assisting the watershed Secretary in various responsibilities.

Training to Watershed Secretary, Volunteers and Members of WC

Watershed Secretary, Volunteers and the Members of WC are oriented by the WDT regarding participatory planning progress followed so far, for preparation of detailed action plan and their role in consolidation of the proposals into a comprehensive watershed development plan for approval by WA and the district head.

II. Participatory Rural Appraisal (PRA)

a. Rapport building:

It is an entry point to take the village people in confidence. It includes introduction explanation about purpose of the visit, idea in brief about the project and how it can benefit the farmers. To make the interaction more fruitful it is necessary that you behave according to their culture viz; pay respect to old aged persons and also do not try to impose your ideas over their views.

b. Historical timeline

It gives background idea of important happenings in the past and the respective changes or developments accordingly in the village viz; establishment of village, introduction of roads, electricity, television, radio, vehicle, school, irrigation facilities, crops grown, animals reared, occurrence of drought, flood or famine and the changes in the culture and people's attitude over the period of time.

Year	Activity
1700	Village was established
1800	Village path (Churki rasta) was constructed through Sharamdan by the
1950	Fish catch festival started
1960	First radio was purchased in the villages
1964	Tank for drinking was constructed
1980	Pucca road was constructed
1982	Small fish shop started in the local market
1987	Village was electrified
1987	Severe drought occurred
1990	Heavy hailstorm occurred in the area
1991	Severe flood occurred
1994	Fish farming started in the village pond
1995	Primary school was opened.
1995	Tanks for irrigation water were constructed
1998	Tanks for fish farming were constructed
2003	First television was purchased in the village

c. Social map

Generally in village condition mapping is done with chalk or Rangoli on the ground or on cemented floor if available, by the farmers itself according to the instructions given by the facilitator. Social map includes an outline of village boundary, roads, location of forest, community land agricultural land, habitation, schools, temple, mosque, hand pump, Panchayat Bhawan and other infrastructures available in the village. It also gives an idea about human population, livestock population, size of land holdings, caste and religion wise distribution of farm families and level of education in the village.

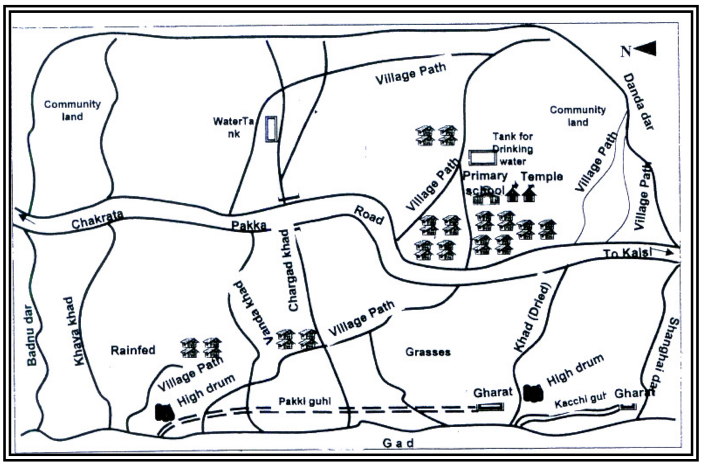


Fig. Social Map

d. Resource map

In resource map, farmers indicate village boundary with total geographical area, location and area under forest, community land and agricultural land (irrigated, rainfed), soil types, different sources of drinking water (well, hand pumps etc.), irrigation water (ponds, guhls, water springs, tubewells, canal etc.) and sources of water(perennial, seasonal streams & springs, village ponds, kuchcha/ pucca tanks) for fish farming .

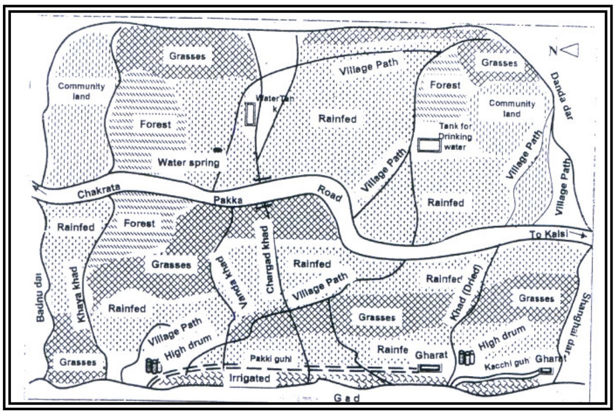
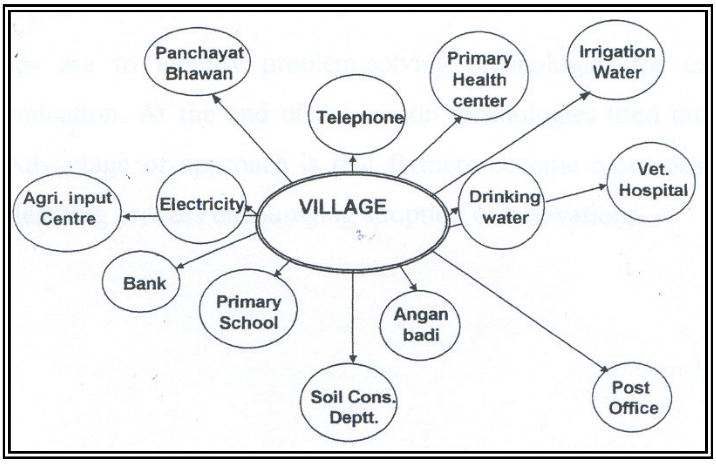


Fig. Resource map

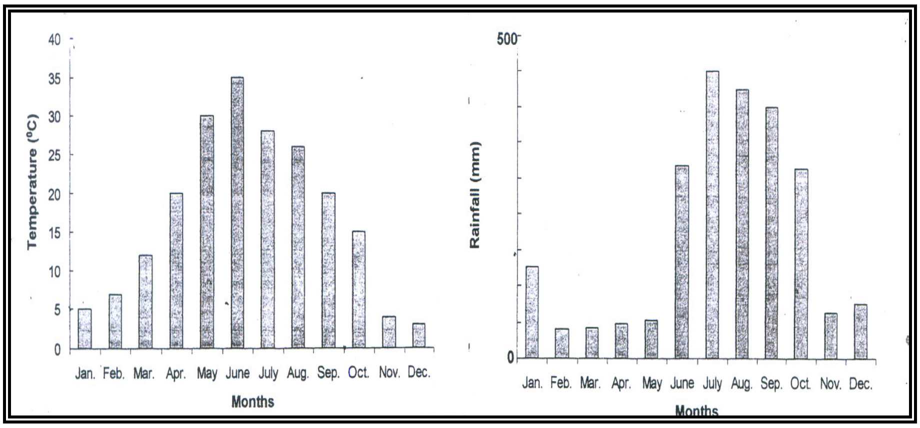
e. Venn diagram

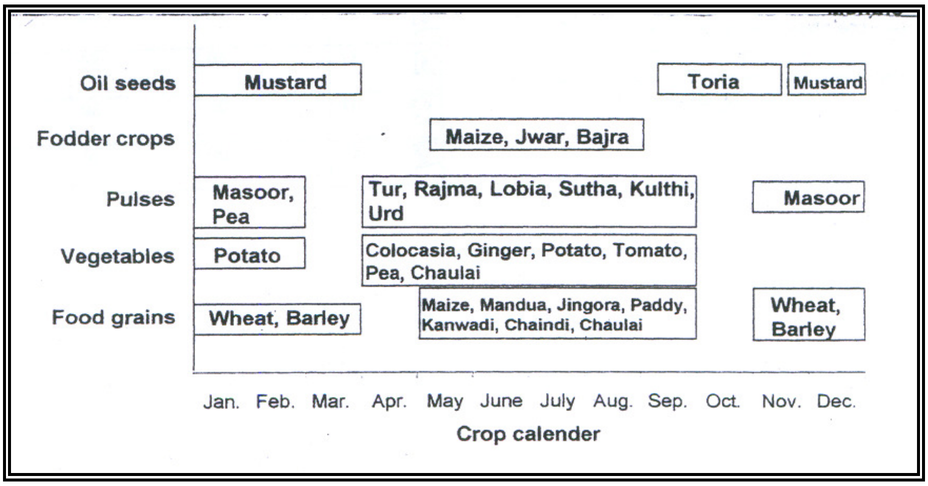
Venn diagram shows the existing key institutions and their importance and role for socio-economic development of the village. Each institution is represented by a circle. The size of circle shows the significance of the organization. The degree of overlapping from the village circle indicates level of involvement in the village development. If size of circle is bigger, it shows that services of that institution is very much important / required for the village and at the same time if circle is nearer to village circle, it shows that services of that institution is very much available in the village. Small size of circle shows less importance and more distance from village circle shows less evolvement of that institution in village development activities.



f. Seasonal analysis

It gives an idea of weather condition prevailing over, fish grown and practices followed during different months of the year. It also helps in identifying the irrigation water, fuelwood, fodder and labourer availability and requirements. Occurrences of insect-pest and diseases in crops, fish and livestock in different months of the year are also identified in the said exercise.





g. Priority ranking

Different criteria and attributes are ranked in matrix by giving scoring to particular aspects. They are ranked on the basis of fixed scoring or free scoring methods according to their relative importance. For example what are the crops, trees, fodder, fish or animals are more suited in their environment and why.

Farmers preferences for fish spp. (Max. score for each attribute = 10)

Fish spp.	**Scientific name**	**Preference attributes**				**Total**	**Rank**
		Production	**Market**	**Taste**	**Medicinal value**		
Catla	*Catla catla*	08	08	09	09	34	III
Rohu	*Labeo rohita*	08	1 0	10	09	37	I
Mrigal	*Cirrhinus mrigala*	08	09	09	10	36	II
Silver carp	*Hypophthal michthis molitrix*	08	05	05	07	25	V
Grass carp	*Ctenopharyngo don idella*	07	05	06	06	24	VI
Common carp	*Cyprinus carpio*	09	07	08	08	32	IV
Trout	-	07	10	10	10	37	I
Mahaseer	-	06	10	10	10	36	II

h. Transact walk

This exercise enables the outsider to have knowledge of different aspects of ecology of the village and verify the information provided by the villagers, by direct observation.

Particulars	**High hills**	**Mid hills**	**Down hills**
Vegetation	Oak, Chir, Sal	Lantana	Asian, dhaura Sal, Sahtul, Sandan
Grasses	Gorda, ulendu, Tachla, Panho, Luenj Baboon, Musul	Gorda, tachla Pano, Ulendu	Gorda, baboon
Soil	Kateel, Doyam and Rainfed, Poorly terraced	Abbal & tachla Pano, Ulendu	Abbal and Doyam Well terraced, Partially irrigated
Crops	Maize, Paddy, Mandua, Ginger, Colocasia, Barley, Mustard, Lentil, Jhingora	Maize, paddy, wheat, lentil, onion, garlic, mustard, potato mandua, jhingora	Paddy, wheat, ginger, peas, lentil, mustard, madua, jhingora
Horticulture	Guava, Peach, Peer, Walnut, Plum, Citrus	Mango, Banana, Citrus, Papaya, Peach	Mango, Litchi, Citrus, Banana, Papaya
Livestock	Sheep, goat, cow	Buffalo, cow, sheep, goat	Buffalo, cow, sheep, goat
Water sources	Seasonal water springs	Seasonal water springs	Perennial water stream
Land use	Forest, community land, kateel	Habitation, Kateel, cultivable land	Cultivable land, habitation, kateel

i. Problem Identification and Prioritization

RBQ = Rank Based Quotient

$$\frac{Fi\,(n+1-i)}{Nxn} \times 100$$

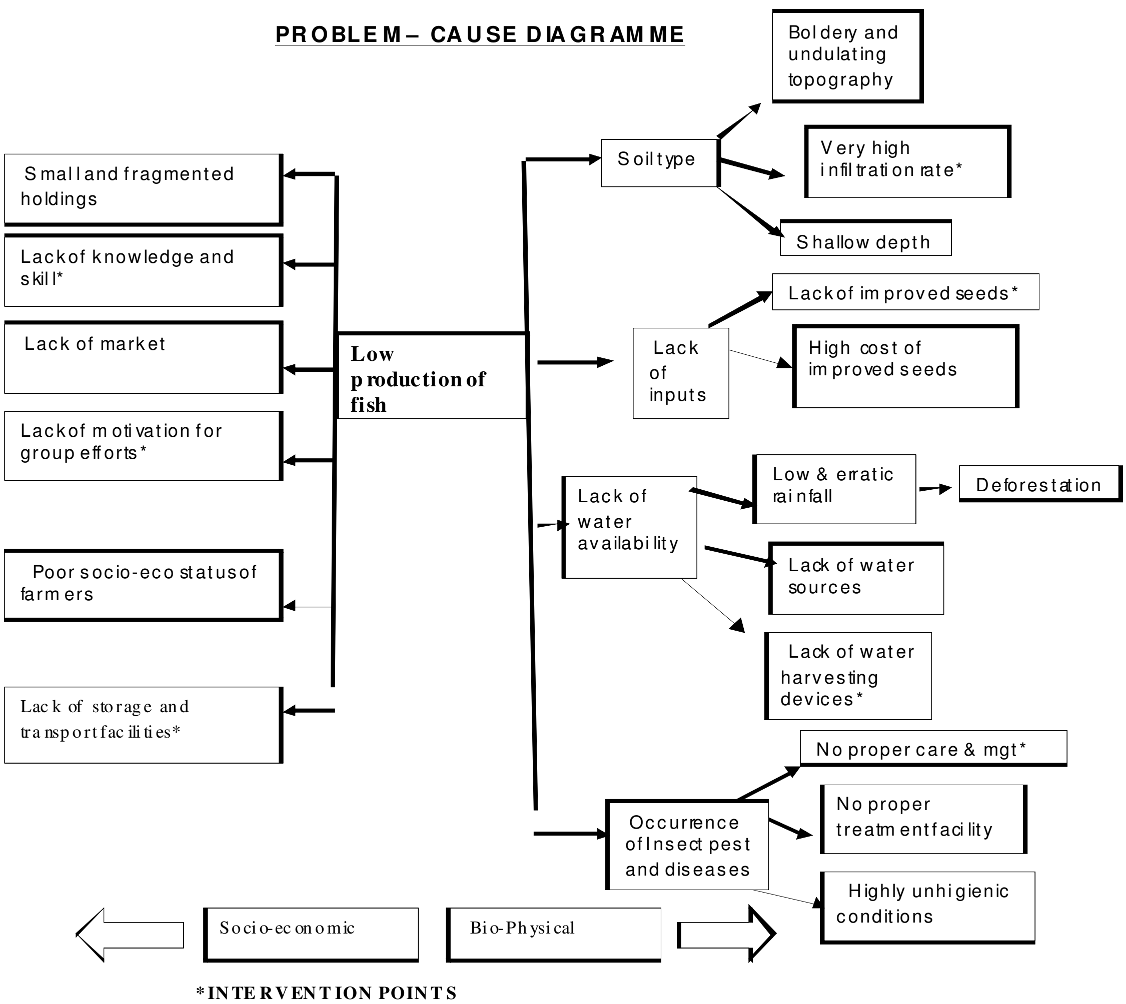
Where: Fi = Frequency of farmers for the ith rank of problem

n = No. of ranks

N = No. of farmers

(N=10)

Problems	Ranks												RBQ	Rank
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII		
Lack of drinking water	**1**	**1**	**5**	**2**	**1**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	82.48	**III**
Lack of Irrigation water	3	6	1	-	-	-	-	-	-	-	-	-	**93.33**	**II**
Lack of water for fish farming	-	-	-	-	-	3	4	2	1	-	-	-	**49.16**	**VII**
Occurance of insect pest and diseases in fish	-	-	-	-	-	-	1	2	5	1	1	-	**34.15**	**IX**
Lack of inputs	1	2	-	-	6	-	1	-	-	-	-	-	**73.32**	**V**
Lack of transport	-	-	-	-	-	-	-	1	2	6	1	-	**27.48**	**X**
Lack of feeds	-	-	-	-	1	1	7	1	-	-	-	-	**59.99**	**VI**
Lack of market	-	1	1	5	2	-	1	-	-	-	-	-	**73.33**	**IV**
Lack of support system	-	-	-	-	-	3	-	6	1	-	-	-	**45.80**	**VIII**
Low production of fish	7	2	1	-	-	-	-	-	-	-	-	-	**96.66**	**I**



III. Participatory Planning and Implementation

Planning is done based on problems identified and prioritized. To know the different causes responsible for different problems, problem-cause diagram is prepared separately for all the problems, after thorough discussion with the farmers. Accordingly, to address the causes responsible for the problems, technological interventions (keeping in view the natural, physical and social resources available, seasonality, preference rankings etc. - check with information collected through PRA & other secondary sources) are proposed and implemented.

Action Plan

1. Very high infiltration rate

T1= *Farmers practice*

T2= *Technological option –I*

Technological option –II

Technological option –III

…………………… and *likewise for all the intervention points.*

"If farmers of the watershed are not at all aware about fish farming and it is going to be introduced for the first time, farmers may or may not be aware about package of practices, different fish spp., insect pest & diseases and other seasonality issues. It becomes difficult for the project team to conduct the PRA because it totally depends on reciprocity and in-depth discussions with the farmers. In such cases project team should adopt different approach. Information on agro-ecological & technical issues should be discussed and collected from the concerned department officials in the real field situations. At the farmers level along with general awareness, knowledge, attitude and willingness should be discussed & analysed. Accordingly, before planning of interventions, sufficient no. of discussions with the experts and farmers should be arranged."

AQUACULTURE CONSIDERATIONS FOR THE DESIGN OF WATERSHED PONDS

M. Muruganandam*

Introduction

Management of natural resources by watersheds to sustain food availability is proved to be effective for targeted developments in any given region. In recent days, watershed development programmes are multifariously growing across the country. For the success of watershed management plans and activities, multidisciplinary interaction and proper understanding of various disciplines are essential. Critically, farm ponds and watershed ponds are main components of any farm or watershed developments. Farm or watershed ponds are primarily constructed for the purpose of resource conservation and integrated uses. A renewed importance for farm ponds and watershed ponds is being attached for their basic and value added potentials. In fact, they find use in irrigation, animal watering, household purposes, wildlife management and fish farming besides in flood moderation, water storage and groundwater recharge. Also, ponds provide excellent recreational activities such as fishing, swimming and wildlife viewing as well as potential water sources for firefighting especially in forest environments. Further, a properly located, planned and well-constructed pond can be an aesthetic addition to a landscape besides its basic support for fish farming and other benefits. Fish farming in farm ponds is one of the viable accommodative and alternative resource-use proposals.

Although, farm, watershed and conservation engineering are derived from principles of general civil engineering, aquaculture engineering is slightly specific in nature to provide life-supporting systems for aquatic organisms. At times, it differs in certain basic requirements from general and conservation engineering that needs to be bear in mind while developing multipurpose ponds meant for aquaculture.

The farm or watershed ponds are one of the major farming systems available to augment fish production in the country and they require to have certain specifications for organized and successful fish farming. Often, the aquaculture requirements of farm ponds may vary with the general requirements for water conservation that need special considerations during construction for ideal and strategic management. In already developed farm ponds and Water Harvesting Structures (WHS) under watershed development programmes, the suggested improvements need be implemented to make them more fit for organized aquaculture. For maintaining a quality pond some basic information are needed so as to understand the process involved in establishment of pond ecosystems, productivity and management. They are essential to avoid costly mistakes, to communicate more effectively with pond engineers and to be successful at building and maintaining the best possible pond. Overall, accomplishing requirements of farm ponds to accommodate fish farming needs specific construction considerations that are to be taken care all through the construction activities as detailed herein.

*** Senior Scientist (Fisheries), Central Soil & Water Conservation Research & Training Institute, Dehradun-284 195 (Uttarakhand)**

Features of watersheds, water yield and watershed ponds

In Integrated Watershed Management (IWM), management of natural resources and mountain environments are emphasized greatly. In the efforts, treatments of catchment through various biophysical means including pond development at the downhill or strategic locations are advocated for sustainable productivity as shown in fig. 1. Strategic ponds established in low-lying areas or on terraces can be improved or managed for fish production for additional benefits. Watersheds that are poorly maintained can erode the land. This can muddy pond and eventually silt it in. Mud in a pond reduces phytoplankton and hence zooplankton life because it cuts out sunlight energy. Poor plankton life will eventually lead to poor fish production. Erosion and contamination from watershed may pose good management impossible. Hence in eroding watersheds, good plant cover is to be provided. Conservation tillage, optimum fertilization and appropriate seeding with recommended grass seeds may be necessary to maintain good land cover so as to improve pond water and ecosystem. Ponds built on cultivated watershed may have serious problems with erosion and pesticides. A buffer zone of grass around pond may prevent eroded soil from reaching pond. Pesticides sprayed on crops may be washed into ponds that may kill fish. Hence more eroding or problematic practices like deep tillage, up-down (along the slope) cultivation, excessive fertilization and pesticide application should be checked to prevent watershed oriented problems. If livestock use the pond, they may damage pond edges and dams to cause shallow areas due to soil sliding and that may facilitate the development of waterweeds and turbid water. Hence, in integrated watershed management efforts possible impacts of one sector or system on another are needed to be characterized before any development activity taken-up.

Watershed ponds are standing impoundment built by damming ravines or small valleys from few ha of watersheds to supply water for one or a fraction of a surface ha-m pond. In general, farm ponds in India are mostly rain-fed. According to earlier reports, normally, a surface acre of pond should have 10 to 20 acres of watershed if the watershed is pasture. It should have 20 to 30 acres if it is forested. If watershed is too large a diversion ditch around one side of the pond to keep away excessive water from running into it and to keep the pond safe from flushing too rapidly and frequently. If watershed is too large and water yield is high, series of ponds can be built for productive use. In Dehra Dun, for every 1 ha-m of surface water 10 ha of watershed area is required in agriculture dominated areas (Sastry *et al.,* 1981). Similarly, in Bundelkhand region, 3 - 6 ha watershed may be necessary for a unit ha-m water (Tiwari *et al.,* 1999). Overall, watershed to water surface acreage ratio should be large enough to fill ponds during rainy months but allow them to drop at least no more than 2 feet during summer months. Watershed to water surface ratios vary from 5 acres of land for each acre of pond in heavy clay soil on open site (5:1) to 30 acres or more for each surface acre of pond (> 30:1) on porous wooded sites. In arid zones the ratio could be 50:1 because of sparse rainfall and runoff potential. When ponds are built in series in humid valley or sloppy terrain, less watershed area may be needed to maintain ponds. Before harvest, water can be pumped or drained from one pond to another for storage. This allows ponds to be refilled using stored water, immediately after harvest during non-rainy periods. Water level in rain-fed or watershed ponds fluctuates considerably depending on amount and distribution of rainfall, fluctuation of water table, soil permeability and evaporation potential. Obviously, water level decreases during dry-spell periods and large amount of out-flow occurs during rainy season. Watershed ponds impose less control over water management activities towards achieving better fish production. The advantages and limitations of farm ponds for fish farming are listed in table 5. In deeper ponds, thermal, dissolved oxygen and hence biotic composition especially plankton's stratification will be observed to affect fish production greatly. If ponds are in forest or surrounded with trees, sunlight would be screened and that would alter ecological situation by leaf fall and rotting vegetation to lower productivity. As source water is almost only rainfall-runoff, control over water levels and out-flow becomes very minimum. Ponds usually are operated without water exchange or addition, but may be siphoned-out for irrigation causing water loss in addition to evaporation and seepage. Furthermore, these ponds have multiple uses such as irrigation, animal watering and domestic purposes. Hence, availability of water for aquaculture depends on intensity of competition for water among multiple users. Regulations requiring water conservation and reuse for crop irrigation is likely to become increasingly common for aquaculture in the future.

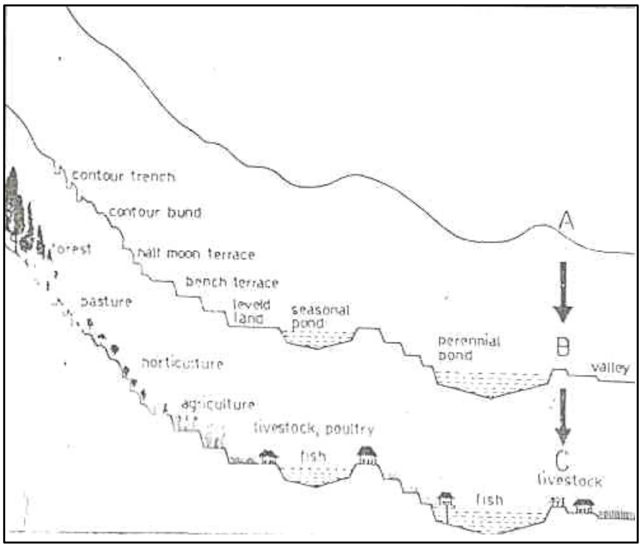


Fig 1: Biophysical Treatment and Establishment of Fishponds in Mountain Watersheds; A-Untreated, B-Partially Treated, C-Complete Biophysical Treatment of Watersheds

Features of watershed ponds

Water level in rain-fed or watershed ponds fluctuates considerably depending on amount and distribution of rainfall, fluctuation of water table, soil permeability and evaporation potential. Watershed ponds impose less control over water management activities towards achieving better fish production. As source water is almost only rainfall-runoff, control over water levels and out-flow becomes very minimum. Ponds usually are operated without water exchange or addition, but may be siphoned-out for irrigation causing water loss in addition to evaporation and seepage. Furthermore, these ponds have multiple uses such as for irrigation, animal watering and domestic purposes. Hence, availability of water for aquaculture depends on intensity of competition for water among multiple users. Obviously, water level decreases during dry-spell periods and large amount of out-flow occurs during rainy season. In general, freshwater ponds in India are mostly rain-fed. In deeper ponds, thermal, dissolved oxygen and hence biotic composition especially plankton's stratification will be observed to affect fish production greatly. If ponds are in forest or surrounded with trees, sunlight would be screened and that would alter ecological situation by leaf fall and rotting vegetation to lower productivity.

Risks

1. Unusually hot, cold or cloudy weather can stress fish and bring out disease.
2. Demand for fish can be affected by off-flavor problems that make them unmarketable for weeks or months.
3. Flooding and the resultant loss of fish plague many fish farms.
4. Fluctuating feed prices and associated economic problems.
5. Fish eating birds and poaching.
6. Medicinal chemicals are less in number and in short supply.
7. Unreliable water supply and regulations.
   Regulations requiring water conservation and reuse for crop irrigation are likely to become increasingly common for aquaculture in the future.

Watershed ponds are standing impoundment built by damming ravines or small valleys from 3 to 30 ha of watersheds to supply water for 1 surface ha-m pond.

Advantages

Lower construction costs than levee pond
Ability to make use of steeper sites
Additional benefits from integrated water use

Disadvantages

Inability to refill ponds at will
Lack of O_2 at greater depths and thermal stratification
Minimum or no control over water use

Site selection

The process of choosing a pond site is as important as the actual construction process for the success of ponds and fish farming therein. Site features and the availability of prime inputs largely influence size, shape, orientation and side slopes of pond and dykes. A site with poor soil conditions and more porous will lead to excessive seepage and thereby cause heavy loss of water, nutrients and energy, which otherwise would have available for fish production. All these are to be bear in mind in selecting pond site and construction. In fact, for various reasons, many sites are not suitable for ponds. Minor problems may be correctable at some sites; other sites often end in failure no matter how well the pond is constructed. For a reasonably good pond, it is critical to be aware of basic criteria necessary for a suitable site for pond construction. As regard to land, pond and water, limiting parameters are to be critically considered while beginning for fish farming under watershed management. Ranges of suitable pond land and soil parameters for watershed-based aquaculture are given in table-6. The ideal pond lands may be sandy clayey loams and clayey-loam those have less seepage and more water holding capacity. Ponds with adequate capacity to harvest available rainfall and overland flow should be built in strategically low-lying area, but above the frequent flood level of watersheds or streams. Ideally, levee ponds built on flat, leveled or gently sloping land and filled with ground water or surface water is suitable for commercial fish production. In hilly terrain, advantages of abundant runoff from rainfall and easy damming across valleys to form WHS can be availed (Table - 5). Rolling terrain with water shortage may eventually limit their use for fish production. Sites with mild slope, suitable soil parameters (Table - 6), less contaminant, easy approachability, construction ease, drainage possibility and less value for other users are opt for fishponds or WHS. While site selection, soil properties, water qualities and their seasonal availability, approachability and construction facilities are to be considered for successful functional ponds. Pond soil should have minimum of 20% clay for good construction, compaction and water holding. Watershed Pond Ratio (WPR) should also be matching at the proposed site of pond construction. The WPR (i.e. Volume of runoff/pond volume) is derived from the following:

$$\frac{\text{Watershed area } (m^2)}{\text{Pond storage volume } (m^3)} \times \text{annual runoff (m)}$$

If ponds are constructed near permanent water source, water scarcity during summer or inadequate rainfall season could be avoided. Slightly alkaline soil or soil pH 7 - 8 are preferred for non-problematic ponds. Otherwise, treatment with lime calcium oxide (CaO), calcium carbonate ($CaCO_3$) and calcium hydroxide ($Ca(OH)_2$) for acidity reduction or gypsum for alkalinity reduction to adjust pond soil pH is required. Soil amendments may be necessary for problematic soils. For example, if poor nutrient or highly porous or acid sulfate soils are selected for pond construction due to non-availability of suitable land for certain difficulties, the top soil of 3 - 5 inches can be replaced with good quality soils taken from other sources. In all these treatments and amendments, the costs and difficulties involved again are to be critically accounted for success of the efforts. The shedding seasonal trees near ponds may be uprooted for clearer pond environment as shed leaves and sticks inside pond water cause loading of organic matter, excessive decomposition and oxygen consumption. Alternatively, regular cleaning of shed leaves becomes essential to upkeep pond environment and water quality congenial for fish growth. Unwanted grasses, root sticks and materials are to be out from pond premises to evade latter stage problems.

As water is the prime medium in which fish culture is taken up, its source, quality and carrying capacity for fish culture are very critical to be appraised before planning fish production in large scale. Source water for fish farming generally could range from sewage, streams, rivers, glaciers, Ocean, underground water, surface water to sub-surface and surface runoff. The source water normally be fed from gradient runoff or base flow, tube and open wells, diverting or abstracting the stream flow by off-stream ponds in watershed based aquaculture. Although source water could be many, prime considerations are towards rainwater harvesting, use of runoff and base flow for fish farming as the main interest here are in resource conservation and integrated watershed management. Sub-surface harvesting may be the good source water as it comes filtered through soil for high quality with no allochanthous materials. Surface runoff may bring litter fall and other extraneous materials to ponds. Hence, filtering at pond inlets becomes emphasized. The source water quality and quantity are prime important for enhanced fish production. Physical and chemical characteristics such as suspended solids, temperature, dissolved gases, pH, mineral content, and the potential danger of toxic metals must be considered in the selection of a suitable water source. In existing systems, a close watch should be kept on these critical characteristics.

Water quality and water budget

Design and construction of watershed ponds should consider water availability, its quality and water budget for success of fish farming. Fish farming requires abundant good quality water for non-consumptive use. Water budgeting based on comprehensive climatological data and water demand of fish farming is therefore needed to be worked out to promote watershed-based fish farming. Aquaculture as a component of integrated water management, the relationships between aquaculture, fisheries and water resources that support development are to be examined before pond construction and implementation of the development programs. While water sources mainly include regulated runoff inflow and direct precipitation, source of water losses include evaporation, seepage, outflow, if any as outlined hereunder. Since watershed ponds have free water surface at all times, evaporation is never repressed by lack of moisture as it may be in terrestrial ecosystems.

Inflow = Outflow ± change in storage

Where, Inflow = direct precipitation (P), regulated runoff inflow (Q)
Outflow = Evaporation (E), seepage (S), discharge when drained
Change in storage = Storage does not change appreciably until ponds are drained

Hence, water budget for the most levee ponds could be, **P + Q = S + E + V**

Where, V = Pond volume; Q = (S + E + V) – P

Surface or ground water may be used as supplementary water resources particularly during dry spell. Conjunctive use of ground and surface water as primary or supplementary source of water for fish production would evade risk of water shortage. Water lost from ponds by seepage through infiltration into ground would replace water pumped from aquifer to fill pond. In areas where evaporation does not exceed precipitation, seepage may recharge aquifers with more water than was removed to maintain water levels. However, fishponds supplied by wells normally require more water from aquifer than they could replace, as large amount of water is required to fill ponds. As the management by watersheds is aimed to have balancing effect on resources, demand and production, the approach must consider available water resources accounting inflows, storage and outflows critically optimising water budget. Runoff (water) production potentials are to be assessed prior to construction and during aquaculture through set of parameters (Table 8) to assure estimated production. Intensification of fish production and watershed approach would minimise land-water requirements to the sub-sector. Simulation models can be used to optimise water budget considering climatic parameters and water demand.

Design

Watershed ponds are normally designed considering purpose, availability of quality soil, rainfall, water yield, suitable land, capital and such other factors. The watershed should be large enough to keep pond full but not so large that excess water washes through pond regularly. Pond site selection and design may be most important factors determining aquaculture success and profitability. Ponds that leak, have irregular bottoms or suffer from routine water shortage cannot be used to produce commercial fish crops. Poorly designed and constructed ponds are always difficult to manage. Hence, watershed ponds should be designed in appropriate sites with strategic guidelines. While designing watershed ponds, site selection, fixing storage capacity, shape, slope, dimensions, (depth, top, bottom widths), inlet, outlet, mechanical and emergency spillway, free board, foundation, local material availability etc. are to be accounted critically. The dykes should have a compacted clay core that is trenched into impervious soil or rock layer below the pond bottom to avoid leaks. Ponds are to be designed with the provisions of aquaculture engineering as given in table 2 for successful fish farming.

A farm or watershed pond design should include the principles of aquaculture engineering in addition or modification to mere conservation engineering and have suitable specifications to accommodate fish culture as given in table 2. While designing, depth, capacity, size shape, cost-effectiveness considerations, materials availability, easy operation and management provisions, like aeration possibilities are to be analysed. A depth of 1 - 2 m with a free board of about 0.5 m with wider flexibility will be suitable for farm ponds that meant for inclusive fish farming. Deeper ponds may pose problems for water management, fish growth and harvesting. However site-specific modifications and adjustment can be proposed either during construction and culture. Accordingly more depth ponds may also be considered and can be managed through stocking more of column feeders like rohu (*Labeo rohita*) and grass carp (C*tenopheringodon idella*). The capacity of the ponds must match seasonal water availability, needs of different sectors including fish farming, irrigation, animal watering and nature's pressures like seepage and evapo-transpirations. Ideally the potential runoff need to be harvested may be through series of ponds for productive and conservative uses, if suitable land is available and demands for productive ponds exists or can be created. As already mentioned, the WPR should match watershed areas, potential runoff therein and pond volume for augmented production.

Size, shape and direction of ponds suitable for fish farming management

The watershed is more applied to hilly regions and topography. But, the topographies of hill watersheds normally do not permit large sized ponds, because of the rolling terrain and the possibility of lands in terraces mostly. Size of the ponds should facilitate easy and effective management for optimum production. Pond size should be closely matched to watershed areas and management intensities. Capacity of ponds normally depends on purpose, annual water yield, storage losses from evaporation and seepage, siltation rates, desilting period and pond area available for construction. Hence, design ponds strategically that enough water is available year round to maintain water levels close to the optimum. Ponds of 200 m^2 area may be more suitably designed for mountain watershed if land for watershed ponds is constrained. Normally, smaller the ponds, better the management efficiency. However, location specific size and dimensions can be opted keeping overall benefits of ponds. Instead of a bigger pond, many smaller sized ponds may be more suited for easy operation and differential production management practices. Suitable pond sizes could be 0.1 - 1.5 ha with the wide range of acceptability. The shape of the pond, most often, depends on site features and existing landscape. Rectangular, square and circular may be preferred respectively for easy operation, proper orientation of ponds to have more sunlight and natural oxygenation of ponds water through photosynthesis and wind actions. The orientation or direction of the major pond areas should be faced towards sunny and windy directions so as to have natural benefits of augmented aeration, photosynthesis, oxygen dissolution, energy trapping and conversion to increase dissolved oxygen availability and productivity. In most cases the direction should be east west for this purpose. In case of rectangular ponds, the length proportion may be 3:1 for the said the benefit. However, wind actions should not cause the erosion of pond dykes and banks.

Water control and holding structure in watershed ponds for aquaculture

As the intensity of fish culture practice increases, the need for economic and effective structures and methods for easy operation of the inlet and outlet at reasonable cost will assume greater importance. Proper inlets and spillways are also essential for effective management of ponds and optimum productivity. In the science and technology of aquaculture, inlets and outlets are not mere conduits carrying water from watersheds to ponds and ponds to downside channels as normally planned in conservation engineering. They also have to serve for flow regulations such as in water entry, storage, exchange if needed, in most cases, preventing entry of unwanted fish and lives to the ponds and restriction of stocked fish escaping out of ponds along with outflow. Inlets must invariably have suitable net screens or filters to control the entry of unwanted lives and allocanthous materials. Preferably few Sediment Detention Structures (SDSs) in the inlet watercourse may be provided, especially if runoff comes from erosion prone watersheds and tectonically poor geographical regions. Strategically planned and constructed SDSs will detain incoming sediments and silts and reduce their entry into ponds. The waterways also preferably grassed or smoothened that feed ponds should have SDSs to retain sediments intermittently so as to avoid siltation and attendant problems like capacity reduction, enhanced turbidity, poor water quality and clogging of fish in ponds. Inlets of specific mesh sizes to filter out incoming unproductive and problematic species and materials. Nets of iron, nylon, coir and plastic materials may be used for inlet and outlet linings with due care for durability and costs involved. Mosquito nets and chicken mesh may also preferably be used. The importance to restrict unwanted species entry into ponds comes from their potential damages to productivity of ponds. Unwanted species competes with stocked fish for food, space, dissolved oxygen and such other essential needs. Unproductive species consumes the feeds given for stocked fish besides foraging natural feeds of ponds like plankton, insects and benthos. Dissolved oxygen and space available are also reduced due to the entry of weed fish into ponds. Ultimately, they reduce overall production and hence need to be restricted through inlet filters/net liners. These nets will filter out allocanthous materials getting into ponds. Allocanthous materials tend to consume oxygen on decomposition and cause production damages and loss in the ponds. Thus, they also need to be prevented from entry into ponds.

Net lines at the outlets and spillways are also equally essential to prevent the escape of stocked fish through outflows. Outlets need to be given with shutters to regulate water levels in ponds, if supplementary water available and need arises out of pond management. A provision for selective release or exchange of bottom, column or top water of pond will improve the culture ecosystems of the ponds. Often, pond bottoms get damaged and become black coloured with obnoxious conditions due to excessive organic loads settled out of un-fed feeds and accumulated wastes and settlements in pond-beds. To correct spoiled pond-beds, exchange of bottom water, lime application to water and if possible to pond-beds and flow through of water may become essential. Hence, while construction itself, provisions for shutters and nets for regulated water entry, management and culture are to be provided to inlets, outlets and spillways of the ponds. Any shortfall in these structures and provision will bother farm/pond managers often seriously. Three to four groves in the inlet, outlet and spillway sluices may be provided at the time of construction for the operation of shutters, nets etc. Few spares of net lines or filters are to be kept ready to circumvent unforeseen damages of installed nets or filters. Also, periodic renovation and maintenance of ponds, inlet and outlet structures, net filters and other farming materials by desilting, cleaning and repairing for lasting quality of services of them. The considerations for size and dimensions of inlet and outlets or spillways should include easy and reasonably quick water passage, exchange, drainage and proportionate time required for emptying. Given a time, whole water of the pond should be able to filled or emptied in 2 - 3 hours time for ideal pond management, if conjunctive water use provision available in addition to runoff. As far as possible, ponds should be completely drainable with uniformly slopped bottom towards outlets for easy drainage. However, if drainable ponds become impossible due to existing landscapes and geography, un-drainable or partially drainable ponds can also be managed through pumping in and out for drainage, water exchange and harvesting. Pond construction criteria and their implications towards effective ponds and fish farming therein are described in table 7. Few critical points to be considered in planning and construction of watershed ponds are as follows:

1. Banks should slope rapidly with 1:1 or 1:1.5 ratio to a depth of at least 2.5 feet to avoid the establishment of aquatic weed plants. So, construct ponds to reduce habitats that are favorable to undesirable aquatic weed plants.
2. Drains and overflow pipes should be built through the dam.
3. Inlet and outlet with appropriate screen nets should be strategically designed such that screening of incoming sediments, willful draining, water exchange, if ground or surface water available and total harvesting through total de-watering.
4. An emergency spillway with proper net screen should be constructed for safe disposal of excess runoff and preventing fish escape.
5. Livestock should have limited access to the pond and hence animal-watering pits with regulated water flow may be designed adjacent to or rear side of pond dykes as in Bunga watershed pond of Haryana developed by the Regional Center of Central Soil and Water Conservation Research and Training Institute (CSWCRTI), Chandigarh.
6. A minimum dead storage of at least 2 feet water with the provision for total drainage is to be provided if the pond is for integrated use of irrigation, animal watering and such others.

Pond management devises, systems and strategies

Pond management devises and systems like depth monitoring scales, feedings trays, walk paths, sampling and harvesting platforms, nursery tanks, fertilisers/cowdung soaking pits, watch sheds and stores are also be properly designed and installed for success of farming. Graduated scales in ponds will help monitoring water levels for needy management. Feeding trays in strategic locations of the ponds will help reduce feed wastage and effective feeding. Fish feeds may normally be spread casted all over ponds or kept in feeding trays from dykes and lowered into the ponds at strategic depths for feeding. Feeding trays can be operated either from pond dykes or from the gateways constructed in the pond. One or two small secondary ponds near every main pond may be necessary to acclimatize fish seeds and nourish with close monitoring for initial 10 - 20 days before stocking in the main pond. The same secondary ponds can also be used as harvesting (icing) tanks or cow-dung and fertilizer soaking pits. A nursery tank of 5 - 10 % of total waterspread area may also be advised to maintain seeds for few months prior to stocking so as to adjust seed availability and right seeding times every year. Nursery tanks or ponds near main ponds will improve survivability, growth and management of fish in ponds. Watch shed and stores are also equally important for the success of farming efforts.

Structural improvement for regulated livestock watering access

Water from a pond is often used as a primary source of drinking water for livestock. However, the practice of allowing cattle unrestricted access to a pond has detrimental effects on pond water quality, health of cattle as such and vegetative cover on dam and shoreline. As direct access of cattle are detrimental to pond, they should not have uncontrolled entry in to the pond. Virtually, any uncontrolled livestock access will cause damage to dams, banks and substantially shorten the life of a pond. Cattle damage ponds by trampling edges, exposing soil of pond banks through overgrazing and muddying the pond through wading. The physical trampling of pond edges and erosion from overgrazing will cause premature siltation and shallowing of the edges. Shallowing of pond edges promotes aquatic weed growth. Cattle wading in the pond cause excessive muddiness, that lowers pond productivity and can lead to conditions of low dissolved oxygen resulting in sudden fish kill. An excessive quantity of manure in the pond can also result in excess fertility and possible fish kills due to low dissolved oxygen developed.

Ponds can serve the purpose of stock watering without allowing direct animal access to the pond. Either cattle watering pit/ramp or cattle pond at rear or spillover side of the pond respectively will be very useful to reduce the disturbance damage to dam or pond caused by cattle interference. Additionally, the regulated flow to cattle ramp will provide water on need to cattle reducing water wastage. Realizing this, limited access for cattle provided at a planned location (watering ramp) in the Bunga watershed pond developed by the Regional Centre of CSWCRTI, Chandigarh, to fence cattle entirely out of main pond proves useful as one of the best livestock watering systems. Water flows by gravity into the cemented trough or water ramp below pond on the rear side. In Bunga pond, cattle have access only to cattle pond at spill over side of the main pond and at the ramp location. This allows cattle access to pond without miring in mud to get water. The trough or ramp placed downstream of the dam and connected to pond water by a 1.5 inch Galvanised Iron (GI) pipe. The outlet in the trough is equipped with a valve to regulate water supply. The intakes in pond and ramp should have a strainer to prevent the entry of clogging materials. At minimum, a watering line can be installed through the dam during construction to provide water to a trough below the dam. Gravity-flow waterlines can also be installed over the dam of existing ponds. A pasture pump may be needed if water cannot be supplied by gravity. This device requires no electricity. Livestock's pushing a diaphragm with their muzzles to pump water provides the power. Grossly, the areas around trough need to be protected from erosion using either concrete or geotextile filter fabric and crushed stones. Potential shade around watering ramp needs to be eliminated to keep cattle from loafing in or near pond.

Establishing vegetation and pond maintenance

The final step in good pond construction, and one of the most important, is to establish good vegetative cover over all exposed areas around the pond to avoid dams and banks suffering from severe erosion and siltation. Ideally, topsoil should be set-aside during the initial site preparation for construction. Following construction, the stockpiled topsoil should be spread, limed (if needed), and fertilized. The prepared soil can then be seeded, sprigged, or sodded with the appropriate grasses. Once pond is completed, the dam and spillways require some maintenance. Vegetation on the dam must be mowed and occasionally fertilized. Trees should not be allowed to grow on the dam or in the emergency spillway. Any erosion or scour in the emergency spillway should be immediately repaired and re-vegetated. The trash rack should have debris removed from it periodically.

However, excessive aquatic vegetation can interfere with fishing, decrease the quality and quantity of the fish and make ponds unattractive. Once aquatic vegetation increases in coverage to become a nuisance, it can be considered a weed that is not wanted. Proper pond design and construction is the first and most important step in preventing aquatic weed problems. Shallow water areas are more likely to develop aquatic weed infestations. Pond edges should slope off quickly (2:1 to 3:1) for the first 2½ feet or more of depth. Ponds should be designed and constructed so that there are no significant shallow areas less than 2½ feet deep.

Integrated farming systems

An integration of multi-sectors and multi-resource users is the need of the time for sustainable development of various regions. For example, the newly formed Uttaranchal state alone has about 8 lakh water mills for various purposes and an integration of them with aquaculture and other possible sectors will promote effective use of water and local wastes. A beginning is made at CSWCRTI, Dehra Dun to use the perennial water flowing through series of water mills for fish and poultry production under participatory mode in Sainji Watersheds of Mussouri Hill (Fig. 2). To promote integrated farming, site-specific systems including farm ponds and WHS along with their accessories according to existing features and needs as discussed here are to be evolved so as to accommodate all possible farming sectors together for enduring benefits.

Conclusion

For long, watershed management and aquaculture did not have interaction due to various interrelated problems. As a result, many watershed ponds and WHS are being developed without much consideration to accommodate fish culture. Such structures need structural improvements and strategic modifications in the light of above discussions in order to make them amenable for aquaculture. Very particularly, improvements in the inlets, outlets, spillways and pond-bottom in terms of SDSs, net liners, filters, shutters, and creation of accessory needs of main ponds such as nursery tank(s), fertiliser soaking pits, harvesting tanks etc to promote organised and scientific fish farming in such structures are essential. Any new proposals of watershed ponds or farm ponds under watershed management plans should invariably consider all these essentialities prior to actual start of constructions and management for greater success.

Appendix 1: Pond construction criteria and their implications for aquaculture engineering

Sl. No.	Features/ Criteria	Implications/Importance
1.	Site selection	• For safety of location. • Water-holding of soil in pond. • Water sources with good quality and needed quantity. • Approachability. • Favoring geologic make-up. • Topography favoring pond building. • Managed/undisturbed watershed for water supply and others.
2.	Pond safety	• Dam failure, pond damages due to water pressure and others. • Loss of life, injury to persons, livestock, damage to residences, industries, rail or highways or loss of cultured biomass. • Power-lines, overhead transmission dependent hazards.
3.	Pond soils	• Soil texture varies with depth and over short distances. • Suitable texture depends on water holding capacity, minimum seepage. • Clay or silty clay excellent for ponds; sandy clay would be satisfactory; coarse-textured sands and sand gravel mixtures unsuitable for ponds. • Soil containing at least 20 % clay is necessary for building dams and spillways. • If poor soil with no other optional sites exists, soil amendments may be proposed.
4.	Geology	• Geology contributes to success of ponds. • Limestone area hazardous as pond sites just that may have invisible crevices, sinkholes or caverns below surface soil to cause leaking pond. • Granular soil to remain highly permeable even when wetted.
5.	Topography	• It determines ultimate construction cost of pond; steep terrain costs more per acre pond than ponds built in gently rolling terrain. • It determines size, shape and slopes of watershed ponds. • The steeper the slope of pond site, the smaller the pond possible. • Generally, steep slopes in V-shaped valleys require larger volume dams per water surface acre than sites with gently sloping hills and wide-flat valleys. • Locate ponds where largest storage volume can be obtained with least amount of earth fill for dam. • Damming between two ridges crossing a narrow section of a valley suited for more water storage with least expenses. • Excavated ponds are expensive per volume of water stored. So, prefer ponding above ground behind a small earthen dam.
	Wetland or wildlife restrictions	• Important wetlands or wildlife potent sites for pond should be avoided in the interest of ecology and national development
6.	Adequacy of watershed area	• Large enough to fill and maintain adequate water in pond. Excessively large watershed may yield floodwater requiring expensive overflow structures for safe disposal. • Land slope, soil infiltration and plant covers of watershed are variable and site specific and affect water yield to pond. Excessive watershed areas tend to muddy, silt in rapidly and have erosion problems in outlets and spillways. • Also, flush out nutrients, plankton and natural fish food etc. reducing production potential.

		• Stocked fish may also escape during heavy flow. • Wild or weed fish may enter ponds during sudden or uncontrolled flow. • Pollution potent areas need to be avoided. • Inflow must be free of silts and sediments from eroding watersheds for longevity and quality of ponds. • Erosion control in watersheds will provide silt free water in ponds. • Cultivated row-crop field, gravel roads and construction sites may yield sediment-loaded water. • Parking land will yield more water than grass watershed.
7.	Water sources and quality	• Undisturbed well-vegetated covers of protected timberland or grassland watersheds are good for watershed ponds as they yield high quality water. • Addition to rainfall-runoff, availability of ground water or subsurface and surface water source will improve pond performance and overall fish productivity in ponds. • Correct programming of fish culture in time coinciding with water availability, growth period and demand is essential. • Polluted water and pesticide or nutrient-rich water should be avoided. • Primary or supplementary water sources of ground (sub-surface) or surface water (springs, streams, reservoirs etc) in addition to rainfall-runoff will improve productivity. • Incoming water need to be filtered to eliminate weed fishes and foreign materials.
8.	Watershed management and water supply	• Water yield from catchment is an interaction product of rainfall factors like intensity, duration, distribution, frequency etc. and physiographic features of area, such as topography, shape, size, slope, altitude, geology etc. • The watershed features, land treatment, present landuse and proposed landuse plan would affect ultimate water yield and influence water quality. • If the watershed is dominated with acidic soils or limestone, water of low or high alkalinity respectively will be available for production. • A compromise between watershed treatment and runoff yield should be arrived to plan runoff dependent activities including aquaculture for sustainable development. • Intensification of fish production and watershed approach would minimize land-water requirements for the purpose. • Eroding watersheds bring-in more turbid water to ponds. • Alkaline water (50 to 300 ppm as CaCO3) is most desirable for fish production. • Acid pond soils and low pH water need be neutralized with applications of agricultural limestone.
9.	Cut-off trench and dam core	• To prevent excessive seepage underneath a dam, a cut off trench need to excavated at least 12 inches into impervious layer beneath dam.
10.	Soil moisture and compaction	• Poor soil compaction leads to excessive seepage; adequate compactive efforts and soil moisture are responsible for good compaction. • About 5% of the dam may be overbuilt for gradual settlement subsequent to construction. • At least 3(H): 1(V) side slopes may be needed for good stability and management.

11.	Seepage and water loss control	• Medium soil moisture that is not too dry (unable to be molded in hand) and not too wet (adheres to construction equipment or hand) or saturated is preferred. • Poor site and improper construction would lead to excessive seepage problems needing costly corrective measures and pond management efforts.
12.	Sealing materials and methods	• If pond leaks or seeps down due to poor site or construction, compaction, clay blankets, bentonite, chemical dispersing agents and pond liners may be used to reduce seepage to tolerable level. • Compaction is least expensive, possible on pond sites containing soils of wide range of particle sizes and at least 10% clay silt to make a seal. • Clay brought from other areas may be provided into blanket through compaction to reduce seepage may be opted. • A foot thick blanket spread over 1 acre requires 1.450 m3 clay. • Bentonite powder or granules, a type of clay that absorbs water and swells from 8 - 20 times its original volume; spread on leaking ponds at medium moisture through compaction to reduce seepage; 0.5 – 1.4 kg/11 m2 is suitable; costly and no guarantee for control; applied for small problematic area of pond instead of whole pond treatment considering cost. • Before filling the pond with water, protect treated pond areas from drying by mulching with hay during final compaction. • Common chemical dispersing agents are sodium polyphosphates, including Tetra-Sodium Pyro-Phosphate (TSPP) and Sodium Tri-Poly-Phosphate (STPP); 0.2 – 0.5 kg/m2 may be rate of application; soda ash and sodium chloride is less expensive at rate of 0.5 – 1.6 kg/m2. • HDPE, vinyl or butyl rubber are pond liners to reduce seepage, but costly.
13.	Regulated livestock watering access	• Cattle damage ponds by trampling edges, exposing soil of pond banks through overgrazing and muddying pond through wading; poor water quality and productivity may be resulted of cattle wadding; so, need regulated livestock watering access. • Watering ramp or trough at the rear side of dam can be provided exclusively for animal watering.
14.	Raising vegetation and pond maintenance	• Establish vegetation cover around pond to avoid dam and banks suffering from severe erosion and siltation.
15.	Control of vegetation on pond banks and dams.	• Restrict uncontrolled vegetation on and around pond banks and dams as they limit access to ponds, hinder fishing and farming related activities, besides attracting rats and other burrowers. It makes pond unattractive, cause nuisance and less valuable for fish production. • Ponds with suitable slops and deeper area may not have weed infestation problems. • Grass carps may also be stocked to reduce weed infestation.
16.	Control rats and burrowers	• To avoid caving and leakage due to rats and burrowers, provide control measures
17.	Considerations during Pond construction	• A pond of more than 2 ha area need careful planning to contain environmental negative impacts. • Best management practices and conscious monitoring to check erosion need to be adopted. • Establishment of vegetation just after dam construction to control erosion. • Essential equipments that need to be arranged include a bulldozer, self-loading scraper, backhoe, farm tractor and implements, sheep's foot or tamping roller and manually directed power tampers.

Appendix 2: Projected pond features in conservation *vis-à-vis* aquaculture engineering

Sl. No.	Features	Conservation Engineering	Aquaculture Engineering
1.	Direction	**No specificity:** Do not have much influence on storage or general use	**East-west, high sunny and windy direction:** Maximum area and length of the pond need to be oriented towards existing maximum sunny and wind action for enhanced natural aeration, oxidation and productivity.
2.	Pond size	**No specificity in general and extensive areas proposed:** To store maximum possible water.	**0.1 – 2 ha in general; In hills – 0.1 – 0.3 ha; In plains – 0.5 – 2 ha:** For easy management towards intensive production.
3.	Shape	**Circular:** For geometrical advantage to have highest storage capacity and least circumferential length for given surface and slopes.	**Rectangular (length : breath ratio = 3:1):** To have more pond surface facing sunny and windy direction for augmented photosynthesis, biological productivity and natural oxygenation.
4.	Depth	**Deeper with range of 3 - 4 m:** Deeper the pond, lesser is the area needed for given water volume and minimum evaporation losses. However, potential seepage loss will be inevitable.	**Average of 1.0 – 2 m:** To have more light penetration and hence to augment primary productivity and oxidation. Pond areas deeper than 2 m are not generally suitable as bottom and deeper regions will be anoxic due to reduced euphotic zone. Effective stocking and feeding of fish possible only in 1 - 2 m depths as fish do not occupy deeper niches normally. To avoid water stratification related problems.
5.	Area *Vs* Volume	**Equally important**: Related to depth of ponds.	**Area is more important:** Stocking densities are determined according to area.
6.	Pond bottom	**Not seriously considered** except looking at with reference to seepage and cost problems and no worry for twigs, roots and uneven bottom.	**Mud bottom is preferred.** It absorbs/stores nutrients to facilitate slow release for phytoplankton productivity, helps fish feeding and provide good feeding ground. Twigs, roots and uneven bottom disturb netting and fish farming related activities

7.	Side slopes	**1 - 2 (H) :1 (V)** Although depends on soil and location specific angle of repose, flatter side slopes are preferred to avoid slippage due to saturation and wave action of standing water.	**2 - 3 (H) :1(V)** To have more stability during aquaculture activities, to integrate agriculture with pond activities and areas. However, up to 0.5 - 1.0 m depth, steep slopes may be preferred to avoid vegetation growth on slopes and banks. The margins and corners of pond should not be shallow enough to prevent the growth of weed and nuisance vegetation.
8.	Inlet	**Chute spillway with silt trap:** To conduct runoff into pond and to control entry of silts into pond. Entry waters need not to be rid of all sediments, but it should not plug conveyance systems.	**Sediment Detention Structures (SDSs), net liners or filters:** To detain sediments silts, allochanthous materials. To screen out incoming weed fishes and foreign materials.
9.	Outlet	**Mostly inlet-cum-outlet structures or ordinary outlets or spillways:** Necessity of retaining stocked fish or species does not arise.	**Outlet with net-liners, shutters, wooden planks and regulatory provisions:** To control the escape of stocked fish and fingerlings. To regulate water levels or to have selective water exchange of bottom, column or top water of pond, if water deteriorated and water available for supplementary or conjunctive use.
10.	Outlet size and duration for water release or pond emptying	**Not emphasised:** Only water storage is aimed and normally safe disposal of excessive runoff only considered.	**Outlet sizes opt for pond emptying within 1 - 2 hrs duration:** For quick release of water while harvesting or emergencies, water exchange and pond conditioning.
11.	Water ramp/ trough at outward dyke slope	**Not emphasised:** May not be needed.	**Necessary:** To reduce cattle disturbance, silt and clay turbidity and improve water quality for fish farming.
12.	Water quality	**No specificity:** Often, quality of conserved/stored water may not be important, as quantity only matters generally.	**Specified range of physical, chemical, physico-chemical and biological parameter:** Important for successful and optimum fish production.

13.	Pond accessories: Accessory (nursery) ponds, fertiliser/ cowdung soaking and harvesting tanks etc.	**Not emphasised:** No specified uses	**Important:** To improve seed survivability, better fertiliser application and harvest processing.
14.	Pond qualities: Devoid of stumps, rocks trash excessive organic loaded etc.	**Not emphasised:** No much disturbances or specified loss in uses.	**Essential to be clear:** For easy operation of nets (gears), crafts and other fishing operations.
15.	**Ponds sites:** Depth to water table = > 75 cm	**No specificity:** No effect on conservation	**Essential:** Otherwise, hard to drain or dilute will be resulted.
	Thickness of organic soil material = < 50 cm	**No specificity:** No effect on conservation	**Essential:** Otherwise, excessive seepage, hard to compact will be observed.
	Depth to suldific or sulphuric layer = > 100 cm	**No specificity:** No effect on conservation	**Essential:** Otherwise, potential acidity or toxicity will be experienced.
	Frequency and flooding = None	**Not emphasised:** However, frequent flooding might damage conservation structures and pond itself.	**Important:** Frequent flooding might damage fishponds and stocks.

RECENT ADVANCEMENT AND POTENTIAL TECHNOLOGIES OF COLDWATER FISHERIES AND FISH FARMING

P.C. Mahanta* and N.N. Pandey**

Introduction

About one-fifth of the land surface of the world is covered by mountains, which are home to one-tenth of the world's population, and provide livelihood to some of the poorest communities in the world (FAO, 2003). The lakes and streams situated in the mountainous region are a source of freshwater for many of the riparian human communities residing in the hill, support many industries, provide water for storages for irrigation and hydropower electricity production and for fish. The long stretch of Himalayas of around 2500 km from west to east and 200-400 km from north to south comprising an area of 5,33,604 km^2 contains different types of coldwater resources mainly in the form of upland streams, rivers, high and low altitudinal lakes and reservoirs located in different hill states of India. Around 8,243 km long streams and rivers, 20,500 ha natural lakes, 50,000 ha of reservoirs both natural and manmade and 2500 ha brackish water lakes at high altitude inhabits large population of indigenous and exotic coldwater fish species in these mountain water bodies which have immense potential for aquaculture practices as well as capture fisheries to some extent. However, the role of inland capture fisheries and aquaculture in mountain regions has rarely been fully acknowledged or fully estimated in the past. The mountain areas being landlocked fish of lakes, streams, rivers and reservoirs are an important source of animal protein, always in short supplies in the hill regions. While there are certain limitations of cold water fisheries such as accessibility, difficult hilly terrain, lack of proper market but recent success of developing aquaculture in mountain areas of India shows that fish farmers in the rural areas can become the direct beneficiaries of the implementation of inexpensive aquaculture technologies, and as a consequence achieve significant improvement in their standard of living. As fisheries play an important role in providing food and income to people in mountain areas, they must be integrated into the rural development and water resource development initiatives.

Major occupation in the mountain region of the country is agriculture based activities. The land holding in the hill area is smaller (700-900 m^2) as compared to the national average (1370 m^2). The farmers in the hill region have integrated type of farming pattern. Fish can serve as an additional source of income if integrated with the water conservation and horticulture. To cop up the climatic stress, animals are the main source of protein in the hills but animal flesh is more expensive due to adding in transport cost. Locally farm produced fish is suggested to be the best substitute of the animal protein as is provide meat in fresh condition, cheaper source and alternate source of income to the dwellers. Moreover, fish culture in hills encourage conserving the water as well as indigenous biodiversity. The coldwater fisheries may play an important role in providing the protein and improving socio-economic life of the people dwelling in the mountainous zones of the country.

*** Director and ** Senior Scientist (Aquaculture), Directorate of Coldwater Fisheries Research, Bhimtal-263136, Distt. Nainital (Uttarakhand)**

Fish diversity

The water bodies of the Himalayan region inhabit diverse kind of fish fauna. Out of total fish fauna available in India 17% fishes were documented from the mountain ecosystem establishing the status of the area as a center of origin and evolution of biotic forms (Ghosh, 1997). About 36 species of freshwater fishes (out of 1,300) are endemic to the Himalayan region (Ghosh, 1997). For the whole Himalayas, 218 species are listed (Menon, 1962).The distribution of fish species in the Himalayan streams depends on the flow rate, nature of substratum, water temperature and the availability of food. The species distribution in the upper reaches of the stream/river where water has a torrential flow is different from the mid and lower reaches of the stream where flow is moderate and water current is soft. A number of fish species such as *Noemacheilus gracilis*, *N. stoliczkae*, *Glyptosternum reticulatum*, *Diptychus maculates*, *Noemacheilus* spp., *Schizothoraichthys esocinus*, *S. progastus*, *Schizothorax richardsonii*, *Schizopygopsis stoliczkae*, *Schizothorax longipinnis*, *S. planifrons*, *S. micropogon, Garragotyla*, *Crossocheilus diplochilus*, *Labeo dero* and *L. dyocheilus* are found distributed in the different reaches of the river. The eastern Himalaya drained by the Brahmaputra has a greater diversity of Coldwater fish than the western Himalayan drainage. Among all these species a few supports the capture fishery while some are being cultivated in the farm condition at different altitudes based on their temperature tolerances.

Important Coldwater Fishes

Snow trout:	**Exotic trout**:	**Barils/Minnows/Catfishes/ Loaches:**
Schizothorax richardsonni	*Onchorhynchus mykiss*	*Barilius bendelisis*
Schizothoraichthys curvifrons	*Salmo trutta fario*	*B. Bakeri*
S. longipinnis	*Salvelinus fontinalis*	*B. Vagra*
S. esocinus	**Other exotics**:	*B. Barila*
S. niger	*Cyprinus carpio var. specularis*	*Raimas bola*
S. plannifrons	*C. carpio var. communis*	*Danio divario*
S. micropogon	*C. Carpio Var. nudus*	*Botia birdi*
S. progastus	*Tinca tinca*	*Glyptothorax pectinopterus*
S. nasus	*Carrasius carrasius*	*G. conirostre conirostre*
S. hugelli	**Minor carps**:	
Lepidopygopsis typus	*Labeo dyocheilus*,	
Mahseer:	*Labeo dero*,	
Tor putitora	*Crossocheilus latius latius*	
T. tor	*Gara gotyla*,	
T. khudree	*G. hughi*,	
T. malabaricus	*Puntius ophicephalus*	
Neolissochilus hexagonolepis		

Mountain fisheries in India

On a global level, mountains are the world's largest repositories of biological diversity. Mountain regions are characterized by the presence of cold waters, many of which harbor fish and support largely subsistence fisheries. The farming or husbandry of trout has a relatively long history in Europe and North America. In the Indian Sub-continent two main types of trouts *viz.* brown trout (*Salmo trutta fario*) and rainbow trout (*Oncorhynchus mykiss* (Walbaum)) were transplanted from Europe by British settlers around the beginning of the last century primarily to meet their needs for sport fishing or recreational angling. The transplantation of brown and rainbow trout was attempted independently in the Himalayan and in the non-Himalayan States. In the Himalayan States the brown trout (*Salmo trutta fario Linnaeus*) was first brought in Kashmir through the private efforts of F.J. Mitchell in 1899. These introductions in the hill states could be considered as the formal beginning of Coldwater fisheries or mountain fisheries development in India. For many decades the mere intention remained to develop recreational fisheries to satisfy the needs of anglers for sports. Later on, these species were started being cultured for food and hatcheries were setup for the production of seed. The development of hill fisheries thus started in the selected locations particularly in the Kashmir valley and some parts of the peninsular India. The breeding and culture techniques for the rainbow and brown trouts were standardized and now being practiced with greater success and accuracy.

Available technologies/Recent practices:

Technology developed for the culture, breeding and management of the economically viable fishes suitable for mid Himalayan region has a positive impact on the employment generation in these regions since the technology was taken as hot cake among the farmers in some areas of the hills. There is great scope for disseminating these promising technologies in sub to mid Himalayan belt in order to upgrade the socio-economic conditions of the inhabitants.

Flow-through hatchery and seed production of golden mahseer

Golden mahseer is the most prized sport fish distributed in all the Himalayan waters. A flow through Mahseer hatchery has been designed for the mass seed production of this fish species. The system is simple and farmers friendly for breeding, egg incubation and larval rearing with continuous water flow. Artificial mass seed production of this species is helpful for the rehabilitation of this species through ranching in the uplands water bodies and also for enhancement of aquaculture production.

Breeding and culture of rainbow trout

Trout farming has immense scope in the Himalayan and some peninsular regions, where sufficient quantity of quality water is available. Trout need highly oxygenated (above 6 ppm) cool water (5-20 °C) and protein rich diet. Seed production technology for Trout and culture technique in raceway is available for the trout production. The rainbow trout farming in the states of Jammu & Kashmir and Himachal Pradesh is being practiced successfully. Now, the trout farming is also developing in other hill states such as Sikkim, Uttarakhand and Arunachal Pradesh. Many of the farmers in the hill states particularly in Himachal Pradesh have taken up trout farming which has now helping them to improve their standard of living.

Carp farming in mid altitudinal areas

In the upland waters, the Indian major carps do not grow well, due to the low thermal regime. Therefore, Chinese carps found suitable for the Mid-Himalayan region as the candidate species for polyculture. Exotic carp farming in the mid Himalayan region has shown good results that are extended to various regions; in hill states for improving total fish production and further promotion of integrated fish farming. This model has become very popular in North West Himalayan region and was extended to North East Himalaya.

Introduction of improved Hungarian strains of common carp

Common carp is a major candidate species for polyculture in mid hills. The common carp presently grown in India originated from two introductions, in 1939(German strain) and 1957 (Bangkok strain). These have become mixed over many generations to give the current stock. This stock of common carp is characterized by early sexual maturation and slow growth rate. This is considered as a serious problem in the culture of this species in uplands. For faster growth and successful aquaculture of this species in coldwater system, it is required to replace the stock with improved strain. Two improved strains Ropsha scaly and Felsosomogy mirror carp were imported from Hungary, at DCFR, Bhimtal. The strains were reared and successfully bred at Champawat farm of DCFR. Hungarian strain gave 47% more growth rate over the existing strain in polyculture system. After field trials at different locations, these strains would be available for the coldwater aquaculture practice.

A new model of integrated aquaculture for mid hills using polytanks

Exotic carp farming in the mid Himalayan region is a common practice in North West Himalayan region. But, there is low productivity due to low temperature during winter that restrict growing period to 6-7 month in a year. A refined multi-tier model for carp culture was developed for which the poly-cum-irrigation tanks were constructed for the water storage and lined with polythene to control the seepage. These deeper ponds would act as buffer stock of water and over flow water from these tanks is used for the irrigation of horticultural crops. The same pond is stocked with Chinese carps. This is a more economic, farmer's friendly and diversified practice with more fish production in compare to the existing practice.

Feed for coldwater fish

Successful larval rearing of mahseer requires nutritious, protein rich and easily digestible feed of the adequate particle size. Traditional feeding for this purpose is based on goat liver wet feeding and simple formulated larvae feed. Formulated microparticulate diet was developed on the basis of the nutrients requirement and ontogeny of the digestive enzymes of golden mahseer larvae with adequate particle size. NANHE MAHSEER is an improved efficient larval feed for Golden mahseer. As Chocolate mahseer is a slow growing fish in coldwater environment, fish meal is required as protein supplement and spirulina for better growth, which contains all the essential vitamins, minerals, trace elements and carotenoids. Developed Chocolate mahseer feed is nutritious and cost effective feed for the better growth and survival. Trout requires protein rich diet and fish meal is the main ingredient in the trout feed. The existing trout feed in the practice is costly due to the fish meal. Hence, a growout trout feed was developed with inclusion of Solvent extracted soybean to replace 40% fish meal, papain powder to improve protein utilization, turmeric powder to increase feed intake and Ashwagandha (*Withania somnifera*) as anti stress with other ingredients.

Low cost grit filter for pond water purification and recirculation

Semi-intensive mixed carp culture practice is popular in the mid hills. When the temperature rises during April to June months there are frequent incidences of shooting up the algal production in the ponds resulting in mortality in the ponds due to sudden decrease of dissolved oxygen content in the water during night time. Addition to it, there is problem of water scarcity and water replacement is not possible. Therefore, a low cost grit filter has been designed for water purification and recirculation. This filter is efficient to remove 70% physical impurities with 1-1.5 ppm improvement in D.O level. This is based on the indigenous knowledge by using local sand material.

Considerations required for further development

The potential areas of the coldwater aquaculture are in trout production, carp production, trout feed manufacturing, induced breeding, hatchery production, processing of the trout fish, ornamental fish trade and fish culture based eco-tourism. At present attention should be directed towards the standardization of species and resource-based culture systems suitable to hilly cold areas. The following points should be considered in order to further enhancement of hill aquaculture-

- Imparting training to farmers and entrepreneurs at different levels along with better co-ordination between Extension Functionaries.
- Large scale expansion of trout farming.
- Development of area specific integrated models for carp culture.
- Development of brood fish bank for production of sufficient quality seed.
- Intensification and diversification of cold water aquaculture in tune with the geomorphological feature of the region.
- Exploration of new candidate fish species for cold water aquaculture.
- Fish health management and diagnostic tests.
- Initiatives for open water cage culture in Himalayan lakes for stock enhancement as well as for the fish production using natural productivity.
- Development of Fish culture based eco-tourism.
- Small-scale enterprise in ornamental fish trade.
- Establishment of Post-Harvest and Value addition units.

While there are certain limitations of cold water fisheries such as accessibility, difficult hilly terrain, slow growth of coldwater fish species, limited candidate species, lack of proper market but recent success of developing aquaculture in mountain areas of India shows that fish farmers in the rural areas can become the direct beneficiaries of the implementation of inexpensive aquaculture technologies, and as a consequence achieve significant improvement in their standard of living. As fisheries play an important role in providing food and income to people in mountain areas, they must be integrated into the rural development and water resource development initiatives.

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PRESENT STATUS AND FUTURE SCOPE OF TROUT FARMING IN WESTERN HIMALAYAS

N.N.Pandey* and S.K.Srivastava*

Introduction

On a global level, mountains are the world's largest repositories of biological diversity. Mountain regions are characterized by the presence of cold waters, many of which harbour fish and support largely subsistence fisheries. The farming or husbandry of trout has a relatively long history in Europe and North America. In the Indian Sub-continent two main types of trouts *viz.* brown trout (*Salmo trutta fario*) and rainbow trout (*Oncorhynchus mykiss* (Walbaum)) were transplanted from Europe by British settlers around the beginning of the last century primarily to meet their needs for sport fishing or recreational angling. The transplantation of brown and rainbow trout was attempted independently in the Himalayan and in the non-Himalayan States. In the Himalayan States the brown trout (*Salmo trutta fario* Linnaeus) was first brought in Kashmir through the private efforts of F.J. Mitchell in 1899. These introductions in the hill states could be considered as the formal beginning of Coldwater fisheries or mountain fisheries development in India.

Trout farming in India

The general concept of trout as a highly expensive fish to cultivate in the farms and as a luxury food beyond the reach of the common man still holds good amongst the fisheries planners. Research and development carried out in India by State and Central organizations during the past three decades have shown appreciable achievements in trout farming practices. Adoption of the techniques that are currently in vague with suitable modifications to suit the prevailing conditions in trout farming of the country has led to achieving very high survival rates in the hatcheries and nurseries as well as the increased production of trout. Development of the some artificial diets based on locally available ingredients resulted in efficient food conversion and enhanced growth. The research in this area has clearly shown that trout farming can be done in this country by achieving high production at moderate cost of feeds. Presently the bulk of trout production is contributed by the Jammu & Kashmir and Himachal Pradesh, while the other hill states like Uttarakhand, Sikkim and Arunachal Pradesh are lagging behind in the trout production. In order to popularize trout production in other hill states, the Directorate of Coldwater Fisheries Research, (DCFR), Bhimtal has made concerted efforts towards the development of location specific trout farming practices. However, there is ample scope for further enhancement of trout production in these states through participatory approach. The present trout production of the country is around 500 tons against an annual demand of around 800 tons, which may increase during the coming decade. Being a low volume high value commodity, the trout has good potential for domestic consumptions as well as foreign export. Presently the rainbow trout has been established in Indian water and is now introduced successfully as a cultivable species having many positive traits such as:

* **Senior Scientist (Fisheries), Directorate of Coldwater Fisheries Research, Bhimtal-263136, Distt. Nainital (Uttarakhand)**

- Trout farming provided excellent opportunity for utilizing the abundant resources of coldwater having the temperature range of 0-25^{0}C in different hill states.
- Small scale trout farming provides a great opportunity for livelihood and nutritional security to the hill community.
- Despite of its low production trout fetch a very good market price, thus, trout farming has been one of the highly profitable coldwater aquaculture practice.
- Trout has higher export potential having high demand in international market.

Rainbow trout (*Oncorhynchus mykiss*) is one of the most suitable fish to cultivate in coldwater. It can survive in coldwater having a water temperature range from 0-25^{0}C, but perform relatively well for growth at 16-18^{0}C. The water temperature range from 9-14 ^{0}C is considered suitable for hatchery operation. To grow the trout at commercial scale water volume, quality and constant water temperature play important role. Trout culture is intensive type of farming require more input resources compared to other species for survival and growth. The feasibility of achieving required production naturally depends on a number of factors including seed, feed, health management and environmental consideration. Potential success in trout production requires better governance and significant improvement in the management practices. Therefore, it is necessary to have strategic plan to address technical, social and environmental constraints including:

- Availability of high quality seed at an affordable price.
- Good quality low cost feed.
- Control of disease and health management practices.
- Suitable culture system for efficient use of water resources.
- Development of market channel.

In order to achieve the goal of enhancing trout production, it is quite necessary to focus on improving existing technologies or developing new ones for increased and sustained production. Seed availability is the main bottleneck in the trout production. The transportation of seed is only possible at eyed ova stage therefore, a feasible technology is required to develop for the transportation of live trout seed at fry or fingerling stage. This is important because most of the fish farmer do not have facility for the incubation of trout eggs. Trout feed is also a second most important constraint in increasing the productivity and profitability of trout farming. At present the cost of trout production is high mainly due to high cost of feed. It is a major factor limiting the development of trout farming among the small and marginal farmers. Therefore, the development of low cost feed based on locally available ingredients would be helpful to reduce the cost of feed without reducing their efficacy. Disease plays a key role in sustaining aquaculture. Most of the disease in trout culture belongs to parasite, fungal and bacterial. The main strategy for the health management of trout is required to reduce the level of risk and accelerate the trout farming. Currently the cemented raceways are the dominant culture system for the trout cultivation. It may provide limited opportunity for expansion as it involves high investment cost. Strategy is necessary to develop the other production system such as cages, earthen raceways and tanks at various level of intensity as practices in many other countries, which would help in achieving national goal. Current trout production and demand suggests that there is high market demand for trout. Research is required to study the market demand and supply with projection for the future and how farmer should target consumer group for the future success of trout industry. Therefore, technologies to produce trout at competitive price adding value and regulation to maintain product quality and sanitary standards acceptable to world market are inevitable. Currently the trout farmers have fragmented production units. Strategy is required to promote for collective production and marketing in pocket areas/cluster to ensure that input transportation and delivery of harvested fish to market at a cheaper price.

Requisitions for trout culture

The more desirable features of the terrain and water supply for a trout farm are:

i) Moderate rainfall, ii) moderate gradient, iii) moderate foliage cover, iv) moderate but uniform temperature, v) adequate lime stone, vi) absence of grazing, logging, mining and similar activities on the water shed, vii) provision of underground hatchery intake from source of water supply, viii) provision of underground pipe lines in the hatchery to minimize water temperature and ix) covering of water supply channels to prevent surface contamination. Further, ideal site is with accessible roads, electricity, low risks of flooding and landslides.

Water is the foremost criteria for site selection for trout culture.

- For Survival-0-25 ^{0}C
- For normal feeding & growth-14-18 ^{0}C
- For spawning & Hatching-9-14 ^{0}C

Water supply

In fact, the quality and quantity requirements of the water of a trout farm are so rigid, that success or failure of the farm mainly hinges on this single factor. There should be sufficient infallible supply of pollution and silt free clean water, of right chemical quality. Amongst different source, water supply from a spring is considered to be the better having little fluctuation in temperature all the year round. Before going to trout culture practices, following of the basic things are need to be taken in to consideration:

- Water source should be permanent
- The water should be free from heavy metals and turbidity
- Water needs to be in enough quantity
- Water temperature should below 20^{0}C round the year
- Dissolved Oxygen (DO) in the water should be more than 7mg/l.
- pH of water should range 6.5.to 8.0
- The site should be of 1-3 % slope to permit adequate quantity of water.
- The site should be accessible to road
- Electricity connection is needed to be there.

One litre of water per minute per age- month is needed for every 1,000 fry and fingerlings.

Raceway culture of trout

Rearing tanks are needed in partial system whereas hatchery for breeding activities is necessary in addition to rearing tanks. The suitable size and depth of the ideal rearing tank should be 50 – 150 m^2 and 60-90 cm, respectively. Parallel types of pond construction is advisable if the water souse is reliable, permanent and enough to avoid the cross contamination of diseases.

The trout culture, whether it is for producing stocking material for sport fishing waters or for food, involves i) brood stock maintenance, ii) spawning or egg taking from healthy brood fish, iii) incubation of eggs, iv) rearing of young fry in nurseries, v) raising of fingerlings/ yearlings in growing ponds / raceways / circular ponds and vii) raising table fish and brood stock etc.

For raising table rainbow trout in captivity, the fingerling (av. 5 g) produced are transferred to bigger growing concrete rectangular ponds / raceways (30 - 100 m^2). The fish is fed intensively on artificial dry feeds, with an emphasis that no compromise is to be made with the quality and quantity of feed ingredients. At various growing stages, periodical thinning and grading of trout stocks should be carried out to avoid cannibalism and to allow all fishes to grow uniformly.

Proposed rearing facilities

To start with, for demonstration purpose and/ or for a marginal interested trout farmers, for production of table fish only for sale, in a land area of 1000 m^2, about 10 concrete rearing ponds/ raceways (100 m^2 having 0.9m depth) with individual water supply constructed having sufficient space for walking and sampling etc. besides a desilting tank near the entry point of water source**.**

Stocking of the ponds

Fish stocking density depends on quantity and quality of water. Trout can be stocked 10 kg /m^3 at 1 litre/second of water flow and 15-20 kg/m^3 fish can be produced during harvesting. However, the size grading of fish is required time to time to avoid the cannibalism and to allow the fish to grow equally. The stocking ponds are generally graded during four stages; i) 2-5 gm size, ii) 10-20 gm size, iii) 50-60 gm size and iv) more than 100 gm size.

Feed and feeding for trout

Being carnivorous and delicate fish, trout need high protein content of quality feed.

Table: Protein content for the different stages of trout

Size of the fish	Protein content	% of body weight	Times
< 10 gm	40 %	5-10 %	7-8
<50 gm	35 %	5- 6 %	3-4
> 50 gm	35 %	2-3 %	2-3

Dry floating pelleted feed is used for the feeding of grow-out stock. Trout feed processing involves grinding, mixing, agglomerating, heating, drying, screening, pelleting and crumbling.

Growth performance

Under suitable water and sufficient supply of good quality of feed trout attains 200-300 grams size after 14-15 months but same size is attained in 10 months if stocking size remains 5-10 gm. The marketable size of the fish depends on the demand but 200-300 gm size is most preferred by the people. In a culture experiment conducted at the Experimental fish farm, Champawat the fish attained maximum growth of 200 gm, 1100 gm, 2100 gm and 3000gm respectively, during 1-4 year's life span.

Breeding and seed production

Rainbow trout is one of the most popular candidate fish species of Coldwater aquaculture. For sustainable cultivation of trout pure seed is produced in flow-through hatchery. Rainbow trout require cold, clean and highly oxygenated water for ripening of brooder, successful breeding and hatchery activities. Feeding condition notably influences the fecundity and high quality feed is one of the important parts of brood management for producing quality seed. The quality of eggs or milt and the egg size remains better with brood fish of large size. It means larger the brooder size, larger the egg size, larger the alevin and more resistant young one.

Brood care

Female rainbow trout spawn best at the age of four to seven years and males at the age of three to six years. Brooders are selected well before the spawning on the basis of general health condition, absence of deformities, good external appearance, good coloration and condition of maturity. The male rainbow trout attained maturity after 2nd year and female after completion of 3rd year. Generally, they are selected two to three months (Sept.-Oct) before the breeding season (Nov - Jan). The selected brooders are kept separately in the raceway with stocking density of 5-10 kg./m^3. The water flow is maintained to exchange whole water at least 4-6 times in 24 hours. The brooders are fed with normal feed of 35% protein level @ 2-3 % of total body weight, twice a day in the morning and the evening, but the rate of feed is reduced to half before few days of spawning. During the pre-stripping period observations are made for their maturity especially for the ovulation in female and oozing milt in males. Immature female are checked periodically an interval of 3-4 days.

Sexual dimorphism

Gravid fish shows the pronounced sexual dimorphism both in male and female. The mature females can be recognized by their round body appearance, bloat and soft belly and swollen and reddened vent. The male fishes are dark and dull in appearance, large pointed snout with hooked lower jaw and dark brown and black bellies. The oozing of milt can also be observed in ripe male with a slight pressure near the vent.

Breeding and incubation

Stripping is a process by which eggs from female fish and milt from male fish is obtained.

The whole process of breeding is given hereunder:

1. Female fishes are weighed and stripped in already weighed plastic bowl by single handed spawning method. The selected fish is wiped with soft and dry cloth in order to remove moisture from the body surface. The fish is handled with the left hand by wearing woolen glove and kept laterally at a cushioned frame stand. The fish is then stripped with thumb and index finger of the right hand applying mild pressure first on lower part of the ovary (near the vent) then upward the ovary over the ventral side of the fish, till all the eggs are taken out. The fish is then immediately released in the aerated water. Good quality eggs can be recognized by bright coloration and proper egg size. (average egg size- 4-5mm)

2. Total eggs are weighed on an electronic balance. Numbers of eggs are counted for five gram of weight and fecundity is calculated accordingly. (average fecundity-1500-2000)
3. In first batch all female fishes are stripped and their fecundity is calculated.
4. Stripping of male fishes is followed by the females. The male fish is held dorsally with left hand and belly portion is pressed gently with thumb and index finger. The milt is taken in to a beaker after keeping a strainer on its mouth to avoid the faces in the milt.
5. The filtered milt is poured on the eggs and eggs are stirred gently for mixing with the help of feather. The ratio of female and male fishes is generally kept 2:1.
6. Eggs and milt mixture is kept for 1-2 minutes for fertilization.
7. 100 ml of saline water (0.9 % Nacl) is poured carefully from the side of the container and kept it for 5 minutes in order to remove the dirt and cleaning the fertilized eggs.
8. The saline water is drained from the bowl after 5 minutes and fertilized green eggs are washed thoroughly with the fresh water until the water becomes transparent.
9. The eggs are then transferred to the hatching tray of 36 x 36 x 3 cm size in a single layer and are fitted over the flow through rectangular trough. The impurities and dead eggs are segregated with the help of bamboo made forceps.
10. The hatching trays are then kept one over other. One empty tray of the same dimension is kept on the top "up side down" and are tide with the plastic rope.
11. The batch of trays is then transferred in the rectangular flow through hatching tank. It is to be mind that the whole batch is submersed in the water. The trays are tightened with the sponge to avoid floating of the trays. Continuous and uniform water flow is maintained @2 liter per minute for 10,000 eggs. The optimum requirement of the dissolved oxygen in the incubation apparatus is about 6-8 mg/lit. During the whole incubation period the trays are cleaned twice to remove the dead eggs.
12. The fertilized eggs are normally hatched in 27-30 days at 9-14 ^{0}C water temperature. The health of spawn is depends on the water temperature during the incubation period. If the temperature is on higher side the incubation period will be reduced and the hatchlings were reported to be weak and cause heavy mortality during rearing.
13. After hatching sac fry are carefully removed from the trays into the mesh caged arranged into rectangular troughs where running water is maintained @0.3-0.5 liter per minute for 1000 larvae. The sac fry are protected from bright light and remained in the tray until the absorption of the yolk sac and the fry become able to swim.
14. Free swimming fry are fed 10 times a day @5-10% with crumble feed or minced buffalo liver. After one week, feeding frequency is reduced to 3-4 times a day and fry are transferred into fry rearing tanks.

FRESHWATER FISHES OF INDIA: SAMPLING TECHNIQUES, CONSERVATION AND MANAGEMENT ISSUES WITH REFERENCE TO RIVERINE ECOSYSTEMS

K. Sivakumar*

Introduction to biodiversity of India

India is one of the 17-mega biodiversity countries of the world. With only 2.4% of the land area, India already accounts for 7-8% of the recorded species of the world. Over 46,000 species of plants and 81,000 species of animals have been recorded in the country so far by the Botanical Survey of India, and the Zoological Survey of India, respectively. India is an acknowledged centre of crop diversity, and harbours many wild relatives and breeds of domesticated animals.

India possesses a distinct identity, not only because of its geography, history and culture but also because of the great diversity of its natural ecosystems. The panorama of Indian forests ranges from evergreen tropical rain forests in the Andaman and Nicobar Islands, the Western Ghats, and the north-eastern states, to dry alpine scrub high in the Himalaya to the north. Between the two extremes, the country has semi-evergreen rain forests, deciduous monsoon forests, thorn forests, subtropical pine forests in the lower montane zone and temperate montane forests.

India has a rich variety of wetland habitats. The total area of wetlands (excluding rivers) in India is 58,286,000ha, or 18.4% of the country, 70% of which comprises areas under paddy cultivation. A total of 1,193 wetlands, covering an area of about 3,904,543 ha, were recorded in a preliminary inventory coordinated by the Department of Science and Technology, of which 572 were natural. Two sites - Chilka Lake (Orissa) and Keoladeo National Park (Bharatpur) - have been designated under the Convention of Wetlands of International Importance (Ramsar Convention) as being especially significant waterfowl habitats.

Biodiversity concept seems to provide a scientific foundation for wide spread desires to preserve natural ecosystems in aquaregimes. While, adequate protection of fish diversity often requires an extensive network of aquaregimes which exclude human intervention, its conservation elsewhere does not necessarily prohibit resource use. It is important for fishermen, fish farmers and planners to understand the basic concepts of fish diversity. "Ichthyological diversity" in aquatic eco system refers to variety of fish species. Depending on context and scale, ichthyo diversity can refer to alleles or genotypes within a piscian population, to species or life forms within a fish community, and to species or life forms across an aquaregime. Further, biodiversity is essential for stabilisation of ecosystems, protection of overall environmental quality, for understanding intrinsic worth of all species on the earth.

Of the 27,800 fish species known to science, over 40% live in freshwaters and majority of them live in tropics. In India, 2,411 fish species so far recorded, of these, 783 species are primary fresh water fishes. Nowhere in the world is a zoogeographic region so blessed as the Indian subcontinent in respect of the diversity of fish wildlife that dwells the inland waters. The major rivers of India and their tributaries traverse through varied geoclimatic zones, displaying high diversity in their biotic and abiotic charactersitistcs throughout their 28000 km linear drift.

*** Senior Scientist (Fisheries), Wildlife Institute of India, Dehradun-248001 (Uttarakhand)**

Fishes of India

The current distribution of 783 species belonging to 89 genera under 17 families is recorded in India. Of the 17 families, the Cyprinidae are the largest and account for no less than 31 genera and 373 species. The 11 families of Siluroid fishes with 41 genera and 176 species come next in importance. The Oriental of India has perhaps the largest number of genera, viz. 58 genera, representing nearly 63% of the total genera of primary freshwater fishes known so far from within our faunal limits. Within the Oriental of India, the Indo-Chinese and Malayan subregions have a larger number of endemic genera, viz. 19 than the Indian subregion, which has only 9 endemic genera. The eventual number of living fish species may be close to 28,000 in the world. Day (1889) described 1418 species of fish under 342 genera from the British India. Jayaram (1981) listed 742 freshwater species of fishes under 233 genera, 64 families and 16 orders from the Indian region. Talwar (1991) estimated 2546 species of fish belonging to 969 genera, 254 families and 40 orders. The Indian fish population represent 11.72% of species, 23.96% of genera, 57% of families and 80% of the global fishes.

The management of ecosystems supporting fisheries has an extensive history of specialisation. In freshwater fisheries, the trend towards little mechanisation of gears and crafts and the cultivation of fish in large monocultures have directed fisheries management practice towards a small number of particular species of commercial interest.

Information on the interaction between hydrobiological conditions and fish yield in any water body is of prime importance before endeavoring to utilise it as a productive fishery. Limnological and watershed parameters such as water temperature (WT), turbidity (t), Water pH (WpH), dissolved oxygen (DO), free carbon dioxide (FCO2), total alkalinity (TA), water conductivity (WC), soil temperature (ST), soil pH (SpH), soil organic carbon (SOC), soil phosphorus (SP), soil potassium (SK) and aquatic macrophytic biomass (AMB) have significant role on fish yield in an aquatic ecosystem.

There are about 450 families of freshwater fishes globally. Roughly 40 are represented in India (warm freshwater species). About 25 of these families contain commercially important species. Number of endemic species in warm water is about 544. Major warm water species are: *Bagarius bagarius, Catla catla, Channa marulius, C. punctatus, C. striatus, Cirrhinus mrigala, Clarias batrachus, Heteropneustes fossilis, Labeo bata, L. calbasu, L. rohita, Aorichthys seenghala, Notopterus chitala, N. notopterus, Pangasius pangasius, Rita rita, Wallago attu*.

Cyprinidae is one of the largest families and is well represented in India with species ranging from few milimeters in length (minnows) to more than a metre (major carps). Among the Í 544 freshwater fish species in India, Cyprinidae accounts for nearly 24.12% of them.

Many of the Cyprinids, especially carps, are widely captured and form the mainstay of culture operations. Depending on their growth and utility in culture systems, the carps are grouped as the major carps (*Catla catla, Cirrhinus mrigala, Labeo calbasu, Labeo rohita*) and minor carps (*L. fimbriatus, L. bata, C. cirrhosus, C. reba*). A few exotic carps, as indicated below, have also been introduced into the country mainly for culture purposes (*Hypopthalmichthys molitrix, Ctenopharyngodon idella, Cyprinus carpio*). The mahseers are also included in cyprinidae. Though many species of the genus Tor are found in the high altitude cold waters, some species like *Tor khudree* and *Tor putitora* occur in warmer waters. The genus Tor thus reveals a wide range of species diversity as regards adaptation to different ecological conditions. There is a serious decline of mahseer fishery in different ecosystems endangering its very existence, thus warranting adequate conservation of the fishes.

Traditional fishing in central India (A case study)

Fishing is probably oldest and one of the important activity of humankind. Ancient remains of spears, hooks and fishnet have been found in ruins of the Stone Age. The people of the early civilization drew pictures of nets and fishing lines in their arts. Early hooks were made from the upper bills of eagles and from bones, shells, horns and thorns of plant. Spears were tipped with the same materials, or sometimes with flints. Lines and nets were made from leaves, plant stalk and cocoon silk. Ancient fishing nets were rough in design and material but they were amazingly, as if some now use. Literature on the indigenous fishing practices is very scanty. Use of the herbal fish poisons in catching fishes from fresh water and sea documented from New Caledonia. There was a documentation on fishing techniques and overall life style of the Mukkuvar fishing Community of Kanyakumari district of Tamilnadu, India. Tribal people using various plants for medicinal and various purposes) extends the use notion for herbal fish stupefying plants. Use of the fish poisons is very old practice in the history of human kind. In 1212 AD King Frederick II prohibited the use of certain plant piscicides, and by the fifteenth century similar laws had been decreed in other European countries as well. All over the globe, indigenous people use various fish poisons to kill the fishes, documented in America and among Tarahumara Indian. An ecological niche refers to the way in which a species utilizes the resources of its environment and its relation to other species in the biological community. In biological community, no two coexisting species share the same niche. Similarly, no two coexisting castes have the same traditional niche in rural India; their niches are so differentiated as to preempt excessive competition for the same resources. The concept of the ecological niche has been used in a number of ways in anthropology: as a specialized part of human society, as synonymous with culture, and as a segment of the habitat. Indian society is an agglomeration of several thousand endogamous groups or castes each with a restricted geographical range and a hereditarily determine mode of subsistence. These reproductively isolated castes may be compared to biological species, and the society thought of as a biological community with each caste having its specific ecological niche.

The fishing techniques studied among Gond and Dhivar people give some useful insight into the traditional resource extraction strategies. These strategies are found to be based on the locally available material and always updating its status by importing new strategies that are more efficient.

It was found that fish stupefying agents are excellent means of fishing, which do not kill whole fish stock like chemical poisons. Many of the fish stupefying plants are being used since long time by local people are recently well tested by many workers and are found to have many important medicinal properties like *Carreya arborea* is well-tested plant used as analgesic. Some of the plants like *C. collinus* are a traditional poison used in the different part of the country. The stem bark extracts of *Lannea coromandelica* are also used for fishing.
Earlier studies show that there is an intricate link between various fishing techniques and users' knowledge about the fish behaviors, taxonomy and knowledge about the habitat (Keegan 1986). All fish traps and methods of catching the fishes are based on the people's intimate knowledge about the fish behavior. Some important behaviors are migration behavior, foraging behavior, habitat of the fishes etc.

In Dhivar community, there are more fishing techniques and gadgets are in use than in Gond, but overall diversity of the fish catching devices is low. Most of the fishing gadgets are the one or the other type of the gill net.

Both communities are living proximity to each other. In spite, both communities i.e. Dhivar and Gond use their own niche of fishing, as there ways of resource extraction are very different. In Gond community unlike Dhivar, fishing is not earning source. Peak fishing occurs only in the Pre and post Monsoon. Gond people catch small number of fishes for there household needs and strictly not for the market. Gond people have no expertise to use cast nets and use of the gill net is occasional. However, they prudently can use herbal fish poisons that have not been reported among the Dhivar. Dhivar people can skillfully use cast and gill net. As Gond are mainly depend upon the forest for their subsistence, the fishing practices are evolved according to the available forest resources like those that of herbal fish poisons, bamboo etc. Most of the fishing gadgets used by the Dhivar are made up of some kind of thread, which is not the case for Gond. This might be because cotton fibers are introduced very late among Gond tribal.

The material, frequency and fishing nets are changing day by day. Thus, now a day some people are using mosquito nets for catching fishes. Initially fishing nets were generally prepared by locally available threads but now synthetic fibers are in use. Recently, people of Mendha and adjacent Ilakha (a group of 32 villages) have banned use of herbal or other fish poisons. According to local people, due to use of fish poison the population of fishes is adversely affected. In addition, there is popular belief among people that river Kathani is the home of hypothetical Mermaid (Locally called Kanya) whose curse will lead to poor rain and drought. By using herbal fish poisons the Kanya may be harmed.

Among the Gond, Dhiri, Zinka and Dandoor are the structures applied generally in night (Some time these are used for whole fishing season only remove to collect the fishes and to clean). Without guarding these structures, people will go home. However, in this area no thefts of these gadgets are recorded, because of some religious taboo. Local people believe that if somebody steals these structures then he or she will have some unknown disease.

Threats

India is the seventh largest country in the world and Asia's second largest nation with an area of 3,287,263 square km. The country is home to around 846 million people, about 16% of the World's population. Most of the threats to Indian biodiversity are contributed directly or indirectly by human beings. A global phenomenon such as climate change is also threatening Indian biodiversity in a greater way.

Riverine ecosystem of India have suffered from intense human intervention resulting in habitat loss and degradation and as a consequence many fresh water fish species have become heavily endangered, particular in Ganges basin where heavy demand is placed on fresh water. This was coupled with irreversible changes in natural population by introduction of exotic species and diseases. River conservation and management activities in most countries including India suffer from inadequate knowledge of the constituent biota. Therefore, research is being pursued globally to develop conservation planning to protect freshwater biodiversity.

The effects of climate change on fresh waters are already evident in different regions of the country. Climate change impacts on freshwater fishes may include variation in year class strength of different species, change in bioenergetics and growth, shift in geographical species distributions and altered trophic dynamics.

The distributions of freshwater fishes are influenced by many factors operating at different scales At a regional scale, freshwater fish distributions are influenced by historical (postglacial dispersal) and environmental (climate) factors. At local scales, distributions are influenced by abiotic (e.g. water chemistry) and biotic (i.e. species interactions) factors. These factors can be viewed as hierarchical filters that influence fish. Over fishing, indiscriminate fishing, poor landuse pattern in the basin, pollution and shortage of water sources are believed to be major threats to fishes of India.

Threatened fishes of India

According to the assessment of the CAMP workshop (1997), a total of 227 Indian freshwater fishes are threatened based on the IUCN Red list Categories of 1994. The high percentage of restricted taxa being threatened is due to localized distribution of these taxa along with other man-induced threats to their well-being. Freshwater fishes are a poorly studied group since information regarding distribution, population dynamics and threats is incomplete, and most of the information available is from a few well-studied locations only. Threats to Indian freshwater fishes are physical in nature, such as habitat destruction, fragmentation, poisoning, pollution, pesticides, destructive fishing, and other kinds of human interference. Trade is an important contributing factor in threatening some freshwater fish taxa in India. This is mainly because of unsustainable harvest, poor scientific practices in fishing and an ever-growing demand.

In 2010, the National Bureau for Fish Genetics Resources has assessed the status of freshwater fishes of India largely following the guidelines prescribed by IUCN. As per the latest assessment, there are 71 freshwater fish species are endangered in India. Moreover, 49 fish species have been assessed as vulnerable. Recently, Zoo Outreach organization assessed the status of freshwater fishes of Western Ghats and Eastern Himalaya. However, India is yet to assess the status of all its freshwater fishes.

Protected fish species in India

Fish forms highest species diversity among all vertebral groups apart from its economic importance in India. Further, India contributing 11.72% of global fish diversity mainly from greater Himalayan, eastern and Western Ghats. Throughout the world, however, aquatic environments are experiencing serious threats so as to fish diversity. Indian Fisheries Act, 1879 is a landmark in the conservation of fishes in India but it could not make remarkable impact in this regard. Although several fish species in India are threatened but none of freshwater fishes are protected from the Wildlife (Protection) Act 1972. However, fishing is strictly protected inside the Wildlife Protected Areas such as Tiger Reserve, National Park, Sanctuary, Conservation Reserve and Community Reserve. Currently, these protected areas are supporting and protecting the several source populations of fishes. However, existing protected areas are seems to be significantly contributing in conservation of fishes in the country especially river fishes as it require larger basin level conservation strategy.

Protected areas and wildlife conservation in India

Communities of high species richness and of high levels of endemism need special consideration which can be conserved efficiently by bringing them into the Protected Area Network. Entire Indian geographic region has been classified into 10 biogeographic zones. The objective of protected area planning within the biogeographic framework of India has been to ensure that at least one major protected area of national park status covers a representative range of available biomes in each biogeographic divisions.

The first few wildlife protected areas were set up some fifty years ago, but it was only in the last 1960s that growing concern at the scale of environmental degradation allowed the development of PAs in many parts of the country. Presently in India, 608 PAs covering an area of 4.77% of its total geographic areas. So far, there is no Protected Area established exclusively for freshwater fishes, however, there are more than 50 freshwater wetlands in India have been protected as either bird sanctuaries or dolphin sanctuary or wildlife national parks. These wetlands protected areas are also protect the fishes within it.

Needs relook towards conservation of fish resources

Though, India is one of the most populated countries in the world still it could conserve its wonderful wildlife in its nature environment this is because the people of India traditionally attached to Indian wildlife, their traditional knowledge on the conservation needs to be fully utilized to safeguard our natural resources in future. India learned in due course that the higher level participation of local communities in conservation of wildlife is important and workable. So far, India could add 10% of its Protected Areas as wetlands which provide highest protection to fishes. Moreover, a total of 25 wetlands in India have been declared as RAMSAR wetlands due to its uniqueness and it is high value in biodiversity conservation. Further, freshwater fishes in India have always been looked as commercial product instead of appreciating its ecological roles and services in the ecosystem. This attitude needs to be changed not only among people and also of fisheries managers, scientists and policy makers for the long term sustainability of fisheries in the country.

Need for sampling of fish resources

Monitoring the status of fish populations and their habitat is foremost importance in promoting fisheries as well as fish conservation. There is a strong positive correlation between biomass production and species abundance has been recorded in various earlier studies. The species diversity of an ecosystem is often related to the amount of living and non-living organic matter present in it. However, apparently, species diversity depends less on the characteristics of a single ecosystem than on the interactions between ecosystems, e.g. transport of living animals across the different gradient zones in the water body. The effect of such transport is an important "information" exchange enhancing the genetic diversity. The genetic imprinting of various populations of lentic fish species is essential since the freshwater ecosystems constitute crucial parts of their life-support systems by providing nursing grounds and feeding areas.

Fish catches have always fluctuated widely, as reported in the very earliest historical records (Bertram, 1985) and is documented repeatedly in modern times. The aspect of variation in the fish catches began to receive scientific attention in the middle and late 1800's (Whymper, 1883). Attempts had been made to overcome difficulties in interpreting data collected in different ways and to establish standard approaches for estimating total catches.

Fish is captured in natural Lakes, reservoirs, streams, rivers and oceans. From an estimated 500 million hectares of inland waters of the world, the estimated total catch of fish is about seven million metric tonnes per annum. This excludes the catch of subsistence and sport fisherman. In many Asian countries, inland catches make up 40-70 per cent of the total fish production.

However, few species, inspite of their great commercial interest, have been comprehensively studied to establish the importance of their distribution for their successful management. Species diversity is a property at the population level, while the functional diversity concept is more strongly related to ecosystem stability and stresses, physical and chemical factors for determining population dynamics in the aquatic ecosystem. Inspite of its tremendous significance in determining productivity and calculating species diversity, few studies had been done on the fish population dynamics, ichthyo diversity and conservation of fishes in India in general as compared to elsewhere in the world.

Therefore, it is important to sample all kinds of streams in the region covering different altitudinal gradient, habitat and other environmental settings for exploration of fish species diversity and its habitat use. Streams which should be chosen for sampling will also represent the different land-use types of the region. Species composition should be studied in each sampling streams to understand the spatio-temporal changes in fish habitat structure and resource utilization patterns of fishes especially threatened fishes. However, the sampling efforts, sampling site and design need to be finalized after a reconnaissance survey.

Habitat inventory

Fish habitat inventorization needs to be carried out in all streams which has been chosen for fish sampling. Each sampling point should be geo-referenced so that this reference point can be readily recognizable and repeated in the future. Different types of habitat types such as pools, riffles, runs and cascades need to be identified within 100 m reach of the sampling. Each habitat will be quantified for depth, flow, substrate characteristics. Number of transects usually 5-10 to be taken across the stream channel depend upon length of river, the habitat variables should be estimated at 0.5 or 1 m intervals across these transects. Water velocity needs to be recorded with a digital electronic water current meter. Catch Per Unit Effort method may be adopted while sampling in the lakes and ponds in the landscape. Substrate in each habitat will be classified into Bedrock (>512mm diameter), boulder (128-512mm), cobble (64-128), gravel (16-64mm), sand (1-16) and leaf litters.

Microhabitat use of fish

Microhabitats observations should be made from all selected streams and lakes wherever sampling take place. For each observation, fish need to be identified to species, their standard length and weight should be measured using vernier caliper and spring balances, and the following microhabitat variables should also be measured: maximum depth of water column, water velocity at the surface and at the substratum. A pygmy type current meter may be useful to measure velocities and depths of water. Each substratum category (from 1 to 14) was scored in percentage based on a modified Wentworth particle scale as described above. Water temperature and turbidity are also need to be measured using thermometer and Secchi disc respectively. Nearby vegetation types and channel slopes should also need to be recorded.

Microhabitat parameters such as depth of water column, distance of fish from bottom, water velocity near fish, substrate composition over fish and fish cover complex may also be recorded using microscope.

Fish sampling techniques

Fish sampling will be performed in each habitat types (pool, riffle, run and cascade) using monofilamentous gill nets (mesh size 8mm to 25mm) cast net and drag net. Electric fishing will also be carried whenever and wherever possible. Fishes will be identified using available taxonomic literature (Hamilton, 1822; Talwar and Jhingran, 1991) and current IUCN conservation status will be assessed based on Conservation Assessment and Management Plan report (CAMP, 1998). For each observation, fish will be identified to species, their standard length and weight will be measured using vernier caliper and Pasola spring balances to study their condition factor.

Water chemistry

Water quality parameters such as temperature, pH, conductivity, dissolved oxygen, total alkalinity, hardness, phosphates and nitrates need to be estimated using standard procedures (APHA, 1995) in different reaches of streams.

Human activities

Human activities especially the alteration of forest biomes into monospecific cultivation, fishing, agriculture activities and steam bank stability need to be assessed for habitat degradation, impact on water discharge, impact on nutrient cycling and organic matter and the impact on the food base for stream biota should also be assessed in various streams.

Data analysis

Based on the fish catch, diversity of fish population at each site could be estimate using different diversity indices. Habitat inventory data may be analyzed for evaluating habitat diversity complex (H'/H_{max}) and habitat utilization patterns of fishes (based on Pusey *et al.,* 1993). Distribution of fish in relation to habitats and other environmental parameters (habitat and Water quality) could be done using ordination techniques (Canonical Correspondence Analysis and Principal Component Analysis). Habitat conditions and loss of habitats need to be correlated for human activities. Response of individual species and communities to changes in water conditions and habitat availability due to human perturbations could be analyzed later.

Fisheries management in the wake of large dams

Dam or any construction across rivers is always a barrier for fish, which move one part of stream to another. These structures of obstacle are always detrimental to the survival of fishes especially on migrants which use different habitats for different life history requirements. Mahseer migrate from main river to smaller streams for spawning, or downstream of river to upstream for the same. Any obstacle such as dam across river will break this normal migratory behaviour which would ultimately affect the breeding cycle. Therefore, there would be decline in population that has already been observed due to Tehri Dam, which prevented migration of mahseer to upstream. Based on literatures and observations made through WII study has confirmed that there was a decline in the populations of mahseer in the upstream of Bagirathi River due to barrier effect caused by Tehri Dam.

Therefore, it would be prudent to assume that the taller dam without proper fish passes would be detrimental to the populations of migratory fishes such as mahseer. Any kind of ex-situ conservation programme (as an alternate conservation strategy) to artificially restock the fish populations of species that would be threatened due to dams or any other kinds of barrier constructions across rivers or streams may not fully compensate the natural breeding phenomenon of migration of Himalayan fishes, however, it would be an alternative option for conservation if fish passes are not feasible.

Aquatic fauna especially the fish fauna of the Bhagirathi river have already been adversely affected by the Tehri Dam as there is no fish ladder exist to facilitate the movement of migratory fishes such as threatened mahseer and snow trouts. In this circumstances, proposed Kotibhel IA will further reduce the habitat of downstream migratory species at least upto Koteshwar HEP. Therefore, it is important to have a Fisheries Management Guideline for the region to minimise the project impact on the threatened fish fauna. Fisheries management guideline should assure the presence of viable populations of native fishes forever. The following guidelines are proposed to minimise the adverse impact of the dam on the native fish biodiversity:

General management recommendations

1. **Fish passes** are often believed to be an engineered mitigation measure for reducing impacts on fish especially migrants. However, very few of the over several hundreds of dams in world have fish passes of any description. In general, the efficiency of those fish passes are also considered low, and fish migrations are severely affected (World Commission on Dams, 2000). Even when fish passes have been installed successfully, migrations can be delayed by the absence of better navigational cues, such as strong currents etc. Even in the salmon (known for anadromous migration) countries the fish passes have been observed with inefficiency if the dam height is more than 16 m. When compare to salmon, mahseer and snow trouts are poor jumpers. WII study had observed that the snow trout jumping upto 1.5 m height and mahseer upto 2.0 m height above the water surface when waterfalls. If larger volume of water flows down then these fishes may climb further high using flowing water column as a support. However, the efficiency of fish pass in Himalayan Rivers would be highly doubtful if the dam height is more than 16 m. However, there was no comprehensive study carried out in Himalaya to prescribe the better fish passes for Himalayan fishes and it is also not advisable to use the fish passes models that have been used to facilitate the salmon or trout migration for Himalayan fishes. In this connection, fish ladder/pass may not be an appropriate passage for fish as the dam height of Kotibhel IA is more than 80 m and also very narrow.

2. **Fish lift**: Experts with adequate knowledge and experiences on this technique need to be consulted to study the feasibility of installing the fish lift at Kotibhel IA HEP (as the dam height is more than 80 m) to facilitate the movements of migratory and other native fishes. If the fish lift is found to be feasible to install then the management of the fish lift facility includes monitoring of fish traffic in terms of species, numbers, length/weight range. An assessment should be carried out of the efficiency of this lift in providing an access route for individual species, and appropriate adjustments made to the structure to improve its efficiency. The overall impact of the fish lift on upstream fish diversity and downstream river fisheries should be determined by the professional institutions such as the Cold Water Fisheries Research Institute, NBFGR etc.

3. **Ranching of threatened/migratory fishes to link the connectivity between upstream and downstream gene pools**: Since fish ladder/passes may not be a feasible option and moreover, the efficiency of fish lift needs to be studied, it is important to build fish hatchery facilities for ranching of those fishes which would be affected by the Dam especially migratory fishes e.g. mahseer, snow trout etc. Ranching needs to be carried out in both the downstream and upstream of the dam. Only native species such as mahseer, snow trouts, and other species occur in the region can be produced in this hatchery. Fish Hatchery should use brooders collected from both upstream and downstream waters so that the genetic connectivity of migratory/threatened fishes are linked at least at minimum level. Minimum 0.5 millions of fingerlings comprising mahseer, snow trout etc should be released in the zone of influence of the project at every year for the first three years of project operation. Based on the successful survival rates of fingerlings, number of fingerlings to be released later years may be increased or decreased. Exotic fish species should not be introduced into this water as they are known to adversely affect the native species. Hatchery must be maintained by the state Fisheries Department in consultation with the Cold Water Fisheries Research Institute, Bhimtal. Progress of this fish Ranching programme needs to be reviewed/monitored by a Steering Committee comprising experts from State Fisheries Department, State Forest Department, Cold Water Fisheries Research Institute, etc.

Fisheries management during the project construction phase (adopted from FAO, TP-419, 2001):

During the construction phase of the dam, the main potential environmental impact on fish originates from soil erosion, silt and toxic materials runoff into the river due to clearing and excavation activities. This impairs water quality and can lead to acute or sublethal toxicity to fish. There is also danger of siltation of key fish breeding, nursery or overwintering habitats in the river. Another hazard to fishes originates from the use of explosives. Blast shocks may cause lethal or sublethal damage to fish stocks. Blockage to fish migration is usually not a problem at dam sites where topography allows the excavation of a temporary bypass channel for river discharge. However, the constrained topography of dam situated in narrow river gorges may not allow excavation of bypass channels for river discharge. Water velocity, tunnel gradient and hydraulic jumps may create fish-unfriendly conditions and effectively block upstream migrations of fish. Therefore, the following measures need to be taken;

i. **Soil erosion and silt runoff into the river:** Proper construction practices and diligent attention to the control of erosion near the river banks during the removal of trees and soil cover will minimize problems of turbidity in the river and threats to fish stocks. Rainfall on the construction site will however still result in some fines (mostly clay) finding their way into the river. The washload should be carefully monitored upstream and downstream of the construction site(s) and preventive steps taken before mortality or undue stress occur among downstream fish stocks.
ii. **Siltation of key fish breeding, nursery or overwintering habitats in the river:** Excessive bedload originating from the construction site should not be allowed to materialise. This can be controlled by proper construction practices. Key downstream fish habitats should be monitored to determine if a problem with sedimentation is developing.
iii. **Use of explosives:** Damage to fish stocks from blast shocks can be controlled by preventing fish from gaining access to the blast area (i.e. erecting temporary fencing or screens in the river) and timing the use of explosives to periods when fish might less likely be in the area (i.e. daylight hours, dry season).

iv. **Fisheries management during dam construction** is essentially an exercise in local damage control. This is best carried out by a specialist fisheries team working under the project office. The fisheries team should have access to construction site managers and supervisors, funds for field work and construction activity, and authority to implement protective measures. The team should also involve the local fishing communities (if any) and state fisheries department in monitoring the impacts of construction on fish stocks and downstream fishery environments. The team should review all planned construction activities and schedules prior to commencement and suggest any improvements that could help to avoid detrimental impacts or might be beneficial to fisheries.

v. **Fisheries information base requirements:** Fisheries management activities are very `hands on' in nature during dam construction. Responsiveness to construction schedules is very important and much of the information must be real time (daily, hourly) in nature if it is to be used effectively to guide and control activities on the ground. Accordingly, sampling, data analysis and formulation of recommendation must be rapid and accurate, and inputs provided to the construction teams in a timely manner. Specific parameters that the fisheries team will need to monitor on a continuous or frequent basis include:

- Suspended solids (washload) in the river downstream from construction sites.
- Bedload sediment transported downstream and deposition rates in key fish habitats.
- Any type of fish mortality, e.g. mortality of fish due to blasting.
- Migration of fish through dam site area.
- Fish biodiversity in the dam site area.
- Forest and bush clearing in the reservoir basin (to ensure compliance with plans for conserving certain areas as standing timber for fish shelters).

Professional fisheries expertise required to collect data and implement fisheries management during dam construction include fisheries biology. Experts should be posted full time at the dam construction site.

Fisheries management during project operation phase (adopted from FAO, TP-419, 2001): Management of fishing effort in downstream fish diversity in the river channels and on the floodplain should follow community-based management protocols, with appropriate support from State Fisheries Department and State Forest Department. Because many dams will dramatically alter hydrological conditions and water quality parameters, special attention should be paid to minimising any negative impacts. The following impacts require implementation of effective mitigation measures:

i. **First filling of a reservoir:** This can severely reduce river flow and depress fish stocks. Minimum Environmental flow guidelines should be followed.

ii. **Discharge of cool and/or anoxic water from the hypolimnion:** This can drive fish downstream or even cause fish kills. Changes in fish abundance in the river below dams - due to oxygen depletion and altered discharge - have been recorded world-wide. Positioning of discharge structures at the highest possible elevation in the dam wall, improved turbine design and artificial aeration of discharge water would help to minimize this problem.

iii. **High turbulence in the stilling pool immediately below the dam/tunnel:** This can kill migrating fish by mechanical damage or nitrogen supersaturation, as well as block migration. Appropriate design of discharge structures to minimize turbulence and eliminate hydraulic jumps is needed.

iv. **Blocking of fish migration:** Dams usually block upstream fish migration and interfere with downstream fish migration. A variety of mitigation measures have been used to deal with these problems, and research is continuing to improve them further. Follow recommendations No.5.1.a to 5.1.c mentioned above.

v. Even if effective mitigation measures are implemented for the above impacts, fish biodiversity may still suffer due to the alterations in annual hydrological discharge pattern. Additional measures such as captive breeding and special sanctuary habitats may need to be introduced to assist endangered species (see Point No.5.1.c).

vi. **Maintenance of adequate flows** in downstream river channels is crucial for providing a viable aquatic environment for river fish. The prospect for rehabilitating populations of long distance migrating species such as salmon and sturgeon in impounded rivers in developed countries is very heavily dependent on providing an adequate flow regime in the river downstream of the dam. This will require the release of mini-floods which mimic the pre-existing natural flooding regime, and strict maintenance of adequate dry season flows. The duration of the flood release must be long enough to allow the stocks to migrate over the full distance of the migration route.

vii. **Fisheries information base requirements during operational phase**: Various data on fish biodiversity, fish stocks and environmental parameters that will allow monitoring of the efficiency of the environmental mitigation measures for fish biodiversity and fisheries being implemented need to be collected. A portion of this data needs to be in real time or near real time format in order to allow rapid corrective management responses to unforeseen impacts. In general, there should be comprehensive monitoring of project impacts on fish biodiversity and fish production upstream and downstream. The focus should be on water quality, fish migration behaviour and the numbers of fish per species actually passing the dam, fish biodiversity inventory, fishing activity, the effect of water level drawdown and impounding in the reservoir, and the effect of dam discharges on downstream aquatic environments.

viii. **Professional fisheries expertise required** to collect data and implement fisheries management during dam construction include fisheries biology, limnology, and fisheries engineering.

ix. **A team of experts** from the State Fishery Department, State Forest Department, Cold Water Fisheries Research Institute, etc needs to be formed to monitor the fisheries management plan in the region.

Suggested research activities on fish biodiversity

1. Prioritization and gap analysis of fish biodiversity research needs in India. For this, a database as well as review on completed and ongoing research and conservation activities on fish diversity of India is required to be prepared.
2. Detail survey on both marine and freshwater fish fauna of India to review their legal protection status in the Indian Wildlife (Protection) Act, 1972.
3. Fish germplasm inventorization and evaluation in both Protected Areas and Non-Protected Areas.
4. Preparation of species wise distribution and status map for all freshwater fishes.
5. Preparation of temporal and spatial distribution map of threatened marine species of India.
6. Studies on fish population dynamic for selected species.

7. A study to identify one or two **Fish Conservation Reserves** in each **Fish Zones of India** such as Indus river system, Upland cold water bodies, Gangetic river system, Bramhaputra river system, East flowing river system and West flowing river system.
8. Fisheries development in both urban and rural India using native species.
9. Ecology and breeding biology of certain endemic fish fauna of India.
10. Species and habitat recovery programme for endangered species such as mahseers, snow trouts, sea horses, etc.
11. A study on the impact of invasive aquatic fauna and flora on native fishes. Findings should be useful for the preparation of management guidelines to minimize the adverse impact of invasive species on native fish fauna.
12. Monitoring the fish populations and their habitats in the Protected Areas.
13. Research on land-use patterns and its implications on the catchments of various fish zones.

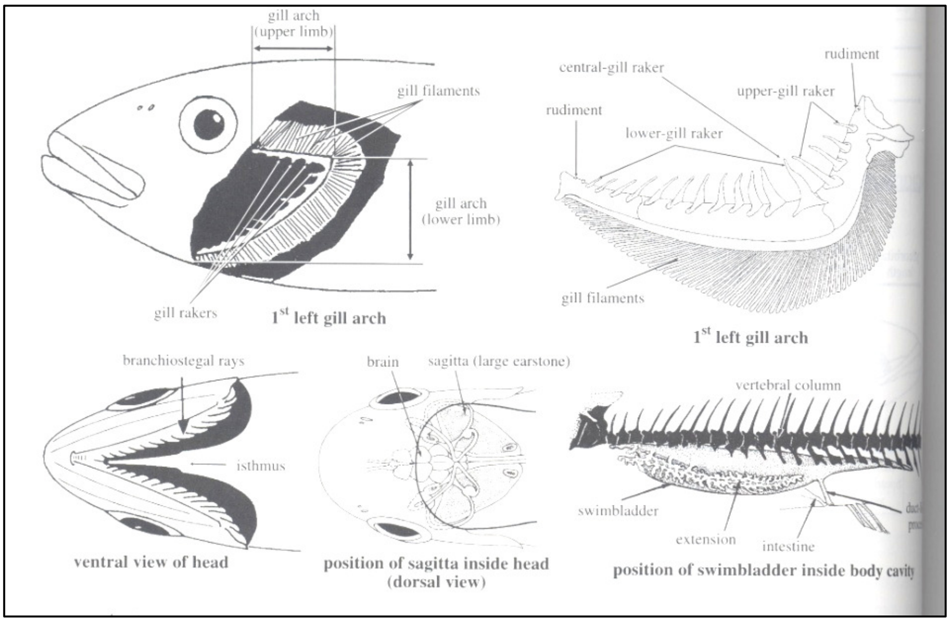

Figure: Gill rakers and swim bladder of fish

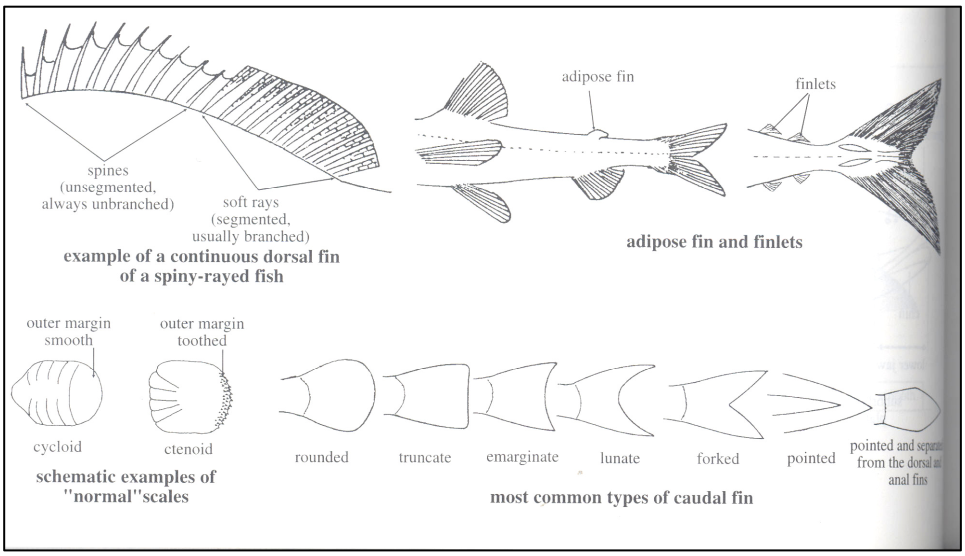

Figure: Morphology of fish

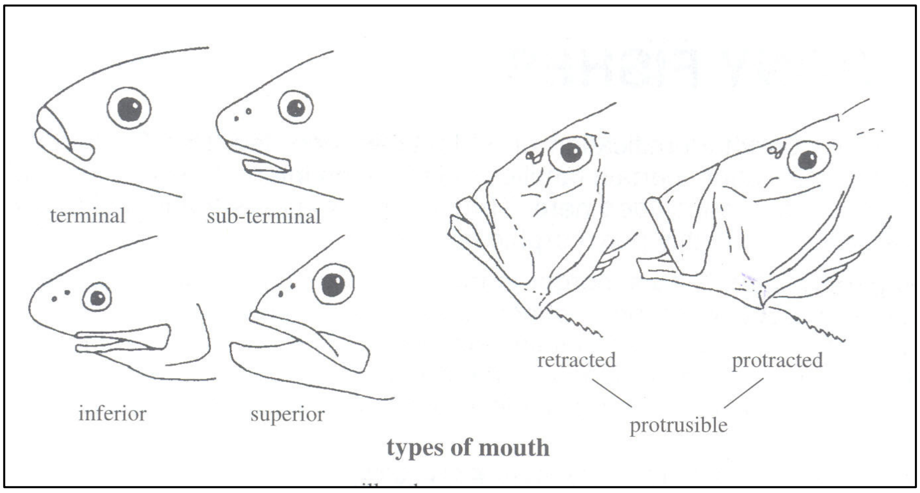

Figure: Different mouth types of fish

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पर्वतीय क्षेत्रों में मत्स्य पालन की सुनियोजित तकनीकें

एम. मुरूगानन्दम*[*] एवम् राकेश कुमार[*]

भारत में रोजगार परक व्यवसाय एवं पोषक, विशेषकर प्रोटीन बहुल आहार के स्रोत के रूप में मछली पालन का विशेष महत्व है। निरन्तर बढ़ रही जनसंख्या के कारण कृषि भूमि से पर्याप्त उत्पादन पाना कठिन हो गया है। अतः समय की यह माँग है कि किसान कृषि या पशुपालन के साथ–साथ कोई दूसरा व्यवसाय जैसे मत्स्य पालन करें, जिससे कि अतिरिक्त आय मिल सके। मछली पालन एक ऐसा व्यवसाय है जिससे कम लागत में अधिक आय प्राप्त की जा सकती है, साथ ही प्रोटीन युक्त संतुलित आहार भी पर्याप्त मात्रा में मिलता हैं।

नवगठित उत्तराखण्ड राज्य में प्राकृतिक जल स्रोतों जैसे नदियों, झरनों, जलाशयों तथा कृषि जल स्रोतों जैसे टैंको, तालाबों इत्यादि की कमी नहीं है। इन जल स्रोतों में मत्स्य पालन की अपार सम्भावनायें हैं। लगभग 1000 मी0 औसत समुद्र तल वाले इलाकों में कॉमन कार्प, ग्रास कार्प, सिल्वर कार्प, महाशीर एवं स्नोट्राउट तथा इससे ज्यादा ऊँचाई के क्षेत्रों में ब्राउन ट्राउट एवं रेनबो ट्राउट का पालन आसानी से किया जा सकता है। पर्वतीय क्षेत्रों के ठण्डे जलाशयों में मत्स्य पालन हेतु नई तकनीकों की जानकारी अत्यन्त आवश्यक है। अतः मत्स्य पालकों को इन तकनीकों को उपयोग में लाना चाहिये जिससे अधिक से अधिक लाभ अर्जित किया जा सके।

मत्स्य पालन हेतु समय–सारणी

पर्वतीय क्षेत्रों में मत्स्य पालन तालाबों, टैंकों तथा डिग्गियों में हो सकता है। कृत्रिम रूप से तालाबों एवं टैंकों को सुधारने के उपरान्त पूरे वर्ष के पखवाड़े में किस प्रकार कार्य करना चाहिए इसकी जानकारी अत्यन्त आवश्यक है। अपने जल क्षेत्र को पूर्ण रूप से उपयोग के लिये मत्स्य पालकों को बताये गये वैज्ञानिक कार्यक्रम के अनुसार कार्य करने का भरसक प्रयत्न करना चाहिए ।

1. अप्रैल, मई, जून

1. पुराने तालाबों/टैंकों में सुधार एवं नये तालाबों के निर्माण के लिये स्थान का चयन।
2. मृदा विश्लेषण।
3. पानी विश्लेषण एवं पानी का स्रोत।
4. चूना एवं उर्वरक का प्रयोग।

2. जुलाई, अगस्त, सितम्बर

1. प्रजनन हेतु नर एवं मादा मछलियों का रख रखाव।
2. उत्प्रेरित मत्स्य प्रजनन।
3. मत्स्य बीज पालन–पोषण/यदि बीज बाहर से खरीदा गया हो तो तैयार किये गये तालाबों में उनका संचय।
4. प्राकृतिक भोजन (प्लवक) की संतोषप्रद मात्रा को खाद एवं उर्वरक के प्रयोग द्वारा प्रतिपादित करना।
5. कृत्रिम भोजन का प्रयोग।
5. मछलियों में वृद्धि की नाप–तोल।

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[*]केन्द्रीय मृदा एवं जल संरक्षण अनुसंधान एवं प्रशिक्षण संस्थान, देहरादून

3. अक्टूबर, नवंबर, दिसम्बर

1. निरन्तरता के आधार पर मछली की नाप–तोल।
2. कृत्रिम भोजन का प्रयोग।
3. जलीय खरपतवार, कीट एवं अवांछनीय मछलियों का नियंत्रण।

4. जनवरी, फरवरी, मार्च

1. कॉमन कार्प का प्रजनन।
2. पाली जा रही मछलियाँ खाने योग्य हो गई हों तो उनकी बिक्री।
3. तालाबों/टैंकों की वार्षिक मरम्मत का कार्य।

मत्स्य पालन के लिए तालाब निर्माण

पर्वतीय क्षेत्राों में तालाब बनाने हेतु बड़े आकार की भूमि क्षेत्र की उपलब्धता कम होती है। अतः वहाँ के तालाबों का औसत आकार 100 – 2000 मी^{2} का होना चाहिए। मत्स्य पालन के लिए साधारणतया आयताकार तालाब उपयुक्त होते हैं (चित्र – 1, 2, 3, 4)। तालाब की गहराई का भी उत्पादकता पर सीधा प्रभाव पड़ता है। पर्वतीय क्षेत्राों में तालाब या टैंक का जल स्तर 1 से 1.5 मीटर का होना उपयुक्त पाया गया है। ये तालाब जल स्रोतों जैसे नदियों, जलाशयों, भूमिगत जल श्रोत, झरनों इत्यादि के निकट ही हों ताकि आवश्यकतानुसार जल की आपूर्ति की जा सके। तालाब में प्रवेश तथा निर्गत जल मार्ग होना भी आवश्यक है। तालाब की उर्वरता बनाये रखने के लिए गोबर एवं चूना की समुचित व्यवस्था करनी पड़ती है ताकि प्रचुर मात्रा में प्राकृतिक मत्स्य भोजन (प्लवक) तैयार होता रहे।

मत्स्य पालन के लिए उपयुक्त अन्य जल क्षेत्र

पर्वतीय क्षेत्रों में तालाबों के अलावा डिग्गियों में मत्स्य पालन किया जा सकता है जिसका निर्माण खेतों की सिंचाई के लिए जल एकत्रित करने के उद्देश्य से किया जाता है। डिग्गियों को प्लास्टिक सीट द्वारा लाइनिंग कर जल धारण क्षमता कम लागत पर पक्के डिग्गियों के समान की जा सकती है। इसके अलावा नहरों या नदियों में महीन जाल द्वारा कुछ भाग को बाँध कर भी मत्स्य पालन किया जा सकता है। जलाशयों एवं नदियों में कृत्रिम रूप से बनवाये गये पिंजड़ो में मत्स्य पालन अच्छी उत्पादकता देता है। यदि इन पिंजड़ों में कृत्रिम पूरक आहार की व्यवस्था की जाये तो साधारण दर से काफी अधिक संख्या में मछलियों का संचय किया जा सकता है और अधिक उत्पादन प्राप्त किया जा सकता है।

जहाँ जल धाराओं में जल प्रवाह वर्ष भर रहता है, उन क्षेत्रों में वहाँ के निवासी जलधारा के किनारे पर क्रम में छोटी छोटी तालाब/डिग्गियाँ बनाकर जल को उन तालाबों से बहाकर फिर उसी जलधारा में छोड़ने की व्यवस्था करें तो उन तालाबों में निरन्तरता के आधार पर जल प्रवाह बना रहेगा ओर उन तालाबों में काफी अधिक संख्या में (लगभग 1000 – 1200 अंगुलिका वे प्रति 100 मी) मछलियों का संचय कर कृत्रिम आहार के सहारे अधिक से अधिक उत्पादकता प्राप्त की जा सकती है।

पालने योग्य मछलियों का चयन

कम से कम व्यय पर अधिक से अधिक लाभ अर्जित करने के लिए ऐसी मत्स्य प्रजातियों का चयन करना चाहिए जिनकी तीव्र वृद्धि क्षमता हो, प्राकृतिक एवं कृत्रिम भोजन ग्रहण करने में समर्थ हों, अधिक प्रतिरोधक क्षमता हो, स्वादिष्ट एवं पौष्टिक हों तथा सुपाच्य हो । उपर्युक्त गुणों के आधार पर विश्व में केवल कॉमन कार्प नामक मछली ही सर्वगुण सम्पन्न पायी गयी है, जिसका

पालन संग्रथित एवं एकल मत्स्य पालन में किया जा रहा है और मत्स्य पालक अधिक से अधिक लाभ पा रहे हैं। पर्वतीय क्षेत्रों के जल क्षेत्रों में पाली जाने वाली अन्य मत्स्य प्रजातियों में सिल्वर कार्प, ग्रास कार्प, महाशीर तथा स्नोट्राउट इत्यादि प्रमुख हैं जिनमें उपर्युक्त सभी गुण पाये जाते हैं। ये शाकाहारी प्रवृत्ति की होतीं है तथा ये सभी मिश्रित कर एक ही जल क्षेत्र में पाली जाती हैं। पर्वतीय क्षेत्रों के अधिक ऊँचाई वाले भागों में ब्राउन ट्राउट तथा रेनबो ट्राउट का पालन किया जा सकता है हालांकि ये दोनों प्रजातियाँ मांसाहारी हैं तथा इनकी वृद्धि क्षमता उपर्युक्त मछलियों से काफी कम है।

मत्स्य पालन विधि

पर्वतीय क्षेत्रों के कम ऊँचाई वाले इलाकों में वैज्ञानिक तकनीकों का प्रयोग कर लोग तालाबों में विधिवत् रूप से मत्स्य पालन कर लाभान्वित हो सकते हैं। इन तालाबों को संचय से पूर्व चूना, उर्वरक एवं गोबर आदि डालकर प्राकृतिक भोज्य पदार्थों से परिपूर्ण बना लेना चाहिए। तालाबों में चूने का प्रयोग बहुमुखी उद्देश्यों के लिये किया जाता है। यह कैल्शियम उपलब्ध कराता है, तालाब की तली में स्थित जैविक पदार्थों के विघटन में तेजी लाता है, तीव्र खनिजीकरण में सहायक है, हानिकारक धातुओं को अवक्षेपित करता है, पी0एच0 को उदासीन बनाये रखता है एवं विभिन्न परजीवियों पर नियंत्रण रखता है इत्यादि। यदि पानी का पी0एच0 6.5 के लगभग हो तो चूना 3 – 5 किग्रा/100 मी^{2} डालने की संस्तुति की जाती है। मध्यम उत्पादकता वाली मिट्टी में 300 – 400 किग्रा/100 मी^{2} गोबर की खाद डालने की आवश्यकता पड़ती है। चूना एवं गोबर के लगभग 15 दिन बाद लगभग 100 – 200 अंगुलिकायें/100 मी^{2} की दर से संचय करें। प्रतिदिन पूरक आहार की व्यवस्था अति आवश्यक है। आमतौर पर चावल की पॉलिस, सरसों/ मूंगफली या सोयाबीन की खली समान मात्रा में मिश्रित कर पूरक आहार के रूप में प्रयोग किया जाता है। पूरक आहार मछलियों के वजन के अनुसार दिया जाता है। प्रारम्भिक दिनों में प्रथम तीन माह मार्च से मई तक मछलियों को उनके वजन का कम से कम 5 – 10 प्रतिशत अन्तिम तीन माह सितम्बर से नवम्बर तक वयस्कों में वजन का 2 – 5 प्रतिशत आहार की मात्रा खिलाने की आवश्यकता होती है । समय–समय पर जाल द्वारा निकालकर मछलियों की वृद्धि एवं रोग आदि की जाँच करते रहना चाहिए तथा प्राकृतिक भोजन की पर्याप्त मात्रा को बनाये रखने के लिए समय–समय पर गोबर भी डालते रहना चाहिए।

मत्स्य उत्पादन में भोजन की व्यवस्था पर ही कुल लागत का लगभग 50 प्रतिशत व्यय होता है, जिसमें गोबर, उर्वरक और कृत्रिम भोजन आदि हैं। यदि इस एक कारक पर हो रहे व्यय को घटाया जा सके तो मत्स्य पालन व्यवसाय में लगे लोगों की आय उतनी ही बढ़ जायेगी। अतः आधुनिक तरीकों से मछली, फसल या पशुपालन को समेकित विधि द्वारा अधिक से अधिक उत्पादन प्राप्त किया जा सकता है, जिससे किसान वर्ष भर विभिन्न प्रकार के कार्यक्रमों में जुटे रहें तथा अपनी आय बढ़ा सकें। समेकित प्रणाली अपशिष्ट पदार्थों के पुनरावर्तन पर आधारित है। इसके अंतर्गत पशु पक्षियों (गाय, भैंस, बकरी, खरगोश, मुर्गी, बत्तख इत्यादि) के मूलभूत एवं अपशिष्ट पदार्थों का कुछ अंश मछलियां भोजन के रूप में ग्रहण करतीं हैं तथा बाकी जल में उनके प्राकृतिक भोजन (प्लवक) की वृद्धि में खाद की तरह काम करता है। इस प्रकार खाद एवं कृत्रिम भोजन पर बिना किसी व्यय के समेकित मत्स्य पालन द्वारा मछली की अच्छी पैदावार ली जा सकती है। पर्वतीय क्षेत्रों में मुख्यतः तीन तरह के समेकित मत्स्य पालन हो सकते हैं –

1. मत्स्य सह पशु/पक्षी पालन
2. मत्स्य सह कृषि/बागवानी
3. मत्स्य सह कृषि सह पशुपालन

मत्स्य सह पशु–पक्षी पालन से अभिप्राय यह है कि मत्स्य पालन के साथ–साथ पशुपालन, बत्तख पालन एवं मुर्गीपालन भी किया जाय । मत्स्य पालन सह कृषि के अंतर्गत मत्स्य सह सब्जी फल उत्पादन पर्वतीय क्षेत्रों में सफल हो सकता है। अब तीन प्रकार की खेती का एक साथ समन्वय अर्थात कृषि बागवानी, मत्स्य पालन एवं पशु/पक्षी पालन भी एक तकनीक है।

इन सभी प्रकार की समेकित मत्स्य पालन तकनीकों में वर्ष के अंत में तालाब को सुखा दिया जाता है तथा तली पर जमे कीचड़ को निकालकर बन्धों पर या पास के खेतों में डलवा दिया जाता है जो मिट्टी की उर्वरता को बढ़ाता है। इसके पश्चात मिट्टी एवं जल की अम्लीयता को सुधारने, कीटाणु एवं कीड़े–मकोड़ों के डिंभक, मोलएक तथा उनके अंडे इत्यादि को नष्ट करने के लिए चूने का प्रयोग करना चाहिए। इसके लगभग 10 – 15 दिन बाद पानी भरवाकर मत्स्य बीज संचय कर देना चाहिए। चूँकि इस प्रकार की व्यवस्था में नित्य ही पशु/पक्षी का अपशिष्ट तालाब में प्रवाहित होता है। अतः कार्बनिक पदार्थ बढ़ने के कारण पी0एच0 को संतुलित बनाये रखने के लिए चूने के प्रयोग पर बल देना चाहिए। प्रत्येक 3–4 महीने में एक बार 3 – 5 किग्रा/100 वर्ग मी की दर से चूने का प्रयोग अति आवश्यक है।

मछलियों के रोग एवं निदान

वैसे तो मछलियों में साधारणतया रोगों का प्रकोप बहुत कम देखा गया है फिर भी प्रदूषित जल, विषैली गैस (अमोनिया), मानव द्वारा रूक्ष व्यवहार के कारण मछलियों के रोग ग्रसित होने की सम्भावना बढ़ जाती है । शीत जलीय मछलियों में होने वाले रोगों में स्प्रींग वाइरेमिया, वाताशय संक्रमण, संक्रामक अग्नाशय उत्तकक्षय, वायरल हिमोरेगिक सेप्टीसीमिया, संक्रामक रक्तोत्पादक उत्तकक्षय, फ्यूरनेकुलोसिस, ड्रॉप्सी, पूंछ एवं पख की सड़न, आंखों का रोग, इच का रोग, सेप्रोलेग्नियोसिस, इत्यादि प्रमुख हैं। एक साधारण मत्स्य पालक के लिए रोगग्रस्त मछली को देखकर स्वयं रोग का पता लगाना संभव नहीं है, क्योंकि लगभग एक ही तरह के लक्षण अनेक रोगों में दिखते हैं, जैसे शरीर पर घाव, पख एवं पूंछ का सड़ना, मछली का सुस्त व कमजोर होना, भोजन न करना, इत्यादि। अतः मत्स्य पालक के लिए इतना पता लगाना हीं पर्याप्त है कि उसकी मछलियाँ सामान्य स्वस्थ मछलियों की तरह हैं या उनका व्यवहार असामान्य है। इसके लिए हर दूसरे महीने जाल चला कर मछलियों को बारी–बारी से ध्यानपूर्वक देंखे कि उनके शरीर पर कोई घाव या उभार या परजीवी तो नहीं हैं। शरीर एवं आँखें चमकदार हैं और गलफड़े लाल हैं । इसके बाद पानी में ही मछली की प्रतिवर्ती क्रिया को भी परखें जैसे जाल से छोड़ते समय ध्यान दें कि मछली तेजी से भागती है या सुस्त सी रहती है। इस प्रकार प्राथमिक जाँच के बाद यदि रोगग्रस्त मछलियाँ मिलें तो उनको (जीवित) पानी से भरी प्लास्टिक की थैली में रखकर शीघ्र ही किसी विशेषज्ञ को दिखायें जो हर प्रकार की जाँच के बाद आपको रोग एवं उपचार के बारे में बतायेंगे। मछलियों को रोगों से बचाने के भी कई उपाय हैं। यदि रख–रखाव अच्छा हो तो मछलियाँ रोगग्रस्त नहीं होती है। इसके लिये कुछ मुख्य बातों पर ध्यान दें जैसे तालाब में स्वच्छ जल की उपयुक्त व्यवस्था हो, संशोधित मत्स्य बीज का ही संचय किया जाये, अवाँछनीय मछलियों, घोंघों तथा पक्षियों पर नियंत्रण, एक ही आयु वर्ग की मछलियों का संचय, तालाब को सुखाना एवं रोगाणुनाशक बनाना एवं भोजन का सुप्रबंध आदि।

इस प्रकार से उचित प्रबन्धन द्वारा एक मछली एक वर्ष में लगभग 500 से 1000 ग्राम तक वजन प्राप्त कर लेती है । एक किग्रा की मछली के उत्पादन की लागत लगभग रू0 25.00 – 30.00 है जबकि इसका बाजार भाव लगभग रू0 80.00 प्रति किग्रा है। इस प्रकार मत्स्य पालक को प्रति किलोग्राम रू0 40.00 – 50.00 शुद्ध लाभ प्राप्त होगा तथा समेकित मत्स्य पालन द्वारा मत्स्य पालक एकल मत्स्य पालन की तुलना में दो गुना शुद्ध लाभ प्राप्त कर सकता है।

Photo: Fishponds and farming systems

Photo: Carps produced from farm ponds

Photo: Carps produced from farm ponds

मध्य हिमालय में सर्वोतोमुखी कृषि विकास परियोजना

एम. मुरूगानन्दम* एवम् राकेश कुमार*

परिचय

निरन्तर बढ़ रही जनसंख्या के कारण कृषि भूमि से पर्याप्त उत्पादन पाना कठिन हो गया है। अतः समय की माँग को देखते हुए किसान के लिए यह जरूरी हो गया है कि कृषि या पशुपालन के साथ अन्य व्यवसाय जैसे मत्स्य पालन करें। मत्स्य पालन एक ऐसा व्यवसाय है जिसमें हम कम लागत व मेहनत से अधिक आय प्राप्त कर सकते हैं।

पर्वतीय अंचल में मत्स्य पालन टैंको, तालाबों तथा डिग्गियों में हो सकता है। पर्वतीय क्षेत्रों जैसे कि उत्तरांचल राज्य में प्राकृतिक जल स्रोतों जैसे नदियों, जलाशयों तथा कृषि जल स्रोतों इत्यादि की कमी नहीं है, जिन्हें देखते हुए यहाँ पर मत्स्य पालन की अपार सम्भावनायें हैं। पर्वतीय क्षेत्रों के ठण्डे जलाशयों में मत्स्य पालन हेतु किसान को नई व आसान तकनीकों की जानकारी अत्यन्त आवश्यक है जिसके माध्यम से किसान अधिक से अधिक जलाशयों में मछली पालन कर अपने को लाभान्वित कर सकता है।

आजकल की जनसंख्या में बढ़ोतरी को देखते हुए यदि किसान संयुक्त कृषि को बढ़ावा दे, यह आज के समय की माँग है। इसमें किसान एक अपने छोटे बंजर क्षेत्र जो कि उसके खेतों के साथ ही हो तो उसमें मुर्गी का घर बनाकर मुर्गियों से भी अच्छी आय प्राप्त कर सकता है और साथ ही साथ तालाब व जलाशयों से मत्स्य पालन करके अतिरिक्त आय प्राप्त कर सकता है। इसके साथ ही अन्य जानवरों जैसे सुअर, गाय, भैंस आदि से भी अत्यन्त समिति क्षेत्र में अधिक से अधिक पैदावार व आय प्राप्त कर सकते हैं। लेकिन जरूरी है कि किसान सर्वप्रथम इन सबके लिए आसान व नई तकनीकों को समझें अन्यथा तकनीकों के अभाव या अधूरी जानकारी द्वारा वह अपनी आमदनी में बढ़ोतरी नहीं कर सकता।

सर्वोतोमुखी कृषि विकास परियोजना

सर्वोतोमुखी कृषि का अर्थ है कि किसान एक साथ दो या अधिक कृषि स्रोतों व जानवरों की समाकलित उत्पादित होने वाली किस्मों को एक साथ एक ही क्षेत्र में स्थापित करके उससे अधिक से अधिक पैदावार ले सके तथा बंजर पड़ी भूमि आदि को भी सदुपयोग करें।

अतः यदि किसान सर्वोतोमुखी कृषि के विकास की ओर घ्यान दें यही आज के समय की माँग है इसमें हम तीन चार किस्मों में मछली, जानवर, मुर्गी व खेती कर फसलें आदि ले सकते है; जरुरी है तो दो चार किसान एक साथ मिल कर भी सयुक्त रूप से इस सर्वोतोमुखी कृषि विकास को अंजाम दे सकते हैं ।

मत्स्य पालन के लिए तालाब का निर्माण

पर्वतीय क्षेत्रों में तालाब बनाने हेतु बड़े आकार की भूमि क्षेत्र की उपलब्धता कम होती है। अतः इन क्षेत्रों में तालाबों का औसत आकार 100–2000 मी0^2 होना चाहिए। मत्स्य पालन के लिए पर्याय आयताकार तालाब उपयुक्त होते हैं यदि किसान के क्षेत्र में आयताकार की अनुकूलता नहीं है तो वह अण्डाकार रूप में भी तालाब बना सकता है। यह क्षेत्र की उपलब्धता पर निर्भर करता है। तालाब की गहराई का भी उत्पादकता से सीधा सम्बन्ध है, इसलिए पर्वतीय क्षेत्रों में तालाब या टैंक का जल स्तर 1 से 1.5 मी0 का होना उपयुक्त पाया गया है यह तालाब जल स्रोतों जैसे नदियों, झरनों व पानी के साफ स्रोतों इत्यादि के निकट होने चाहिए ताकि आवश्यकतानुसार जल की आपूर्ति की जा सके। तालाब में जल का प्रवेश व निर्गत मार्ग होना भी आवश्यक है। तालाब की उर्वरता बनायें रखने के लिए खाद व चूनाकरण की समुचित व्यवस्था होनीं चाहिए ताकि पर्याप्त मात्रा में प्राकृतिक मत्सय भोजन (प्लवक) आदि तैयार होते रहें।

*** केन्द्रीय भूमि एवम् जल सरंक्षण अनुसंधान एवम् प्रशिक्षण संस्थान, 218 कौलागढ़ रोड़, देहरादून।**

पालने योग्य मछलियों का चयन

किसानों को ऐसी मत्स्य प्रजातियों का चयन करना चाहिए जिनकी तीव्र वृद्धि क्षमता से, प्राकृतिक व कृत्रिम भोजन ग्रहण करने में समर्थ हो, अधिक प्रतिरोधक क्षमता हो, स्वादिष्ट व पौष्टिक तथा सुपाच्य हो। मत्स्य पालन में उन प्रजातियों का संयुक्त रूप से पालन करना चाहिए, जिनमें कि कुछ तालाब के जल की उपरी सतह पर भोजन ग्रहण करें, कुछ तालाब में नीचे की सतह पर व कुछ बीच व किनारे पर भोजन ग्रहण करें। ताकि समुचित भोजन को प्रत्येक प्रजाति आराम से ग्रहण करें व मछलियों का विकास (वजन) समान रूप से हों।

पर्वतीय क्षेत्रों के जल क्षेत्रों में पाली जाने वाली मत्स्य प्रजातियों में कॉमन कार्य, सिल्वर कार्य, ग्रास कार्य, महाशीर व ट्राउट आदि प्रमुख हैं इनके साथ–साथ हम लगभग 1800 मी0 (समुद्र तल से ऊँचाई) वाले क्षेत्रों में भी मत्स्य की अन्य प्रजातियॉ जैसे कि नैन, कतला व रोहू आदि भी संयुक्त रूप से पाल सकते हैं। उपरोक्त सभी प्रजातियॉ शाकाहारी प्रवृत्ति की होती है तथा ये सभी मिश्रित कर एक ही जल क्षेत्र में पाल सकते हैं।

मत्स्य पालन गोबर की विधि मत्स्य पालन के समय, सर्वप्रथम तालाबों को संचय से पूर्व चूना, उर्वरक एवं खाद आदि डालकर प्राकृतिक भोज्य (प्लवक) पदार्थों से परिपूर्ण बना लेना चाहिए। यदि पानी का पी0 एच0 6.5 के आसपास हो तो चूना 2–3 किग्रा/100 मी0^2 डालना चाहिए और यदि पी0 एच0 7.5–8 के लगभग हो तो 3–5 किग्रा/100 मी0^2 डालना चाहिए। गोबर की खाद हम मध्यम उत्पादकता वाली मिट्टी के तालाब में 250–300 किग्प्र0/100 मी^{2} की आवश्यकता होती है, यह सब मछली के बच्चे (अंगुलिकाऐं) डालने के 15–20 दिन पहले कर लेना चाहिए ताकि तालाब में पर्याप्त मात्रा में प्राकृतिक भोजन (प्लवक) रहें। अंगुलिकाऐं 150–200/100 मी0^2 के दर से संचय करें। पूरक आहार के रूप में चावल का कन्ना, सरसों, मूंगफली या सोयाबीन की खली 1:1 मात्रा में मिश्रित कर प्रतिदिन प्रयोग करें जो कि 2–5 प्रतिशत मछली के औसत वजन के अनुसार दें। इस में तापमान भी एक अत्यन्त ध्यान देने योग्य बात है। मछली पालन में पर्याप्त वृद्धि के लिए तापमान 35^{o}से0 से 20^{o}से0 होना चाहिए, यदि तापमान 15^{o}से0 से कम है तो वृद्धि कम होती है तथा मछली 10^{o}से0 से कम तापमान पर मछलियों के मरने की आशंका रहती है, अतः अधिकांश तौर पर किसानों को अंगुलिकाएं मार्च–अप्रैल में लगभग 20 से 50 ग्प्रम वजन की डालनी चाहिए और नवम्बर तक गिरते तापमान के अनुसार मछलियों को बेच देना चाहिए।

मत्स्य सह मुर्गी पालन प्रणाली

मत्स्य पालन के साथ–साथ मुर्गी पालन से अभिप्राय यह है कि किसान मुर्गी पालन करके अपनी उत्पादन क्षमता बढ़ायें व साथ ही साथ मुर्गी बाड़े में बचे खुचे खाने की रोजाना सफाई करके मत्स्य तालाबों में मछली के पूरक आहार के रूप में इस्तेमाल कर सकता है तथा मुर्गी की बीट को तालाब में उर्वरकता बढ़ाने के लिए इस्तेमाल कर सकते हैं। यदि किसान के पास 200 मी0^2 का तालाब है तो लगभग 50 मुर्गियों के पालन में बचे खाने का इस्तेमाल तालाब में कर सकता है जिससे कि मत्स्य पालन में प्रयोग होने वाले पूरक आहार की बचत होगी।

मुर्गीपालन में सबसे प्रमुख बात है कि आप मीट के लिए या अण्डे के लिए अच्छी मुर्गियों व ब्रायलर चूजे का प्रयोग करे जिससे कि लगभग 30–40 दिनों में आपकी मुर्गी लगभग 1 से 1.5 किग्रा की हो जाये और अच्छी आमदनी प्राप्त हो सके। अण्डों के लिए लेयर मुर्गियों के चूजे प्रयोग करें जिससे कि 5–6 माह के बाद ही ये मुर्गियॉ अण्डा देना शुरू कर देती है और लगभग 5 माह तक अण्डे देती है तत्पश्चात् इनको मीट के लिए बेच सकते हैं।

चूजों के संचय से पूर्व मुर्गी–बाडे को अच्छी तरह से साफ करना चाहिए ताकि उसमें कोई मैला न रहे अन्यथा चूजों में बीमारी होने का खतरा सबसे ज्यादा होता है, बाड़े के चारों ओर चूने की एक लाईन बना दे जो कि वायु द्वारा होने वाले कीटाणु की रोकथाम में मददगार हो सके। रोजना साफ पीने का पानी साफ बर्तन में रखें। प्रकाश की समुचित व्यवस्था होनी चाहिए। समय–समय पर चूजों के प्रतिरक्षक टीके/दवाई नियमित रूप से दी जानी चाहिए।

जैसे कि

– 0 दिन के चूज़ों को प्रथम दिन से 4 दिन तक – ट्रिपिन पाउडर का घोल 1 ग्रा0 लगभग 5 लीटर साफ पानी में।

. 7 वें दिन – लसोटा दवाई को एक बूँद प्रति चूजें में देना चाहिए।

. 14 वें–15 वें दिन – कॉमबोरा दवाई को एक बूँद प्रति चूजे में देना चाहिए।

3. मत्स्य सह पशुपालन प्रणाली

मत्स्य पालन के साथ किसान पशु पालन जैसे कि सूकर पालन, गाय–भैंस पालन अथवा खरगोश पालन इत्यादि भी कर सकते हैं। सूकर पालन व खरगोश पालन को मीट के लिए तथा गाय–भैंस पालन को दूध के रूप में उत्पादकता में वृद्धि के लिए कर सकते हैं। तथा इनके मल को तालाबों में खाद के रूप में इस्तेमाल कर सकते है। इसमें मीट के लिए सूकरों के बच्चों को पालन कर छः से आठ माह में 50–60 किग्रा बना सकते हैं। सूकरों के बच्चे कम से कम दो माह के लाने चाहिए ताकि वे भोजन सुचारू रूप से कर सके। खाने में चावल का कन्ना, सरसों/मूंगफली की खली, मक्की आदि समान रूप से मिला कर दें। प्रतिदिन लगभग औसत वजन का 5 प्रतिशत भोजन प्रति सूकर प्रतिदिन देना चाहिए। दग्धारी पशुओं को हरियाली, भूसा के साथ–साथ चौकर, खली आदि व मिनरल मिक्चर आदि उचित मात्रा में देनी चाहिए सभी जानवरों व सूकर आदि को समय–समय पर पेट के कीड़े मारने की दवा भी दी जानी चाहिए।

पशुपालन में भी सफाई की जरूरत होती है। पीने का साफ पानी देना चाहिए। समय–समय पर पशुओं का वजन भी करना चाहिए ताकि मीट के उद्देश्यों के लिए दिया जा रहा भोजन ठीक मात्रा में है अथवा नहीं। यदि संभव हो सके तो सूकरों को रसोई घर का बचा खाना भी दे सकते हैं जिससे कि उनके खाने में आया खर्च कम से कम हो तथा अधिक से अधिक उत्पादकता प्राप्त हो। समय–समय पर पशुओं का टीकाकरण होना चाहिए ताकि वे बुखार, गलघोटू अथवा खूरूर रोग से बचे रहें।

4. मत्स्य पालन सह कृषि/बागवानी प्रणाली

मत्स्य पालन सह कृषि के अंतर्गत मत्स्य के साथ–साथ सब्जी, फल व फसल उत्पादन पर्वतीय क्षेत्रों में सफल हो सकता है। इसमें तालाब के पास में ही खेतों में हम सब्जी, फल व फसल का उत्पादन कर सकते हैं तथा खेतो में प्रयुक्त होने वाले पानी के रूप में तालाब के पानी का इस्तेमाल कर सकते हैं। तालाब के पानी में गोबर की खाद व अन्य उर्वरक होने की वजह से यह पानी खेतों में सब्जियों तथा फसलों के लिए काफी अच्छा होता है और लगभग 10–20 प्रतिशत फसलों की उत्पादकता में वृद्धि करता है।

इस प्रकार से पर्वतीय क्षेत्रों में किसान समेकित कृषि प्रणाली से कम क्षेत्र में अधिक से अधिक उत्पादकता प्राप्त कर सकते हैं तथा अधिक आमदनी प्राप्त कर सकते हैं।

उत्तराखण्ड में मत्स्य पालन–तीव्र प्रसार हेतु दिशा देता एक जनसहभागी प्रयास

एम. मुरूगुनन्दम्, बी.एल.ध्यानी, सुरेश कुमार, राकेश कुमार एवम् बाँके बिहारी

भारतीय गणराज्य के अन्य प्रदेशों की भांति नवनिर्मित उत्तराखण्ड राज्य में भी ग्रामीण आर्थिकी का मुख्य घटक कृषि व्यवसाय ही है जिस पर यहां की 70 प्रतिशत से भी अधिक जनसंख्या की आजीविका निर्भर करती है। राज्य में वन क्षेत्र अधिक होने के कारण यहां पर प्रति ईकाई कृषि भूमि पर जनसंख्या दबाव काफी अधिक है। इसके अतिरिक्त विशिष्ट प्राकृतिक सौंर्न्दयता, एवं संसाधनों से भरपूर इस हिमालयी राज्य में 90 प्रतिशत से अधिक भूभाग पर्वतीय है। राज्य की कुछ विषम परिस्थितियों जैसे ऊंची–नीची तलरूपता (समुद्र तल से 300 से 7300 मीटर तक ऊंचाई), भूकम्प अधिक, अधिक वर्षा (लगभग औसतन 1800 मिली मीटर वार्षिक), संवेदनशीलता अस्थिर दुर्गम ढाल की अधिकता वाले नालों में तीव्र जलप्रवाह, मृदा क्षरण, छोटी व बिखरी कृषि जोतों के कारण यहां पर कृषि फसलों का उचित उत्पादन नहीं हो पाता है जिसके कारण यहाँ के कृषकों को अपनी आजीविका जुटाने हेतु काफी परेशानी का सामना करना पड़ता है। उक्त परिस्थिति में यहाँ के कृषकों **हेतु अति आवश्यक हो जाता है कि वो कृषि फसलों के उत्पादन के अतिरिक्त कृषि आधारित अन्य व्यवसाय भी अपनायें।**

चित्र 1: निचले हिमालयी क्षेत्रों में कृषक जनसहभागिता द्वारा विकसित मछली तालाब किये गये मछली तालाब

कृषि आधारित अतिरिक्त व्यवसायों में मत्स्य पालन इस राज्य में कृषकों की आजीविका सुरक्षा हेतु एक सशक्त उपाय साबित हो सकता है क्योंकि यहाँ की विशिष्ट जलवायु, तलरूपता व प्राकृतिक संसाधन का संयोजन मत्स्य पालन को बढ़ावा देने हेतु पूर्णतया अनुकूल हैं। राज्य में गंगा, यमुना तथा उनकी कई सहायक नदियों व नालों में पर्याप्त जल (किलोमीटर) का होने के साथ–साथ बारहमासी जलस्रोतों, झरनों व वर्षा का प्रचुर मात्रा में होना आदि कई ऐसे प्रबल कारक है जिससे यहाँ पर मत्सय पालन व्यवसाय प्रचुर मात्रा में विकसित किया जा सकता है। इसी संभावना को मूर्तरूप देने व इसके परीक्षण हेतु एक प्रयास केन्द्रीय मृ. जल सरंक्षण अनु0 एवं प्रशि0 संस्थान देहरादून ने जनसहभागी आधार पर किया।

जनसहभागी विश्लेषणः राज्य के देहरादून जनपद स्थित विकासखण्ड विकासनगर के ग्राम देवथला, गोडरिया, पसौली व डूंगाखेत गाँवों में 34 कृषक परिवारों को अंगीकृत करते हुए केन्द्रीय मृदा व जल संरक्षण अनुसंधान एवं प्रशिक्षण संस्थान, देहरादून द्वारा ग्रामीण विकास मंत्रालय भारत सरकार के भू संसाधन विभाग वित्त पोषण से उत्तर–पश्चिम हिमालय के वर्षा आधारित क्षेत्रों में आजीविका सुरक्षा हेतु भूमि व जल प्रबन्धन तकनीकों का जनसहभागी प्रसार व मूल्यांकन नामक परियोजना वर्ष, 2007 में शुरू की गई। भूमि,जल एवं अन्य प्राकृतिक संसाधनों का ग्रामीण विकास एवं आजीविका सुरक्षा हेतु जनसहभागिता संवर्द्धन व उपयोग किया जाना उक्त परियोजना का मुख्य उद्देश्य था। परियोजना का नियोजन सहभागी ग्रामीण समीक्षा (पी0आर0ए0) विधि को प्रयोग करते हुये पूर्णतयाः जनसहभागिता आधारित किया गया। इसमें जनसहभागी जल संसाधन प्रबन्धन, मृदा संरक्षण, कम्पोस्ट निर्माण, बागवानी विकास, चारा, घास रोपण, फसल उत्पादन, वनीकरण, गदेरा नियंत्रण, पशुधन विकास, मत्स्य पालन, ग्रामीण आय व रोजगार सृजन आदि से संबंधित तकनीकों के प्रचार–प्रसार हेतु किये जाने वाले कार्यो का निर्धारण किया गया।

केन्द्रीय भूमि एवम् जल सरंक्षण अनुसंधान एवम् प्रशिक्षण संस्थान, 218 कौलागढ़ रोड़, देहरादून।

सहभागी ग्रामीण समीक्षा के दौरान जब स्थानीय लोगों ने मछली पालन व उपभोग के प्रति थोड़ी रूचि दिखाई तो परियाजना की वैज्ञानिक टीम ने क्षेत्र के मत्स्य पालन की संभावनाओं के मद्देनजर मत्स्य व्यवसाय केन्द्रित समूह चर्चाए कर विभिन्न बिंदुओं पर 150 कृषकों से आंकडे एकत्र कर उनका विश्लेषण किया जिसके बिंदुवार निम्नलिखित परिणाम प्राप्त हुए हैः–

- परियोजना के अन्तर्गत अंगीकृत गाँवों के 90 प्रतिशत से अधिक परिवारों में मछली मांस को खाने वाले मांसाहारी सदस्य पाये गये जिनमें महिला, पुरूष व बच्चे सभी शामिल थे।
- मछली मांस पसंद करने वाले परिवारों में 72 प्रतिशत से अधिक कृषक परिवारों के सदस्य सप्ताह में कम से कम एक दिन समूह में मछली मारने हेतु गाँव के बगल में स्थित गौना नाले अथवा क्षेत्र में उपस्थित अन्य नदियों व नालों में सामान्यतः जाते पाये गये। साथ ही मछली मारने जाने की उक्त परम्परा सदियों पुरानी बताई गई।
- मछली मारने जाने वाले लोगों में मध्य आयु वर्ग का प्रतिशत सर्वाधिक 46 प्रतिशत पाया गया जबकि युवा वर्ग के लोगों का 24 प्रतिशत पाया गया। मध्य आयु वर्ग के समस्त लोगों को सभी स्थानीय नालों में उपस्थित मछली प्रजातियों तथा उनके पलायन करने के व्यवहार की पूरी जानकारी भी पाई गई।

चित्र 2ः तालाब में मछली बीज डालनै का प्रदर्शन

- विभिन्न मांसो के प्रति जब लोगों की प्राथमिकताओं का विश्लेषण किया गया तो पाया गया कि वे हिन्दू धर्म में खायें जाने वाले सभी प्रकार के मॉस खाते हैं परन्तु प्राथमिकता के आधार पर बकरा, मछली, मुर्गा व सुअर मांस खाने वालों का प्रतिशत् क्रमशः 33, 31, 26 व 10 पाया गया।
- मछली मारने जाने वाले लोगों को मछली मारने हेतु अपनाये जाने वाले परम्परागत पदार्थो जैसे टिमरू पेड की पत्तियाँ व बीज तथा छिलक आदि का पाउडर बनाकर, ब्लीचिंग पाउडर आदि को प्रयोग किये जाने का भी पर्याप्त अनुभव पाया गया।

प्रयासः उपरोक्त निष्कर्ष के आधार पर स्थानीय कृषकों के बीच मछली के प्रति रूचि का पूर्ण आंकलन किये जाने के उपरान्त परियोजना की वैज्ञानिक टीम द्वारा कृषकों को प्रेरित किया गया कि वो अपने खेतों में ही तालाब बनाकर आसानी से मत्स्य पालन सफलतापूर्वक कर सकते हैं। प्रेरणा हेतू कृषकों को यह भी स्पष्ट किया गया कि अमुक आकार के तालाब से वो प्रति वर्ष कितना मत्स्य उत्पादन कर कितनी आमदनी प्राप्त कर सकते हैं। कृषकों के अन्दर इच्छा जागृति अनुभव की गई तथा उन्हें कैसे करना है, कब करना है आदि के विषय में सम्पूर्ण जानकारी दी गई। इसके उपरांत प्रथम वर्ष 2007 में मछली पालन हेतु एक कृषक(नाम व ग्राम) को चुना गया जिसको जन सहभागी आधार पर तालाब निर्मित करने हेतु परियोजना मद से छः हजार रूपये की धनराशि तालाब निर्माण में लगने वाली सामग्री को खरीदने हेतु दी गई। चुने गये कृषक ने तालाब निर्माण में लगने वाली सामग्री को एवं खरीद । चुने गये कृषक ने तालाब की खुदाई व स्थानीय उपलब्ध सामग्री बजरी, पत्थर आदि एकत्र करते हुये 50 घनमीटर क्षमता वाले के तालाब का निर्माण किया। तालाब में आई कुल लागत 15000 रूपये में कृषक की सहभागिता 9000 रूपये (67 प्रतिशत) रही। तालाब निर्माण के उपरांत कृषक को परियोजना मद से मछली प्रजाति बीज उपलब्ध कराया गया तथा साथ ही उसको किस–किस प्रकार क्या–क्या आहार देना है, के विषय में भी विस्तार–पूर्वक जानकारी दी गई। धीरे–धीरे कृषक के तालाब में मछलियां बड़ी होनी शुरू हो गई तथा प्रथम वर्ष में कृषक के यहां 45 किलोग्राम/100 वर्ग मीटर के हिसाब से मछली का उत्पादन हुआ। इस सफलता को अपनी आंखो से देखकर गांव के अन्य कृषकगण काफी प्रभावित हुये तथा वर्ष 2008 में जहां एक अन्य कृषक के यहां परियोजना मद से केवल एक तालाब बनवाया गया वहीं अन्य कृषकों ने तकनीकी जानकारी प्राप्त कर अपने स्वयं के प्रयासों से तीन तालाब निर्मित कर परियोजना टीम की देख–रेख में मत्स्य पाल शुरू कर दिया। तदोपरांत वर्ष 2009 में भी परियोजना मद से एक अन्य कृषक के यहां एक और तालाब निर्मित कराकर मत्स्य पालन शुरू कराया गया है। वर्तमान में अंगीकृत गांव में कुल 9 कृषकों ने मत्स्य पालन का कार्य शुरू कर दिया है। कुल

मिलाकर जहां परियोजना मद से 3 तालाब निर्मित कराये गये वही कृषकों ने अपने स्वयं के प्रयासों से 6 तालब निर्मित किये। साथ हीं वर्ष 2007 में तालाब क्षेत्र जहां 50 घन मीटर था वहीं वर्तमान में 520 घन मीटर हो गया है जिसमें लगभग 10 गुणा की वृद्धि दर्ज की गई। परियोजना से पूर्व जहां कृषकों का खुद का मत्स्य उत्पादन शून्य था वहीं वर्तमान में उनके यहां 200 किलोग्राम प्रति वर्ष से भी अधिक मछली उत्पादन हो रहा है। जिससे लगभग 16000 रूपये की वार्षिक आय प्राप्त हो रहीं।

चित्र 3 व 4: मछलियों की वृद्धि जाँच हेतू जनसहभागी मुल्यांकन

उक्त सफलताओं के देखते हुये क्षेत्र के सभी कृषकगण अति उत्साहित है एवं इस वर्ष 2010 में लगभग 7 नये तालाब कृषकों द्वारा निर्मित कर लिये गये। इसके अतिरिक्त कृषकगण कम लागत से तालाब निर्माण करने की तकनींको के विषय में जिज्ञासु हुये हैं। कुल मिलाकर अंगीकृत गाँवों में मत्स्य पालन व्यवसाय का विसरण शुरू हो गया है।

चित्र 5 व 6: कृषकों द्वारा निर्मित नयें तालाब एवम् विकय हेतू तैयार मछलियाँ

सीख एवं संस्तुतिः सफलता की उपरोक्त कहानी प्रसार संस्थाओं को स्पष्ट सीख देती है कि ग्रामीण विकास हेतु वो उन कार्यो को प्राथमिकतायें दें, जिनमें कृषक रूचि रखते हों तथा किसी न किसी रूप में उन कार्यो से वो पहले से जुडे हों एवं उनके उत्पाद व उनके उपभोग में भी शामिल हों। इससे एक तो कृषको के बीच तकनींकों का अंगीकरण व विसरण तीव्र होगा, साथ ही तकनीकी के प्रसार हेतु लगने वाले व्यय में भी कमी आयेगी।

GLOSSARY OF AQUACULTURE AND AQUACULTURE SYSTEMS RELATED TERMS

M. Muruganandam*

Algal bloom – A population explosion of algae in surface waters, such as ponds, lakes, streams and Oceans, often resulting in high turbidity and usually green or red colored water. Commonly induced by eutrophication due to nitrogen and phosphorous nutrient enrichment.

Aquaculture - What agriculture is on land, aquaculture is in water or more simply aquaculture is underwater agriculture. It is akin to farming and animal husbandry as it involves rearing and management of living aquatic organisms including fish, prawns, shrimps, crabs, frogs, molluscs, seaweed, aqua chestnut - water fruit (*Trapa bispinosa*) and other aquatic plants in controlled environments for food, profits and related benefits such as socio-economic well-being, ecological and biological conservation. (Synonyms: fish culture, fish farming, prawn culture, shrimp culture, crab culture, seaweed culture,..)

Backyard habitat ponds - Ponds that are built to cater the water needs of wildlife, aquatic and amphibian species. It is a good source of water; in fact, a pond is an essential portion of a well-planned backyard wildlife habitat.

Cage – A floating enclosure in which fish are grown and fed a complete feed. More common cages are rectangular, 3x4x3 feet or 8x4x4 feet; square, 4x4x4 feet or 88x4 feet; and round, 4x4 feet.

Cage culture - The practice of rearing fish in cages, can be applied in extensive bodies of water that cannot be drained or seined and would otherwise not be suitable e for aquaculture. The cages float and placed in the open part of the pond or extensive water bodies with at least two feet of water between the bottoms of the cage and the pond bottom.

Dugout (excavated) pond– Ponds that are built by excavation of earth surface and building dikes around the depression created. Made by digging either the pond itself or the surrounding area is to form levees.

Ecosystem – A functioning interacting system composed of living organisms and their environment.

Embankment pond – Pond built by placing the dam across a stream water flow. Least preferred since it would be washed often**.**

Estuary - A coastal wetland or the zone at the mouth of the river where it meets the sea or the ocean. In other words, the region of river that is affected by tides. Because of the ocean tides, the water is very salty to brackish.

Fen - Waterlogged wetlands dominated by plants called sedges.

Fisheries - A Subject of multi-disciplinary science of agriculture. Broadly fisheries include both wild hunting (fishing) and farming (aquaculture or fish farming). The science and technology of fisheries further classified into varied groups according to land-water environments and level of management and input intensities involved. Some of the groups are fresh water, brackish water, marine water fisheries and traditional, extensive, intensive, rural and industrial fisheries and aquaculture.

*** Senior Scientist (Fisheries), Central Soil & Water Conservation Research & Training Institute, Dehradun-284 195 (Uttarakhand)**

Fish farming activities - Various activities involved in fish production such as fish seed stocking and management, soil-water preparation and management (liming, water exchange, and fertilization), feed preparation, feeding, feed management, harvesting and marketing.

Fish farming chemicals - Various chemicals used in fish production such as potassium permanganate ($KMnO_4$), formalin, bleaching powder, lime, copper, copper sulphate, antibiotics, etc.

Fish feeds – Feeds prepared mainly from rice polish, rice bran, mustard oil cake, groundnut oil cake, silkworm pupae, wheat bran, soybean, agricultural/household/animal wastes etc using water as suitable mixing agent.

Fish Feeding - Controlled fish feeding through trays and monitoring so as to regulate feed use.

Floodplain - Seasonally flooded flat land along rivers and lakes. The land, bordering stream, built up of sediments from overflow of the stream and subject to inundation when the stream is at flood stage. Sometimes called bottom land.

Freshwater - Water with salinity less than 0.5 parts per thousand (ppt).

Grow-out pond/system - A pond or other system used to grow aquatic animals to marketable/table size.

Holding pond/system - Pond or other system used for temporary holding of aquatic animals in live conditions either prior to stocking or after harvesting.

Hydroponic culture – The production system of crops without soil. It requires media other than soil or some structure to support the crop. It is usually identified by type of support media that is used.

Inter-tidal ponds – Ponds built in the zone between low and high tides.

Jheels - Freshwater lakes and associated marshes in the Indo-Gangetic plains of India.

Lake - Large expanse of naturally/artificially formed water bodies.

Lagoons - A shallow stretch of water that is separated from sea by a narrow strip of land.

Landfills - A dump of domestic wastes compacted on site and covered regularly by a layer of earth.

Levee pond – Standing water impoundment built by excavating the pond area to a shallow depth and using the soil obtained to build a perimeter of levees or dykes. These are built such away that they can be drained by gravity easily.

Lined ponds – Ponds that are lined either permanently by cements, stone pitching or by temporarily by High Density Poly-Ethylene (HDPE), Low Density Poly-Ethylene (LDPE), etc to control excessive seepage and to avoid contaminated soils in pond.

Nursery tank/pond – Accessory pond or tank meant for nursing fish seeds prior to stocking. May be present in hatchery or near to main fishponds for nursing.

Off-stream (by-pass) pond - It is built adjacent to the stream with appropriate intake system either by pipe or open channel to divert water from stream to pond for fish production or such other purposes. However, intake screening and control is necessary to avoid sedimentation and flood water. Proper location and good dike building are essential to risk out outflow and flood damage.

On-stream pond – Pond built on the way of a stream or channel.

Pen – Large enclosures using nets and long poles or such others in large open water bodies meant for fish culture.

Pond - Small body or pool of still water. Most common aquaculture production system is earthen pond. Aquaculture ponds may include holding, spawning, rearing and grow-out ponds.

Preformed ponds - Ponds that are available in preformed shapes, usually constructed using fibreglass or Poly Vinyl Chloride (PVC). These ponds can be placed above ground or sunk into the ground. Their main advantage is that they are very rugged. The disadvantage is that they limit one's creativity in designing a pond. This is somewhat overcome by the fact that more and more shapes and sizes are becoming available as interest in backyard ponds increases.

Raceway – Long channels through which large amounts of water flow continuously and then discarded. Usually built on concrete, these also can be earthen channels or long tank constructed of other durable materials like block, tile, bricks and wood. It is arranged in a series on slightly slopping terrain, taking advantage of gravity to move water through each unit. Dimension of raceway vary, but generally a length:width:depth ratio of 30:3:1 provides favourable characteristics.

Rack and raft culture – A kind of culture system using long strips tied on erected poles especially in marine water bodies for the culture of mussels and oysters.

Re-circulatory system – Tank systems that rely on bio-filters to breakdown harmful fish waste products, so water can be reused/re-circled. It can be partially or closed re-circulatory system. The system may include culture chambers, a primary settling chamber, a biological filter and a final clarifier or secondary settling chamber.

Roof catchment device (Roof-top harvesting) - A device, such as a cement tank or cistern that collects rainwater falling from roof of a building.

Reservoir - Large expanse of man-made inland water bodies.

Runoff – Water that flow over ground surface after a rain, *i.e.* overland flow due to rain.

Sewage – Liquid part of sewage system of sanitation or wastewater treatment.

Swamps – An area of land that is usually wet or submerged under shallow freshwater or brackish water and typically supports hydrophilic trees and shrubs. Forested wetlands dominated by trees or shrubs. Inland swamps contain freshwater and coastal swamps contain salt water. For example, Mangrove swamps.

Synergism – The non-obligatory association of organisms that is mutually beneficial. Both populations can survive in their natural environment on their own although, when formed, the association offers mutual advantages.

Symbiosis – The obligatory co-habitations of two dis-similar organisms in intimate association, often, but not always, mutually beneficial.

Tank - Small reservoirs constructed for storage of water and fish culture.

Trophic levels – Levels in a food chain that passes nutrients and energy from one group to another group of organisms.

Waterlogged – Saturated with water.

Watershed pond - Impoundment built by damming stream or small valley. Runoff from the surrounding watershed(s) fills the pond(s).

Water table – The upper surface of groundwater or that level below which the soil is saturated with water.

Water table, Perched – The surface of a local zone of saturation held above the main body of groundwater by an impermeable layer of stratum, usually clay and separated from the main body of groundwater by an unsaturated zone.

Water table ponds - Ponds built near the area where water table is close to ground surface so as to make water fill easy. The precaution needed may be if the water table fluctuates during the year, since the pond may dry up during periods of drought. It may be seasonal pond and meant to support certain wildlife species, but it would not attract as many species as a permanent pond.

Wetland – An area of land that has hydric soil and hydraphytic vegetation, typically flooded for part of the year, and forming a transition zone between aquatic and terrestrial systems.