Design and Operation of Smallholder Irrigation in South Asia (WB, 1995, 134 p.)

Distributors of world bank publications

Prices and credit terms vary from country lo country

Consult your 101 al distributor before placing allan order.

ALBANIA
Adrion Ltd
Penal Rexhepi Str
Par 9, Shk. 1, Ap 4
Tirana
Tel: (42) 274 19; 22172
Fax: (42) 274 19

ARGENTINA
Oficina del Libro International
Av Cordoba 1877

1120 Buenos Aires
Tel: (1) 815 8156
Fax (1) 815-8154

Australia, Fiji Papua New Guinea, Solomon Islands, Vanuatu, and Western Samoa
D A Information Services
648 Whitehorse Road
Milcham 3132
Victoria
Tel: (61) 3 9210 7777
Fax: (61) 3 9210 7788
URL: hftp:/www dadirect.com au

Austria
Gerold and Co
Graben 31
A 1011 Wien
Tel (1) 533 5014-0
Fax (1) 512-47-3D29

Bangladesh
Micro Industries Development
Assistance Society (MIDAS) House 5,
Road 16 Dhanmondi R/Area Dhaka 1209
Tel. 17) 376427
Fax (2) 8 11188

Belgium
Jean De Lannoy
Av du Roi 702
1 060 Brussels
Tel (2) 538 5169
Fax (2) 538 0841

Brazil
Publicaces Tecnicas Internationals Ltda.
Rua Peixolo Gomide, 209
01409 Sao Paulo, SP
Tel: (11) 259 6644
Fax: (11)258-6990

Canada
Renoul Publishing Co Ltd.
1294 Algoma Road
Ottawa, Ontafio K 18 3W8
Tel 613 741-4333
Fax. 613-741 5439

China
China Financial,s Economic Publishing House
6, Da Fo Si Dong Jie
Beijing

Tel (1) 333 8257
Fax (1) 401-7365

Colombia
Infoenlace Ltda
Apartado Aereo 34270
Rogol D E
Tel: (1)285-7798
Far (11 285-2798

Cte d'Ivoire
Centre d Edition el de Diffusion
Africanes (CEDA)
04B.P.541
Abidjan 04 Plateau
Tel 725 24-6510
Fax: 275-25 0567

Cyprus
Center of Applied Research
Cyprus Co/ege
6, Diogenes Street, Engomi
PO Box 2006
Nicosia
Tel 244 1730
Fax: 246 2051

Czech republic National Information
Center prodejna, Konvikiska 5 CS - 113 57 Prague I
Tel (2) 2422 9433
Fax: (2) 2422 1484
URL http:/www nis czl/

Denmark
SambndsLifferalur
Rosenoems All 11
OK-1970 Fredenksberg C
Tel- (31) 351942
Fax (31) 357822

Ecuador
Facultad Lalinoamericana de Ciencias Sociales
FLASCO SEDE Ecuador Caffe Ulpiano Paer
118 yAv Patria Quilo, Ecuador
Tel: (2) 542 714, 542 716:528 200
Fax: (2) 566139

Egypt, Arab republic of Al Ahram
Al Galaa Street
Cairo
Tel: (2) 578-6083
Fax: (7) 578 6833

The Middle East Observer

41. Sherif Street
Cairo
Tel: (2) 393 9732
Fax: (2) 393-9732

Finland
Akaleemmen Kirjakauppa
PO Box 23 FIN-00371 Hetsinki
Tel (0) 12141
Fax: (0) 121-4441
URL: http./booknel cultnet fi/aha/

France
World Bank Publications 66. avenue
d'lna 75116 Paris
Tel (1) 40 59 30 56/57
Fax (1)40-69-3066

Germany
UNO-Verlag
Poppelsdorfer Allee 55
53115 Bonn
Tel: (228) 212940
Fax: (228)217492

Greece
Papasotiriou 8 A

35, Stournara Sh
106 82 Athens
Tel: (1) 364-1826
Fax (1) 364-8254

Hong Kong, Macao
Asia 2000 Ltd
Sales & Circulation Deparlment
Seabird House, unit 1101-02
22-28 Wyndham Street. Central
Hong Kong
Tel 852 2530 1403
Fax- 8522526 1107
URL- http//www sales@asia2000 com hk

Hungary
Foundation for Markel
Economy
Dombovari U1 17 19
H 1 11 7 Budapest
Tel 361204 2951 or 36 1204 2948
Fax: 36 1 204 2953

India
A/ied Publisher s Ltd
751 Mount Road
Madras 600 002

Tel (44) 852 3938
Fax: (44) 852 0649

Indonesia
Pt Indira Limited
Jalan Borobodur 20
PO. Box 181
Jakarta 10320
Tel (21) 390 4290
Far: (21) 421 4289

Iran
Kowkab Publishers
PO Box 19575-511 Teheran
Tel: (21) 2583723
Fax: 98 (21) 258 3723

Ketab
Sara Co Publishers Khaled Eslamboli
Ave . 61h Street Kusheh Detafrooz No. 8 Tehran
Tel 87178I 9 or 8716104
Fax: 8862479

Ireland
Government Supplies Agency Ofig an ISolathair 45
Harcourt Road Dublin 2
Tel: (1)461-3111

Fax: (1) 475 2670

Israel
Yozmol Literature Ltd
PO Box 56055
Tel Aviv 61560
Tel (3) 5285 397
Fax: (3) 5285-397

ROY
International PO Box 13056 Tel Aviv 61130
Tel (3)5461423
Fax: (3) 5461442

Paleslinian Authonly/Middle East
Index Information Services
PO B 19502 Jerusalem
Tel: (2) 271219

ITALY
Licosa Commissionaria Sansoni SPA
Via Duca D Calabna 1/1
Casella Postale 552
50125 Firenze
Tel (55) 645 415
Fax: (55) 641 257

Jamaica
Ian Randle Pubishers Ltd
206 Old Hope Road
Kingston 6
Tel: 809-927 2085
Fax: 809 977 0243

Japan
Eastem Book Service
Hongo 3 Chome
Bunkyo ku 113
Tokyo
Tel (03) 3818 0861
Fax (03) 3818 0864
URL: http://www bekkoame or jp/-svt ebs

Kenya
Africa Book Service (E A) Ltd
Quaran House Mlangano Street
PO Box 45245
Nairobi
Tel (2) 2364 1
Fax: (2) 330272

Korea, republic of Daejon Trading Co Ltd
PO Box 34
Yeoeida

Seoul
Tel (2) 785 1631/4
Fax: (2) 784-0315

Malaysia
University of Malaya Cooperative
Book shop Limited
PO Box 1127
Jalan Panlai Baru
59700 Kuala Lumpur
Tel: (3) 756-S000
Fax: (3) 755 4424

Mexico infotec
Aparlado Postal 22-860
14060 Tlalpan
Mexico D H
Tel (5) 606 00 1 1
Fax: (5) 606-03B6

Netherlands
De Lindeboom/lnOr Publikaties
PO Box 202
7480 AE Haaksbergen
Tel (53) 574 0004
Fax: 153) 572 9296

Private Mail Bag 93914
New Market
Auckland
Tel (915?4 8119
Fax (9) 524 8067

Nigeria
University Press Limited
Three Crowns Building Jericho
Private Mail Bag 5095
Ibadan
Tel: (22)41 1356
Fax: (22) 41-2056

Norway
Narvesen Information Center
Book Department
PO Box 6l25 Etterstad
N-0602 Oslo 6
Tel (22) 57 3300
Fax: (22) 681901

PAKISTAN
Mirza Book Agency
65 Shahrah e Ouaid-e Azam
PO Box No 729
Labore 54000

Tel (42) 7353601
Fax (42) 7565283

Oxford University Press
5 Bangalore Town
Sharae Faisal
PO Box 13033
Karachi-753S0
Tel (21) 446307
Fax (21) 454-7640

Peru
Editorial Desarrollo SA
Apartado 3824
Lima I
Tel: (14) 285380
Fax: (14)28S628

Philippines
International Booksource Center Inc
Suile 720. Cityland 10
Condominium Tower 2
HIV dela Costa comer
Vatero St.
Makati. Metro Manila
Tel (2)817-9676
Fax (2)817 1741

Poland
International Publishing Service U1
Piekna 3 1/37 00-577 Warzawa
Tel (2) 628 6089
Fax (2) 621 7255

Portugal
Livraria Portugal
Rua Do Carmo 70 74
1 200 Lisbon
Tel (1) 347 4982
Fax: (1) 347 0264

Romania
Compani De Librarii Bucuresti SA
Str Lipscani no 26 sector 3
Bucharest
Tel (1) 613 9645
Fax (1) 312 4000

Russian federation lsdalelslvo Ves Mir
9a Kofpachniy Pereufok
Moscow 101831
Tel (95) 917 87 49
Fax: (95) 917 92 59

Saudi Arabia, Qatar

Jarir Book Store
PO Box 3196
Riyadh 11471
Tel (1) 477 3140
Fax (1) 477 2940

Singapore
Taiwan Myanmar Brunei Asahgate
Publishing Asia Pacific Ple Ltd 41 Kaffang
Pudding Road 104 03 Golden Wheel Building Singapore 349116
Tel (65) 7415166
Fax (65) 742 9356
e-mail ashgale@asianconnect com

Slovak republic
Slovart G T G Ltd
Krupinsk8 4
PO Box 152
852 99 Bratislava 5
Tel (7) 839472
Fax (7) 83.9485

South Africa, Botswana
For single titles
Oxford University Press
Southern Africa
PO Box 1141

Cape Town 8000
Tel: (21) 45-72b6
Fax: (21) 45-7265

For subscription omens:
International Subscription Service
PO Box 41095
Craighall
Johannesburg 2024
Tel (11) 8801448
Fax (11) 880 6248

Spain
Mundi-Prensa Libros. S A Castello 37 28001 Madrid
Tel: (1) 431-3399
Fax: (1) 5753998
http //www isai es/mprensa

Mundi- Prensa Barcelona
Consell de Cent 391
08009 Barcelona
Tel (3) 488-3009
Fax (3) 487 7659

Sri Lanka the maldives
Lake House Bookshop PO Box 244 100 Sir Chittampalam
A Gardiner Mawatha Colombo 2

Tel (1) 32105
Fax (1) 432104

Sweden
Fritzes Customer Service
Regeringsgalon 12 5 106 47 Stockholm
Tel: (8) 690 90 90
Fax: (8) 2147 77

Wonnergren-Williams AB
P O Box 1305
5 17175 Solna
Tel (8) 705 97 50
Fax (8) 27-00 71

Switzerland
Libraine Payot
Service Institutional
Cles-de Monthenon 30
1002 Lausanne
Tel (021)-120 2511
Fax (021)-311-1393 1393

Van Dermro Editions Technq
Ch de Lacurez 41
CH1807 Blonay
Tel: (021) 943 2673

Fax: (021) 943 3505

Tanzania
Oxford University Press
Maktaba Street
PO Box 5299
Dar es Salaam
Tel (51) 29209
Fax (51) 46822

Thailand
Central Books Disiribution
306 Silom Road
Bangkok
Tel (2) 235 5400
Fax (2) 237 8321

TRINIDAD & TOBAGO JAM.
Systematix Studies Unit
49 Watts Street
Curepe
Trinidad West Indies
Tel 809-662 5654
Fax: 809 662 5654

Uganda
Gustro Ltd

Madhvani Buiding
PO Box 9397
Plol 16/4 Jinja Rd
Kampala
Tel/Fax (14)254763

United Kingdom
Microinto Ltd
PO Box 3
Anon Hampshine GU34 2PG
England
Tel (1420)86848
Fax: (1420)B98b9

Zambia
University Bookshop
Great East Road Campus
PO. Box 32379
Lusaka
Tel: (1) 213221 E d 482

Zimbabwe
Longman Zimbabwe (Pie Ltd
Tourte Road. Ardbennie
PO Box ST125
Southerton
Harare

Tel: (4)662711
Fax (4) 662716

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Design and Operation of Smallholder Irrigation in South Asia (WB, 1995, 134 p.)

Abstract

A large amount of research has been carried out and a considerable body of literature has been generated on the socio-economic features of smallholder irrigation, in particular, as well as the technical aspects of irrigation, in general. However, the problems of applying such technology to smallholder irrigation are less well covered.

This paper presents the primary sociological, economic and technical factors influencing the design and operation of smallholder irrigation in South Asia. The main emphasis is placed on problems. The aim is to define the problems, without

necessarily acknowledging any obligation to present solutions. Rather, the available options are described and possible direction of further development are suggested. Practical experience and illustrations, primarily from India, are presented.

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Design and Operation of Smallholder Irrigation in South Asia (WB, 1995, 134 p.)

Chapter 1 - Introduction

Most of the problems of smallholder irrigation involve not only technology but also sociological and economic factors. It is particularly unfortunate that practitioners in these specialties generally have a communication problem, even within the same agency. The answer to the frequently expressed plea for a more multi-disciplinary approach (usually aimed at irrigation engineers) is a better understanding by each specialty of the constraints which the others face in this area. The irrigation engineer needs to be familiar with the basic socio-economic problems of smallholder development, and the agro-economist and sociologist

need to be better acquainted with the technical constraints on water distribution in circumstances of varying supply and demand.

In the following pages the principal factors entering into the design and operation of smallholder irrigation are discussed, with main emphasis on problems. Where the subject is contentious, which is often the case in this field, issues and options are presented. The targeted audience includes those working in the areas of irrigation engineering, agricultural economics, sociology, and development planning. As is appropriate to such a range of interest, the degree of technical detail has been kept to a minimum, with references added for those who wish further reading on particular subjects.

The aim is to define the problems, without necessarily acknowledging any obligation to present solutions. As yet, there are no entirely satisfactory solutions to many of the problems of smallholder irrigation. However, the available expedients are described, and the possible direction of further development is suggested.

The text draws upon two decades of experience in project development in South Asia, notably in India, in the service of international organizations. It is emphasized that the comments and opinions expressed are those of the author, and do not reflect the policies of any particular institution.

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Design and Operation of Smallholder Irrigation in South Asia (WB, 1995, 134 p.)

Chapter 2 - Profile of the smallholder

Fractionation and consolidation of the smallholding

The area under discussion embraces India with its neighbors Bangladesh, Pakistan, Nepal and Sri Lanka, and further afield Burma and Thailand. There is wide diversity in the character of the smallholder and the structure of the village society within these areas. But with the possible exception of Burma, there is a strong tradition of individual land ownership. This free-holder situation is largely preserved when the land comes under irrigation, a factor which greatly influences and in some respects complicates the design and operation of irrigation systems. It distinguishes the region from those countries with more authoritarian tradition, where land rights are either vested in the community or at least are subject to

government intervention in matters of supply from public irrigation systems.

The factors influencing irrigation design are partly to do with the cultivator himself, and partly with the size of his holding and the extent to which it is subdivided (fractionated). The half hectare holding of a typical farmer may be divided between six much smaller parcels scattered over a wide area. There is, incidentally, considerable confusion in the use of the word "holding" in statistics of land distribution. The term may be used for an individual parcel, or for the total land owned by a cultivator without regard to parcelization, or for an "operational" holding which can include a number of holdings farmed as a family unit.

Inheritance is of course responsible for the diminishing size of holdings. It is also responsible for the strange shape of some holdings. To illustrate, a farmer may have one hectare in a single unit 40 m in width by 250 m in length. He has four sons who inherit equally, but instead of each receiving an area 40 m by 62.5 m, each receives a strip 10 m wide by 250 m in length, the reason being that the original holding runs down-slope with very shallow infertile soils at the upper end and deep valley-bottom lands at the lower. Equity demands that land productivity be divided between the four sons, although the narrow shape of each parcel received presents problems in cultivation and particularly in irrigation distribution. In the same connection, the reason for parcels originally being acquired in scattered locations rather than contiguously is frequently to include a proportion of different soil types in the family holding, for instance lowlands for paddy cultivation and uplands for other crops. On inheritance the same mix may be preserved, even when it involves division of the separate areas into very small parcels.

Construction of an irrigation distribution and drainage system at the farm level, land shaping for irrigation and provision of formal farm access would be facilitated by land consolidation (consolidation of parcels), or at least by realignment or "rationalization" of property boundaries. However, in the area under discussion, such action is the exception rather than the rule, due largely to farmer resistance. A farmer whose family has toiled for generations to convert a stony shallow field into a reasonably deep fertile soil is not interested in exchanging it for a neighbor's less-improved land in the interests of land consolidation. Other objections include the concern of a large landowner whose title to some of his fields is on somewhat shaky ground and would not stand the scrutiny of consolidation as in West Bengal, and the conviction of the small landowner that he would be cheated by "government" in the same process. Some of the objections are removed in areas of deep homogeneous soils, and consolidation has been successfully carried out in the past in such areas, or is currently being carried out, in some cases with detailed attention to equity. However, attempts to impose land consolidation in areas of diverse soil types and irregular topography as a prerequisite to irrigation, have generally not been successful in the area under discussion, nor have attempts to pool holdings into a communal farming operation. In general, irrigation has to be built around the existing property boundaries. An exception may occur where land redistribution is being carried out in parallel with development of an irrigation area, in which case lands "surplus" to the legal maximum size of holding become available for distribution, and may be divided rationally in that process.

To summarize, consolidation of fragmented smallholdings or realignment of boundaries considerably facilitates the design of water distribution to the farm (the tertiary level). However, where circumstances lead to profound reluctance on

the part of smallholders to participate in such a process, experience has been that there is nothing to be gained by endeavoring to press it.

Smallholder attitude toward farmer-owned and government systems

The character of the individual smallholder in matters affecting irrigation and the nature of the village social structure are too diverse to allow anything but a few general observations. It should be noted that the term "village" as used here denotes an area which includes a group of dwellings (a village in the more popular sense) together with an associated area of farming lands. It is a political and social entity. The operation of a village irrigation system, owned and operated by the community, is often taken as the reference point on which to base the design of water-user groups in larger publicly-owned projects. The popular opinion that farmer-owned village irrigation systems operate very well and publicly-owned systems operate very poorly is not always supported by the evidence, but the history of the village system does give an indication as to what a smallholder and his peers will or will not do if left to their own. At one end of the scale of performance the village systems do very well, using much ingenuity in coping with very variable seasonal supply of water, and producing a wide diversity of crops within a small area. Communal interest is put before the interest of the individual. Such performance requires a close social structure or a long tradition of authoritarian village leadership. At the other end of the scale, particularly where the traditional village authority has broken down under the influence of changing times, performance can be very poor.

In publicly-owned irrigation systems the farmer viewpoint changes radically. The interest of the individual and his family becomes the primary concern, and the

interest of the group becomes secondary. Much attention has been given to the merits of delivery from a publicly-managed system to a farmer-managed unit, such as the service area (the "command") of a secondary or tertiary canal. The issue is whether an area managed by beneficiary cultivators, but supplied from a public canal, will be regarded by the cultivators as their own and treated with the same respect. Although management of water distribution within the tertiary command, and eventually the secondary, by water user groups is highly desirable, in fact cultivators are not generally convinced that the system within such an area is fully their own and should therefore be treated in the same manner as a village system. For one thing the supply of water to the area remains outside of their control (unless cultivator management is extended upstream to the primary canal, which may or may not be practical). There are notable exceptions, but in general if government is in any way a partner in the irrigation of an area, cultivators appear to believe that government should assume all responsibility down to the farm turnout. A similar problem is encountered if any outside assistance, other than simply funds, is provided for the improvement of village systems. The problem of cultivator attitude to any intervention by government, and his readiness to drop responsibility for maintenance in the lap of government as soon as there is any such intervention, must be acknowledged and lived with, even if not fully understood or appreciated. Means of overcoming this attitude are still being sought.

Cultivator willingness to undertake more intensive cultivation

The small cultivator is, by and large, a hard worker, as evidenced by the typical scene of villagers setting out at dawn in single file for the fields, and returning only at dusk, or the farmer with his oxen puddling the paddy field in the torrential

monsoon downpour while his wife drenched in rain and knee-deep in mud stoops in a nearby plot transplanting. And yet there are limits to what a cultivator can be expected to do, or is willing to do, limits which are not always acknowledged in project design or analysis. Anticipations regarding rate of up-take of irrigation, and projections of change to double or triple cropping made possible by the advent of water, are frequently not met in reality. The small cultivator, in general, is not yet fully trapped into the consumer economy. The idea of working in the extremely arduous conditions of the hot weather months, because supply from a tubewell would make a profitable crop in that season possible, may not be appealing. His simple needs can be met without such labor. Even changing to double cropping may be unattractive, at least to the male members of a certain "tribal" village whose ambitions are limited to growing sufficient wet-season rice to ensure a supply of paddy-wine for the remainder of the year. This is an exception of course, and offset by the example of the Punjabi farmer, willing and physically able to work in all seasons, and whose ambitions extend progressively to motor-cycle, tractor, truck, and eventually a car repair shop and haulage business. The conclusion is that assumptions made during design, in pursuit of a favorable economic rate of return, should take into account the character of the particular cultivator who will be party to the project. Aside from attitude to labor, there may be constraints imposed by caste or custom on the type of agriculture which will be undertaken. For instance, raising of sheep or goats or other livestock (other than cows or water-buffaloes) is not acceptable to most cultivators in the Indian sub-continent, and is left to particular castes. Fish culture (in ponds), which can be very profitable, is unlikely to be an attractive occupation to some, and would be positively ruled out to others, except with hired labor of another caste.

Smallholder attitude toward credit

A factor of particular importance in the development of an irrigation area is the need for credit and the attitude of the cultivator to its use. Short-term credit is required for crop production (fertilizer, seeds, cultivation), and long-term credit for farm improvement (land shaping for irrigation, sinking of wells etc). The problem is the reluctance of most cultivators to use other than minimum amounts of credit (except for marriages), resulting in a much slower rate of buildup of production from an area than is economically desirable from the institutional viewpoint, when the capital cost of the irrigation infrastructure is taken into account. In spite of the fact that he would probably be better off financially to use credit to the maximum a farmer generally prefers to go slowly, employing his own resources of family labor and animal-power for land shaping, and using much less fertilizer than optimum, until eventually his cash position permits more intensive production. His reluctance to borrow is understandable, as the amount of money involved, judged by the standards of a cultivator accustomed to subsistence-level rainfed agriculture, is very large, and borrowing for agricultural purposes is not without risk. Crops may fail or market prices may fall. -A Collector (senior Indian administrative officer) recounts his experience in trying to better the lot of landless laborers living in squalid road-side shelters. He arranged the grant of small plots where each man could build a simple dwelling for his family. The men were profuse in their thanks, but a year later the Collector found that few had done anything about actually constructing a dwelling. On questioning one explained that he had no money to buy materials. "Then come with me to the bank and I will see that you get credit to buy bricks." But sir, how will I repay the loan? I barely earn enough to feed my family." Then we will ask for credit also to buy a buffalo, and its milk will pay for both loans." But sir, if the buffalo should die?"

The man was content to remain in his roadside shelter, warmed by the thought that he owned a little plot, something his son could inherit, and he wasn't about to put it at risk by borrowing against it.

Where cultivators are urged to borrow, particularly for land development (compulsion has been attempted in some areas), there is often no intention to repay. The loan becomes virtually a subsidy, and the bank obliged (by government edict) to issue such loans may become a casualty. The question of credit is clearly a subject on which the inclination of the cultivator may run counter to the plans of the development agency. In project planning, while stressing the need to provide ready access to credit in a developing area, a conservative view should be taken in projecting actual demand for credit.

The issue becomes more pointed if there is the intention to finance certain government constructed items such as water courses or deep tubewells through credit obligations issued against cultivators. The problem is the unwilling cultivator. Many irrigators given the choice between continuing with a service provided by government (usually at highly subsidized rates), and cultivator ownership and operation of the facility, will choose the former. Pride of ownership is likely to be secondary to cash considerations, and the cultivator may in any case be unwilling to be committed to the substantial debt obligation involved. The expedient of setting up an autonomous agency which borrows for the purpose of financing the departmental construction of the facility (for instance water courses), and in turn endeavors to recover the cost from the cultivators has been tried, as a means of avoiding the problem of farmer reluctance to incur debt. However, in most case arrears in recovery from farmers have rapidly put the autonomous agency in an untenable financial situation. This does not appear to be

the general solution. In plans for "privatization" of facilities (transfer of ownership to cultivators) which are increasingly being pressed by development institutions, the problems of cultivator aversion to debt and very poor repayment record will be key considerations.

Theft and vandalism of control structures

In the efforts of development institutions to improve the efficiency and productivity of smallholder irrigation, possibly the most frustrating experience is the very common occurrence of theft and vandalism of facilities, frequently by the cultivators themselves. Where the structure concerned imposes some constraint on the individual or local group, such as a gate at the entrance to a water-course, interference with the structure is understandable even if it is clear that increasing the diversion at that point will diminish the supply to others further downstream. If the supply channel can in anyway be regarded as a "government" channel, conscience is apparently clear (if conscience is a factor). Considerable ingenuity can be exercised by the cultivators in such operations, for instance herding water-buffaloes into a distributary canal, as a portable dam, causing the upstream level to rise and break through, with major flow into a nearby drainage channel from which water flows to the fields of the perpetrators. On removal of the buffaloes flow through the breach continues, but no evidence remains that the hand of man was involved. Theft of items which are either saleable or of use on the farm or in the home is also very common. Saleable items include anything of copper, aluminum or brass including transmission lines or motor windings in tubewell areas, and brass hardware on gate structures. Theft of transmission lines is probably by professionals, not by cultivators, but theft of concrete or stone slabs from channel linings comes nearer to home. The fact that their theft causes much

increased seepage loss from the channels serving the same cultivators is not apparently a sufficient deterrent.

More difficult to understand is simple vandalism, in which there is no illicit benefit other than the dubious pleasure of simple destruction. For instance the cattle-herder whiling away the time in the hot sun, sitting on the side of a brickwork irrigation flume and quietly hammering away at it with a heavy stone. The solution was a basalt coping, proof against such demolition, but costly.

There are situations in which cultivator interference with irrigation facilities is prompted by their incorrect design or location, such as the inappropriate location of an outlet to a watercourse. The solution in such cases is simply better design, and consultation with cultivators in the first place. In other situations the problem stems from factors outside the control of the designer. For instance a poor monsoon may result in drastic curtailment of supply to an irrigation scheme, and restriction of deliveries. "Less than farmer expectations" is the phrase often used in excusing illegal diversions in such circumstances. However, farmers living in the areas concerned are well aware of the occurrence of good and bad water years. Simply advising them of the likelihood of need to curtail deliveries in some years and the means of sharing the deficiency is unlikely to avoid illegal operation and conflict in such circumstances. A standing crop about to fail for lack of water, the crop which was to be the sole means of sustenance for the family for the next year, is a powerful incentive to steal water from a nearby canal.

The problems discussed are of much lesser occurrence in purely farmer-owned schemes, as the villagers police their own systems. Furthermore they are generally small in area and being close to habitations are subject to informal

surveillance by all concerned. However, it is clearly impractical to treat every major irrigation scheme as fully farmer owned and operated, and it is the large schemes with substantial storage reservoirs which supply the major part of canal irrigation in adverse water years. Operation of tertiary canals of major public systems by wateruser groups may reduce the problems of interference with irrigation facilities, but as already discussed such an arrangement does not carry full conviction of farmer-ownership.

Tampering with structures and illegal diversions result in reduced supply to the unfortunate downstream tailenders. There are exceptions of course, witness the bearded turbaned Sardarji, draped with cartridge belts, sword, shotgun and pistol. The terrified villagers pointed him out as the principal tailender. Did he have problems? He apparently thought it was a silly question. His reply, waving imperiously to the sky "When a man is thirsty, he drinks." Obviously this is not a universal solution to the tailend problem.

There is room for much further sociological study of cultivator motivations and means of reducing the incidence of interference with irrigation facilities and theft. The small cultivator, popularly cast in the role of victim of irrigation problems, is often the villain. With few new sources of irrigation available, further increases in food production will be contingent on increasing the currently very low efficiency of most existing irrigation systems. This will involve introducing improved technology, however simple, and better management. Success in both areas is at present very limited, largely due to cultivator problems. In the present situation a key factor in the design of improved irrigation facilities has to be their resistance to interference and damage. This obviously puts a limit on the level of technology which can be introduced.

Design and Operation of Smallholder Irrigation in South Asia (WB, 1995, 134 p.)

Chapter 3 - Land shaping and water distribution at the field level

Land shaping by the cultivator vs. institutionally

Shaping of land to receive irrigation can either be a minor operation, as where fields are already leveled and bunded for rainfed paddy, or a major operation, where topography is irregular or sloping and where there has been no prior land preparation. The form of initial land shaping depends to some extent on who is to carry out the work, the cultivator himself, or a contractor or other agency. The principal concern of a cultivator, with only his animal-drawn cultivation equipment, is the volume of earth to be moved. His capacity is very limited, and he

may find it necessary to extend land shaping over several years, beginning either with very small bunded basins or graded furrows and progressively improving the system year by year. In the initial years, efficiency of water distribution at the field, and labor requirements for irrigation are likely to be secondary considerations to the cultivator.

On the other hand, land shaping with mechanical equipment usually aims at bringing fields to their final gross shape in a single operation. Hence longer-term factors such as irrigation efficiency, labor required for water management, volume of earth to be moved, convenience of shape and size of field for cultivation, and cost are taken into account in designing the field shaping system.

Consolidation of holdings provides larger units for land shaping and facilitates the use of mechanical equipment for the operation. However, as noted earlier, with smallholdings land consolidation is the exception rather then the rule in areas of irregular topography, and unless landowners agree otherwise land shaping must be carried out within the boundaries of the holding, more specifically of the parcel. This commonly limits the type of equipment which can be used. A further key factor in the design of land shaping, particularly with mechanical equipment, is the depth of topsoil and the nature of the material underlying it. For example, in contour terracing along a 3% side-slope with 15 cm of top-soil underlain by granular material, a 20 m wide terrace, even with balanced cut and fill, would require 30 cm depth of cut. This would already be 15 cm into the infertile subsoil at the upper boundary of the terrace. Even a 10 m wide terrace would still involve a cut extending down to the top of the subsoil. In the usual case of rolling topography the situation is aggravated by increased depth of cut when rounding each spur. The problem can be remedied, nominally, by stripping and stockpiling

the top-soil before shaping, and subsequently re-spreading, but this is a costly operation and is seldom practiced. Part of the problem of land shaping in shallow soils with heavy equipment lies with the equipment operator himself In a situation which may call for a delicate touch, the approach of a dozer operator is usually more heavy-handed, favoring deeper cut and "full-blade". In a soil situation similar to that described an elderly farmer stood despairing as he watched a machine terracing across his holding, cutting down through the fragile layer of topsoil into the sterile material beneath. The farmer had spent years working up his land into small bunded plots, carefully building up fertility. He had subsequently become a reluctant beneficiary of a communal land development project.

As in all matters to do with irrigation, there are arguments on both sides of the question. There are circumstances in which use of mechanical equipment in land shaping of small holdings is desirable, particularly where the difficulty of the work or the size of the holding puts it beyond the capacity of the cultivator. Clearing of forested lands for conversion to irrigated agriculture is an example. At least initial rough terracing and stumping may best be carried out mechanically. Also where holdings are five to ten hectares in area, rather than the more usual two or three, there is a case for use of mechanical equipment for land shaping on the grounds that only by such means can a project area be brought to full production in reasonable time.

However, there may be other constraints. Consider the case of a project area in gently rolling topography with deep soils. Under the sparse rainfall of the area a holding of six to eight hectares permitted only subsistence-level agriculture. The cultivators were land rich but cashpoor. With the prospect of canal irrigation, a

farmer was faced with two problems, the cost of land shaping to receive water and the cost of cultivation and other inputs needed to bring his holding into full irrigated production. Both would involve amounts well beyond his limited experience. Credit could be provided for mechanized land shaping, but the risk of default would be considerable in view of the limited likely returns from the initial years of operation. Credit could also be provided for cultivation, fertilizers, seeds, etc. But such credit has to be repaid each season or it is not renewed for the next. For the farmer, default is not a practical solution for crop credit.

The alternative course available to the cultivator is the minimum input approach. He prepares only a portion of his holding to receive water in the first year of irrigation. It is, in any case, as much as he can cultivate and plant with his limited initial resources. Each succeeding year as his resources increase, he extends the area under irrigation possibly engaging a small local contractor with farm tractor and blade for limited land shaping and cultivation. Eventually he graduates from subsistence agriculture, becoming the substantial proprietor of eight hectares of land fully under irrigated crops.

This is not a particularly satisfying alternative from the viewpoint of project economics, but it may well be the course chosen by the cultivator. The form of assistance most needed by the cultivator in this latter case, in addition to a limited amount of credit, is agricultural extension relating to irrigated crops and advice on progressive land shaping and water distribution. The last two subjects unfortunately fall in a gray zone between irrigation engineering and agricultural extension, and competent advice has not generally been available to the cultivator in these areas in the past.

As implied in the above discussion there is little advantage in carrying land shaping ahead of the capability of the farmer to put the area fully under irrigation. There are situations in which it is, in fact, very undesirable to do so. An example is in dune sand areas, as in the Rajasthan desert. The area has relatively level interdunal flats, winding between generally low dunes. The size of holding is 6 has. Eventually most of the area of each holding will be under irrigated crops (dune sands can be surprisingly fertile). However, there is an interim problem of wind-blown sand and dune formation. In areas leveled but left fallow dunes can re-form overnight, in a single sandstorm. It is essential to keep an area under irrigated crop (or crop residue) if dune formation is to be avoided. As most of the incoming cultivators (settlers) had few resources and little experience it proved desirable to limit initial land-shaping to that portion of the holding (usually the interdunal areas) which the cultivator could keep under cultivation and to extend land shaping and area under cultivation in successive years. Large scale mechanized land shaping operations originally planned for this area were subsequently dropped.

Land shaping and water management in smallholder irrigation

The form of land shaping for irrigation in smallholder agriculture generally differs from that in large scale cultivation. Where wetland paddy is grown, the bunded, level field is used in either case, the only difference being in size of field or plot. In large scale cultivation convenience in use of mechanical equipment for cultivation and harvesting is an important factor, influencing minimum size and shape of field. In most smallholder situations, however, cultivation is either by animal-drawn equipment or small single-axle cultivator. In either case size, or shape of plot is not an item of priority. Initially, plots can be very small, being progressively

combined year by year, for example in the case of hill-slopes eventually becoming graded terraces each consisting of a series of plots stepped around the contour. Where multiple-cropping is to be practiced, alternating wet-land paddy with non-paddy crops, the bunded level plot is again the unit. Where wetland paddy is not to be grown, however, there are several options in land shaping. It has been the practice in Western countries to use either sprinkler or gravity irrigation using long graded furrows or graded strips. Hence, much attention has been given in the literature to appropriate rates of inflow versus slope of the graded furrow or strip and soil infiltration rates. Recently there has been some return to large level fields with gravity application, in view of the increasing cost of energy for sprinkler operation. A feature of large scale gravity irrigation has been the use of laser beam guided equipment for generating graded or level fields with high precision.

The situation of the smallholder is substantially different. The smallholder does not have available the means to grade a sloping field precisely, or if presented with such a field he does not have the means of maintaining it in that condition. Where land shaping involves varying depths of cut and fill, there is inevitably differential settlement on subsequent irrigation. Even precisely-graded fields require subsequent correction. The smallholder can, however, form and maintain a level field, as distinct from a graded field, because ponding of water rapidly demonstrates whether or not the field is level and the areas where correction is required. Further, the smallholder is not as concerned with labor cost for water application as is the large scale Western farmer, and the long uniformly graded field is not as attractive to him on that count, even if the irregular geometry of his holding permitted such an arrangement. Finally, in some clayey soils encountered in tropical climates, the infiltration rate varies widely with moisture content. The soils may be self-mulching, shrinkage cracking forming small pea-size units

resulting in a crumbly structure of high infiltration rate when dry, rapidly changing to a low infiltration rate when expansion occurs on re-wetting. This situation would call for considerable judgement in irrigating a long graded strip.

In fact, the majority of smallholder irrigation, whether in paddy areas or not, is by level basin, or by strips or furrows within a basin. If presented with a naturally-occurring or man-made graded slope, the small farmer will usually convert it, for water-management purposes, into a stepped series of small level basins, or level furrows extending at right angles to the basic slope, supplied by a down-slope field channel with earthen checks. The basins may be permanent, or if the grade is small, they may be formed, after cultivation, each season by temporary ridges or bunds. The arrangement allows full control of water application, but requires constant attendance during irrigation, as the basins are small and the irrigation stream has to be changed frequently from one to another. Clearly, this is a disadvantage as farmers have an aversion to night irrigation.

Where the grade is slight and can be maintained uniform, the alternative of down-slope furrows each served by a siphon-tube supplied from a contour field channel would appear to be attractive, but is not widely practiced in the South Asia.

A particular soil condition encountered in some areas facilitates irrigation by down-slope furrows, even with non-uniform grade. The top-soil with moderate to high infiltration rate is underlain at shallow depth by a relatively low infiltration rate sub-soil (a lateritic sub-structure in one particular case). In such soil the intake of water during irrigation is self-limiting. After the top-soil profile is saturated there is little further infiltration, making water management relatively simple. However, even in this situation the cultivators preferred to use small

basins stepped down the slope. A soil condition in which basin, or furrow-in-a-basin, irrigation is mandatory is in some very low infiltration rate clay soils, where water must be left ponded for hours to ensure sufficient intake. In contrast are dune sands with very high sustained infiltration rates. These are very effectively handled with high water-application efficiency in north-western India, by dividing a level basin (50 m x 50 m) into 2 m wide strips by temporary ridges. Each strip takes the full flow of around 2 ft^3/sec for a period of minutes only, producing a uniform depth of impondment before appreciable infiltration has occurred. A plastic sheet is placed temporarily where the discharge from the field channel enters the strip, to prevent erosion at that point.

An important question in the operation of irrigation systems under conditions of limited availability of water is the minimum practical amount which can be applied in a single irrigation. As discussed below, some crops respond very well to "sub-optimal" irrigation, ea. mustard, pulses, or millets. In a water scarce situation, the economic amount of water per irrigation may be considerably less than the conventionally estimated demand. While the equivalent of 10 cm depth is often considered to be the minimum which can be applied with reasonable assurance of uniformity, application of half that amount may be desirable on grounds of special plant needs. The custom of referring to the irrigation of non-paddy crops as the application of the equivalent of a uniform depth of water is, in fact, inappropriate. Many such crops are row crops and only the furrows receive water. The "equivalent" of 5 cm, or less, is regularly being applied by experienced cultivators either via furrows, corrugations, or using a micro-distribution within the field. Such limited water application, however, requires precision in landshaping and a fine filth in cultivation.

Land shaping as a project component

Precision in land shaping is a prerequisite to efficient irrigation, from the viewpoints of both application of water to and drainage of water from the field. The quality of land preparation actually encountered varies from excellent to very poor. In formulation of new projects in smallholder areas not already levelled and bunded for rainfed paddy, land shaping in the past has frequently been made a project component, usually involving communal mechanized operations, via credit. However, because of the poor repayment record this practice has largely been discontinued with some exceptions, and land preparation is left to the cultivator's initiative. The missing element in this situation is technical assistance to the cultivator in the design and layout of his progressive land shaping operation.

Improvement in land shaping in areas already under irrigation but where land shaping is notably deficient, would nominally be a desirable subject for the attention of development agencies. However, the assistance actually needed is again the provision of field-level technical staff rather than funding (other than to credit institutions). As back-up to such land development extension efforts, provision of audio-visual demonstration and training material, and the development and demonstration of improved animal-drawn or farm tractor drawn land shaping equipment could be effective areas of assistance.

Home"" """""> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Design and Operation of Smallholder Irrigation in South Asia (WB, 1995, 134 p.)

Chapter 4 - Water supply and demand

Degree of storage regulation

The region under discussion is monsoonal, with river-flows characterized by highly variable seasonal and annual discharge. Storage reservoirs can be provided in some cases where topographic and ecological considerations permit. In general storage capacity can provide partial regulation only, and the project must accommodate to such limited control of flow, or to completely unregulated flows in the absence of any reservoir.

The highly variable nature of monsoon precipitation makes for considerable difficulty in both yield and flood hydrology. The onset of the monsoon, upon which so many agricultural operations depend, may vary by several weeks from year to year, and gaps of weeks duration may occur within the monsoon period. Much of

the monsoon precipitation is in the form of discrete, local rainstorms, often violent, rather than the popularly conceived uniform countrywide downpour. This pattern results in wide random variations in seasonal rainfall between adjacent areas (as much as 50% difference in a particular year, between locations as little as 25 km apart) and makes for considerable difficulty in a statistical approach to estimation of water yield, particularly for small catchments. The problem is aggravated by the limited number of rainfall and river-flow recording stations. While international agencies commonly call for at least five years of actual stream-flow records as a basis for the design of small projects, (much longer for major projects) in remote areas there are commonly none and extrapolation from similar catchments must be resorted to. In these circumstances expansion of the network of rainfall recording and stream gauging stations is a priority item. It is noted, however, that maintenance of calibration of stream gauging stations is no small task in rivers subject to heavy siltation and frequent changes of channel during flood-flows.

The impact of the widely varying pattern of monsoon precipitation on the life of the small cultivator is illustrated by two situations. In one, the monsoon had begun propitiously and then failed, and paddy stood wilting in the fields. It was ploughed in, an unusual event, and when the rains returned was replanted with yellowing spindly seedlings remaining from seed-beds. The monsoon then became violent, flooding and destroying the replanted crop. Cultivators in the area, in the path of monsoon storms moving from the Indian ocean to the Himalaya, commonly borrow ostensibly for purchase of fertilizer but actually for "pujas", religious ceremonies to placate the deity held to be responsible for such outrageous events.

In the other case, the young maize crop, newly sprouted from the red lateritic soil, stood wilting under the backdrop of heavy grey monsoon clouds, but it did not rain. And nearby, the Door of the village reservoir was cracked and dry. The monsoon had failed for two successive years. The next monsoon rains were nine months away.

The seasonal variations in monsoon rainfall can, of course, be studied statistically, and this must be done in project design, but the realities of the situation for the cultivator and his family must also be kept in view.

Given the large variability in water supply, the immediate problem is to take into consideration the uncertainty of water supply into the design of the project. To design for an assured level of supply would avoid certain operational problems, but would grossly underutilize the water available.

Much of the debate over the design and operation of surface irrigation systems centers around the question of how to handle the non-assured component of supply. One approach to limiting the variability of supply to be accommodated is to design the system for the "75% probable" year (or other degree of probability). Then statistically in three years out of four, the amount of water available equals or exceeds the amount for which the system is designed; only in the fourth year is there a deficit. A calendar of twelve months each which is "75% probable" may also be constructed, becoming the "design years". While this is a useful concept for purposes of establishing system capacity, it still leaves the question of how to operate the system in the deficit years, or months. This will be discussed in the next chapter.

If the system is to have storage, a question influencing design and operation is how the storage will be utilized, whether for seasonal regulation within a twelve-month period, or over-yearly. In the first case water stored in the wet season is used in the following dry season, possibly with some carry-over for pre-monsoonal irrigation (particularly puddling and transplanting of paddy) in the following year. In the second case, applicable only to major reservoirs, the storage cycle may extend over several years, partially evening out years with good and bad water supply.

Intensity of irrigation

Once the amount of water to be taken as seasonally available for design purposes is determined, the key question is then the area to be supplied. This involves consideration of cropping pattern, water requirements of individual crops, land availability, and the socioeconomic question of intensity of irrigation. The latter is the contentious item. Should the project be confined to an area all of which can be fully irrigated with the available water (intensive irrigation)? Or should the benefits of irrigation be spread more widely, supplying less than the full irrigation requirements to a larger area (extensive irrigation)? In the second case each cultivator can irrigate only part of his holding, or optionally he can supply all of it with less than the "optimum" quantity of water. The alternatives are described by the irrigated crop intensity (irrigation intensity). This is the percentage of the holding which is to be supplied with irrigation in a particular season, or annually if all seasons are totalled. The question of whether the figure is based upon application of the full "optimum" amount of water, or less than that (a common practice), is usually left unanswered. In some respects a more useful index of intensity of irrigation is simply the depth of water to be supplied, seasonally or

annually, calculated as if applied uniformly over the whole area of the holding. Use of this index avoids the question of what water requirements to assume in calculating irrigation intensities.

The relative merits of intensive vs. extensive irrigation system design are much debated. The intensive approach leads to a smaller area to be served by canals (the "command") and lower canal cost, also lower total cost of land development. The extensive approach is often imposed by social pressures. In fact some states decree an upper limit on the design irrigation intensity, on the grounds that any higher intensity would unfairly benefit those within the command at the expense of those excluded from it. The pressure to expand the area served may continue through the life of the project, with petitions to extend the canal system to peripheral areas, or to introduce or permit pumping from canals to higher areas not served by the original system. Extensive irrigation has certain advantages. By limiting the supply of water to less than apparent need, it imposes an incentive for prudent use of water. It may also permit on-farm rotation of irrigated crop benefiting productivity in light soils. Of particular importance, it encourages development of supplemental groundwater, where wells are technically possible. This in turn may benefit watertable control.

Extensive irrigation may well increase productivity per unit of water supplied. However, it may introduce operational problems, particularly in large projects. In a small system that is village owned and operated, decisions on water-management, including the use of stored water, are likely to be made by consensus of the cultivators. In a large public system the cultivator is aware only of the canal which serves him. He is not aware of project-wide supply problems, the "grand design" of the system. If he receives less water than his apparent

needs, he may endeavor to take it by whatever means are available. The subject of operation of supply systems in situations of water deficiency is discussed later. For present purposes, it is sufficient to underline the fact that supply of sufficient water to irrigate the whole command, in at least one season, is not automatically a design feature. It is a question to be decided in each case.

Crop water requirements and crop water response

Estimation of crop water needs, a basic factor in irrigation design, is by no means as straightforward as might be assumed. Actual water consumption (evapotranspiration), is influenced by climatic factors, including air temperature, humidity, radiation, cloud cover, and wind, and by the nature of the plant itself including its stage of growth. It is also influenced by the amount of moisture in the soil at the time (soil moisture tension). In the face of this number of factors, values for many of which are frequently not known, simplified approximate methods of estimation are commonly used. These employ a limited number of parameters, for instance air temperature and number of daylight hours only, or the measured evaporation from an open pan, as the basis for estimation. Alternatively, approximate estimations of values of climatic factors for which actual measured values are not available are inserted in more general formulae. "Plant factors", the water-consuming characteristics of each particular type of plant at each stage of growth, are based on field observations for which generally-accepted tabular data are available. There is, of course, a more direct method of water-use estimation, which measures water abstraction from a lysimeter containing soil and the growing plant. However, the difficulties of using the Iysimeter have limited its application to basic research.

Values of consumptive use obtained by the various methods of estimation vary widely. A comparison between actual measured water use and estimates made by eighteen different methods was given in the 19 74 report on Irrigation Water Requirements by the Irrigation and Drainage Division of the American Society of Civil Engineers. The investigation was related to alfalfa and grass crops, grown at ten stations in varying climate situations. The two most commonly used methods of estimation, Penman and Modified Blaney Criddle, gave results ranging from 14% low to 30% high (Penman), and 46% low to 35% high (Modified Blaney Criddle), compared with actual measurements. A.S.C.E has issued a further comprehensive report on the same subject (Jensen 1990).

A widely used reference for the estimation of crop water requirements is the Irrigation and Drainage Paper No. 24 (Revision of 1977) of the Food and Agriculture Organization of the U.N. (Doorenbos 1977). This covers the Penman, Blaney Criddle, Radiation, and Pan-evaporation methods of estimation and extends their applicability by calculating coefficients based on climatic factors not otherwise included in the estimation (particularly for the latter three methods, Penman is already comprehensive). However, estimates prepared by the four methods still differ substantially.

The estimates of consumptive use discussed above refer to "optimum" conditions, i.e. with unrestricted availability of water at plant roots or virtually zero soil moisture tension. These are the basic E to values. The customary use of the word "optimum" in this situation is misleading, in that such moisture conditions while possibly optimizing vegetative growth may not result in optimum economic use of water.

The effect of restricting the availability of soil moisture on plant growth is an important issue with respect to two questions. First, can less than "optimum" amounts of irrigation be used without significantly reducing crop yields, and second, how do the fluctuations in soil moisture tension between conventional periodic irrigations affect yields (Jensen 1990, Hillel 1987).

Research relevant to these two questions continues, but work to date indicates that any reduction in transpiration imposed by soil moisture stress automatically reduces the rate of vegetative growth in an approximately linear fashion, and as a corollary, cycling the soil moisture in the root zone from field capacity down to near wilt point, a basic feature of conventional irrigation practice, inevitably adversely affects yields.

However, the above conclusions must be treated with caution, in view of the results of extensive field station trials, which indicate that crop yields can be highly responsive to irrigation at critical stages of plant development, but that with-holding irrigation between such stages for periods of a month or more (with inevitable stress) has little effect on yields. This is notably true for certain crops and less so for others. Moreover, cycling of soil moisture in the root zone is an unavoidable feature of all irrigation systems (other than trickle or sprinkler), and the question of period between irrigations, which affects the range in soil moisture tension, has considerable implications on system design. More data is needed on the relationship between range of soil moisture tension between irrigations and crop yields.

Added to the level of uncertainty regarding crop water use is field efficiency, a factor involving considerable approximation. Consumptive use refers to water use

at the plant. Field efficiency is the ratio between the amount of water consumptively used by the crop and the amount applied at the outlet to the field. Factors contributing to field inefficiency are percolation beneath the reach of the plant root system, evaporation from areas not occupied by the crop, seepage from distribution furrows, spillage from the end of the field, and non-uniformity in distribution of water on the field (i.e. some areas receiving more than sufficient and some less). Some elements contributing to field inefficiency are not, in fact, a loss to the project. Seepage below the root zone may fill a necessary leaching function (unless this is provided seasonally by monsoon rains) or may be recovered by groundwater development. Spill from the end of the field may be used elsewhere in the system. However, these elements contribute to the amount of water which must be applied at the field boundary.

Values of field efficiency are simply judgement figures. They may vary from an upper limit of some 80% to a more generally applicable range of 70-75%, and be much lower in less inadequately managed systems. One procedure which largely avoids the need for separate estimation of field efficiency is to base the estimation of crop water needs on field station data on irrigation requirements at the field boundary (which includes field inefficiency). Such data usually gives crop production under a range of seasonal water applications and irrigation schedules, in particular relating time of watering to stage of plant growth.

Thus, estimation of crop water requirements by conventional formulae inevitably involves considerable approximation. Estimates using different, but well accepted, formulae are likely to differ by 25% or more. Calculation of basic Eto figures for consumptive use under "optimum" soil moisture conditions is a necessary step, as a point of reference. However, for actual project design the use of agricultural

field station data is preferable, if such data is available. If it is necessary to extrapolate, the ratio of Eto values for that station and for the project area can be used.

Because of the differences likely to be obtained in consumptive use estimates using different but reputable approaches, it is most desirable that agreement be reached in this respect between the agencies concerned with formulation and appraisal of a particular project. It is preferable to avoid a situation in which a government agency, or a consultant, carries out detailed designs and prepares cost estimates for a project, only to find at appraisal that the prospective financing organization disagrees with the basic assumptions regarding water requirements.

Effective rainfall

In a monsoonal environment rainfall can provide a major part of crop water requirements in the wet season, and a much lesser part, or none at all, in the dry season. However, not all rainfall can be utilized by the crop. During periods of heavy precipitation much is lost from the field by run-off and during very light showers most rain is intercepted by leaves and reevaporated without ever reaching the ground. Bunding of fields provides temporary pondage of heavy rain, although where crops other than paddy are being grown impondment has to be limited. On the other hand, where paddy is being grown, the bunded plot is likely to have standing water prior to the rainstorm, which limits its capacity for further storage. The soil moisture situation prior to a rainstorm also influences the extent of retention of rainfall, for instance pre-monsoon or early monsoon rain on dry soil may be fully retained, while later in the season it would not be.

Procedures for estimation of the "effectiveness" of rainfall are set out in the paper previously referred to (Doorenbos 1977). However, operational factors make it desirable to view each project separately. Also to be considered are the operational implications of unusual deficiencies in rainfall at particular times, for instance late arrival of the monsoon or rainless periods in mid monsoon. Hold-over storage may be included in the design of the project operation as insurance against delayed rains. Aside from the amount of storage to be reserved for this purpose, irrigation distribution system capacity may be determined by its function during such times of rainfall deficiency. Simulation ("paper operation") of the system, under various historic or postulated rainfall conditions, is the only satisfactory means of testing the system under these circumstances.

The particular case of water requirements for paddy

Rice is the most important single crop in the region under discussion. It is the only food crop which can be grown under conditions of continuous inundation of the root-zone, a feature which makes it uniquely suited to wet-tropic monsoonal cultivation. However yields are also responsive to sunshine, and are inhibited by cloud cover. Hence, highest yields are obtained in lower rainfall areas under irrigation as in the Punjab.

Rice is conventionally grown under conditions of inundation, when it is referred to as paddy (the term is also used for the bunded plot in which rice is grown) or as wet-land or low-land rice. It can also be grown without inundation, soil-moisture being held at near field capacity, in which case it is generally referred to as upland rice. It is basically the same plant in either case, although preferred varieties for the two situations may differ. Between the two limits, of continuous inundation on

the one hand and upland cultivation on the other, lies a wide range of conditions under which rice can be successfully grown and which have a considerable bearing on water requirements.

For wet-land paddy, water is required for cultivation and puddling, and to compensate for seepage and to meet evapotranspiration. Cultivation (initial plowing) may be carried out in dry conditions, but in view of the limited capacity of the draft animals employed prior softening of the soil either by irrigation or by pre-monsoon showers is desirable. Subsequent puddling serves to convert the soil into a fine saturated slurry suitable for transplanting. It also provides weed control, and reduces seepage rate.

With regard to estimation of water requirements for cultivation and puddling, there are two widely different approaches. In traditional wet-tropic areas cultivation and puddling of a plot may extend over a period of a month or more. Emphasis is laid on the merits of allowing time for rotting of the ploughed-in stubble of the previous year's crop, under saturated conditions, before completion of puddling and transplanting the new crop in order to conserve nutrients. In contrast, there are extensive areas where water requirements and time are critical, where cultivation, puddling, and transplanting of an individual plot all occur within a period of twenty-four hours. The difference in water requirements between the two procedures is, of course, substantial (300 to 400 mm compared with 150 mm). It is noted, however, that even where puddling and transplanting in each plot is carried out in short order the operation is likely to be in progress in a large command over a period of several weeks due to limitations in availability of labor, draft animals, and cultivation equipment.

The capacity required of main and distributary canals during puddling in an area predominantly under paddy in the wet season is influenced both by the amount of water used per unit of area (the procedure employed on the individual plot), by the amount of time during which this operation is in progress in the command as a whole, and by the contribution of rainfall during the period. It should be noted that a plot puddled and transplanted early is likely to have little assistance from rainfall during the process, while a plot prepared later may benefit from already being saturated from prior rains. Consequently, averaging water requirements over the whole command is not entirely appropriate to determine the rate of supply required (the "water duty") for an individual sub-area. In this regard, the practice in some small village schemes is to make cultivation, puddling, and transplanting a communal or social event, with the whole population of the village concentrating its labors in one local area at a time, with virtually the entire flow of the main canal temporarily directed into that area. The water duty required at the tertiary or minor canal level in this situation is much higher than at the project-wide level.

Seepage is likely to be a substantial part of water requirements for the standing paddy crop. Rate of seepage is influenced not only by the character of the soil and the extent of puddling (collectively determining its permeability), but also by external factors including topography and watertable depth. On terraced slopes, seepage in upper paddies is likely to be entirely controlled by soil conditions. In the lower paddies, however, it will be influenced by seepage from up-slope areas and may be negative, presenting a drainage problem. In large areas of near-flat terrain, soil conditions will be the controlling factor early in the monsoon, but the watertable is likely to rise to the surface and limit seepage later in the season. An extreme case is provided by a near-flat area of highly permeable sand in a riverine

delta. Heavy monsoon rains rapidly raise the watertable by several feet to the surface and the rate of infiltration becomes virtually nil. A late season crop of paddy is successfully cultivated.

The problem is how to estimate seepage rates for the purpose of project design. Generalized figures based on soil texture may be a useful guide for low permeability soils, but not for more pervious material, where external factors may control. The results of standard field tests (ring infiltrometer) can be entirely misleading for the latter reason. Seepage rates determined from a bunded plot several square meters in area are more relevant, although not necessarily reflecting the effects of repeated puddling, nor of seasonal rise in watertable. Better still are observations from a plot which has been under rainfed paddy cultivation for some time, in the same area, if such is available. It is noted in this connection that much nominally rainfed paddy in fact benefits from run-off (small drainage or surface flow) from adjacent uncultivated slopes. It is "semiirrigated". This fact has a bearing on the relevance of published statistical data comparing irrigated and "un-irrigated" yields (also on comparative projections of "with project" and "without project" crop production).

The above discussion refers to paddy cultivation by transplanting, which is the most common method in the South Asian area. However, paddy may also be direct seeded. This is the usual practice in Western countries, but is also being adopted in some areas of South Asia due to rising costs of labor for puddling and transplanting. Direct seeding also reduces water requirements in the initial stages of the crop, compared with the process of puddling and transplanting.

While the traditional procedure with wet-land paddy is to keep the crop

continuously flooded, this is not essential. Much research has been devoted to the question of by how much crop yields are reduced if paddies are drained at intervals, and how much water can be saved by doing so. The question is particularly relevant to the rotational supply of water to paddy, which may be operationally convenient in some situations. Periodic withdrawal of water does, in fact, have some advantages. It is desirable at the time of fertilizer application (to avoid loss of nutrients with Bow from the end of the field) and it promotes oxygenation of the root zone. Published data indicates that water use can be reduced by 15 to 20% compared with continuous flooding, without significant reduction in crop yield.

However, considerably less water is regularly being used by some cultivators (e.g. Nepalese Terai), with flooding of paddies at fortnightly intervals only, on relatively high infiltration rate soils. With local varietal selection, surprisingly good yields are being obtained with this practice, which is intermediate between wet-land and upland cultivation. It must be acknowledged, however, that the conventional procedure of puddling and transplanting followed by near continuous inundation exercises very effective weed-control. Any departure from that procedure may be at the price of other means of control, although the extent of this problem varies from severe to very modest, from one area to another. The subject of "sub-optimal" irrigation of paddy warrants further investigation.

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Design and Operation of Smallholder Irrigation in South

Design and Operation of Smallholder Irrigation in South Asia (WB, 1995, 134 p.)

Chapter 5 - Cropping patterns in irrigation design

The degree of control of selection of crops

Cropping patterns may, or may not, be dictated by government authority. Government policy may be to steer the selection of crops in a direction believed to be in the best public interest and the supply of project water may be made conditional on a cultivator accepting this direction. Alternatively, cultivators may be left free to follow their own inclinations and the forces of the market. However, even in the latter case there are likely to be unavoidable technical constraints on the supply of water, as few surface systems can be made entirely demand-responsive. A delivery schedule (down to the tertiary level) may be worked out to suit the supply situation and the water needs of the principal crops likely to be grown in the area. Cultivators are then left free to work out their individual cropping patterns around this pre-ordained schedule, deliveries within the tertiary

command being subject to any exchange arrangements which may be set up between neighbors. The primary delivery schedule may be varied seasonally, or from year to year, in accordance with the supply situation or the anticipated pattern of demand.

Restrictions may be placed on cultivation of particular crops, where there is special reason for doing so. For instance, the proportion of a holding under sugarcane may be limited by decree, to avoid waterlogging or salinization in an area with restricted internal drainage. In a situation more generally encountered, some portions of a command are suited (due to soils or other reasons) to irrigation of monsoon season crops, while others are better suited to dry season crops. One course is to divide the command into areas of the two categories, each with different irrigation delivery schedules. This virtually imposes a restriction on the class of crop which may be grown in each area. An alternative course is to leave the choice of crops to the cultivator, within limits as to total water requirements, and to work out a delivery schedule which meets the summation of these demands in each minor or distributary command from month to month. This is a more complicated arrangement operationally, and illustrates the generalization that the greater the degree of freedom left to the cultivator to choose his cropping pattern and delivery schedule, the greater the operational complexity of the delivery system (and the greater the likelihood of its break-down or mismanagement).

The problem discussed does not occur, to any extent, in areas of homogeneous soils and topography (such as the Gangetic and Indus Basins), but there are other areas in which the soil situation unavoidably ranges from shallow upland to heavy wet-land all within the small area of a minor canal command. A solution which

would largely avoid the problem and leave cultivators free to choose their cropping patterns and irrigation schedules is to provide pondages at the minor canal level. This would permit re-regulation between supply from the main canal system and demand within the minor canal command. Unfortunately, there are few sites for such pondages in which flow from the canal to the pond, and from the pond to the irrigated area, can both be by gravity over the full range of pond level. Low-lift pumping would be resorted to in Western systems, but is not yet generally acceptable in South Asia One situation in which gravity inflow/outflow pondage can be achieved is by supply from the primary canal system into existing village reservoirs, tanks, where these are available.

Cropping pattern design and project formulation

Within a few years of project completion actual cropping patterns usually differ considerably from the originally conceived pattern. Nevertheless the design of an irrigation system requires assumptions at least as to the class of crops to be grown in each season, and economic and financial analyses (farm budgets) require more specific assumptions, in short a "project" cropping pattern. In the case of farm budgets several alternative patterns may be explored, as an individual cultivator is unlikely to replicate the whole project-wide pattern.

Eventual departure from the "project" pattern (sometimes referred to appropriately as a "notional" pattern) can be due to a number of factors. These include a change in price structure, the advent of a new type of crop in the area, or simply a difference between the view of the cultivator and that of the designer, who is preoccupied with projecting an acceptable internal rate of return. The original pattern may also be the product of a balancing act by the designer,

between seasonal water supply and demand.

The departure from the design pattern may be as radical as a change from the conceived use of irrigation primarily for pre-monsoon and supplemental monsoon-season irrigation of paddy, to irrigation of hot weather ground-nuts, (an actual case). The advent of a surplus situation in rice in another area has emphasized the need for diversification and radically changed irrigation scheduling requirements. In a third case, in a classically wet tropic area with high population density and deficit in rice, the emancipation of family members from working in the paddy fields and the high cost of hired labor has made paddy financially unattractive. In spite of government edicts forbidding it, conversion of paddy areas to other crops is widespread, producing such odd rotations as bananas (twelve month variety) rotated with paddy, and irrigated coconuts "interplanted" in traditional paddy lands. Finally, in the initial years of operation of a major project when only a portion of the service area is served by canals, a condition which may extend over a decade or more, the available supply of water per unit of area in service may be considerably greater than under design conditions, permitting (in the view of the cultivator) a very different interim cropping pattern.

In some situations future changes in cropping pattern, particularly the introduction of small scale specialty crops, can be catered to by invoking on-farm groundwater development. However, this is not a universally available solution. More generally, it is expedient to examine any proposed canal system to determine how it could adjust to possible major changes in the demand pattern, and whether provisions could be built in which would facilitate meeting such future changes without complicating initial operation.

Design and Operation of Smallholder Irrigation in South Asia (WB, 1995, 134 p.)

Chapter 6 - Irrigability

Soil surveys and land classification

Soil surveys classify the physical and chemical characteristics of the soils of an area. Irrigability surveys (land classification) add a further dimension, i.e. the potential economic productivity of the lands of the area in question. Land classification came into vogue during the major campaign of irrigation development in the Western United States, carried out by the Bureau of Reclamation in the early 1900's. At one point Congress decided that in some cases public funds were being spent on bringing irrigation to lands which, for reasons of soil deficiency or other factors, could not provide a reasonable living to the irrigator nor an economic return on the capital expenditures involved. It was then decreed that future project proposals should include information on the economic irrigability of the lands concerned. The system of irrigability classification evolved by the Bureau at that time has remained a key feature of irrigation planning, and is still widely used. The term "land classification" was -employed, rather than "soil classification. as other factors aside from the type of soil (pedology) were involved, including the cost of bringing water to the particular lands concerned. Criteria for a number of factors including soil depth, infiltration rate etc. were established, also specifications for the field surveys. The soil surveyor who previously had confined himself to soils now became a member of a multi-disciplinary team mapping economic land capability. When the Bureau extended its activities to the investigation of overseas projects the same approach was employed, although irrigability criteria were modified to suit the local situations.

Irrigation of smallholder areas involves the same soil factors (pedology) as does irrigation of larger holdings. However, with respect to irrigability classification, there are substantial differences, the principal one being the prospective input of the cultivator to the development of his holding. This may far exceed conventional economic limits. The wellbeing of the smallholder and his family is irrevocably

determined by the productivity of his holding, and he has little other opportunity for bettering his situation than improvement of his land. The low opportunity cost of labor of the farmer and his family, given time, can accomplish wonders. An apparently barren boulder-strewn area with unproductive subsoil of a few inches depth can be changed, with patience and labor, into a fertile field. Steep slopes can be converted to small terraces, each with carefully constructed stone pitching.

It is not intended to convey that conventional economic irrigability classification is irrelevant in smallholder areas. It is very relevant in determining whether or not to bring irrigation into a particular project area. However, once a decision has been made to proceed with a project, irrigability classification is less important in determining whether to provide service to local areas with particular deficiencies. A small cultivator within the project perimeter but unfortunate enough to have relatively poor soil would be doubly unfortunate if he were to be excluded from supply of water. Provided that there is the technical possibility of substantially improving his holding, particularly under irrigation, it can be argued that equity demands that the cultivator in question be supplied with water and given the opportunity to make that improvement.

Irrigability classification involves making certain assumptions regarding the irrigation practices which will be followed. A case in point is the classification of lands as suitable, or unsuitable, for cultivation of wet-land rice (paddy). This involves consideration of infiltration rates. Rates of more than 2-3 cm per day are usually considered excessive for wet-land (flooded) paddy. Such lands would normally be classified as unsuited to that crop. However, smallholders in traditionally rice-eating areas may irrigate paddy in soils with infiltration rates ten times that amount, using semi-wetland techniques, i.e. without continuous

flooding, rather than growing a more appropriate crop requiring less water.

Incorporation of soils data in an irrigability classification, without also reporting on the soils data separately, may be quite appropriate in a feasibility report prepared by a major organization which is also responsible for detailed design and execution of a project, as well as its investigation. However, where project design is subject to review and possible modification by agencies other than the one which carried out the original field investigation, such as prospective financing institutions, a separate soils survey report should also be provided. It is not readily possible to extract basic pedological data from an irrigability report (to "unscramble the omelette"). Pedology is basic, while irrigability classification involves judgement on many factors other than those related to soils, judgements on which other agencies subsequently involved may not always concur.

Irrigation of many soils, including the commonly-occurring silty or sandy loams, is relatively straight forward and does not call for extensive knowledge of pedology on the part of the irrigation engineer. Problem soils may be encountered, however, and these present the engineer with the difficulty that soils science is a complex subject, obscured by an esoteric nomenclature ("taxonomy") which is intimidating to other than a soils scientist. There is no middle ground in the literature, which either stops at simple soils water relationships, or requires a depth of background in soil chemistry and physics which only a soils scientist would have time or inclination to acquire.

Soil constituents

The following brief description of the principal factors influencing the behavior of

soils under irrigation is given as background to discussion of particular soils problems. For more detailed treatment, reference should be made to Richards (1954), the classic original text on salinity and alkalinity, and to Tanji (1990).

Formation of soils from the parent material produces an array of constituents ranging from relatively unweathered resistant components (notably silica) to fully weathered material, part of the latter being in the form of clays. Organic material is usually also present. From the agronomic viewpoint, the soil may be grouped into relatively inert components, material still in the process of breaking down (a source of nutrients), days, and organic material. Soil moisture is also an essential ingredient.

The clay fraction plays a very important role, due to its ability to absorb ions on its surface. Positively charged ions (cations) of principal significance are calcium, magnesium, sodium, and to a less extent potassium. Although tightly bonded to the clay mineral by electrostatic forces, they may be exchanged with other cations in the soil solutions and thus constitute a source of plant nutrients. The adsorption sites not occupied by these cations may be occupied by hydrogen ions. The ability of a soil to absorb cations is referred to as its Cation Exchange Capacity (C.E.C). The extent to which that capacity is occupied by calcium, magnesium, sodium and potassium is termed the percentage of base saturation.

As cation absorption is a surface phenomenon it is primarily associated with clays, which due to the lamellar nature of the clay mineral have very high specific surface. The "2:1" clays such as mon-tmorillouite and illite which have both "internal" and "external" surfaces have C.E.C of some 100 milk equivalents per 100 g. The "1:1" clays such as kaolinite have C.E.C of 10 to 15 meq/100 g.

Colloidal organic matter (humus) has C.E.C of up to 200 meq/100 g. Fine textured non-laminar minerals (e.g. fine silts) also have adsorptive capacity, but to a much lesser degree than clays.

Values of Cation Exchange Capacity for composite soils commonly range up to 30 milliequivalents per 100 g, the actual figure depending upon the clay content. A relatively high value of C.E.C., particularly with a high degree of base saturation, usually signifies high fertility. However, soils with C.E.C as low as 4 or 5 meq/100 g can grow irrigated crops provided that sufficient fertilizer is applied and that the interval between irrigations is short.

The undesirable cation to have on the exchange complex, if in excess, is sodium. Particularly at low levels of soil moisture salinity, sodium on the adsorption complex above a certain limit may hydrolyze, resulting in an alkaline condition. This can cause deflocculation and dispersion of the clay, with drastic reduction in soil permeability, hence the interest in the percentage of sodium on the exchange complex and in means of controlling it. The concentration of a particular cation on the exchange complex is influenced by the concentration of the same, and other, cations in the soil moisture with which it is in contact. In the long-term an equilibrium is achieved. The equilibrium concentration of sodium on the complex, corresponding to prolonged irrigation with water of a particular chemical make-up, is obviously a matter of primary importance. The relationship is an empirical one, which has been determined by study of a wide range of soils and irrigation waters. It relates the value of a function referred to as the Sodium Absorption Ration (S.A.R.) of the saturation extract of the soil moisture, to the Exchangeable Sodium Percentage (E.S.P.) on the soil exchange complex. It is noted that soil moisture is referred to, rather than irrigation water, as the exchange complex is in

contact with soil moisture, not directly with irrigation water (other than at ground surface). The concentration of cations in the soil moisture at plant root level is two to three times that of the incoming irrigation water (averaged over a period of time), due to extraction of water by the plant. In determining the S.A.R. value of the soil moisture from data on the chemistry of the irrigation water, this increase in cation concentration is taken into account.

It is noted that the term "Sodium Absorption Ratio" causes some confusion as "absorption" occurs on the soil complex, not in the solution. However, it is the term customarily applied to the above-defined function of the soil solution.

Determination of the Exchangeable Sodium Percentage on the exchange complex, the associated S.A.R. of the soil moisture, and the S.A.R. of the proposed irrigation supply, is of interest for three reasons. First for classification of the soil in terms of its alkalinity hazard, second for assessment of the effect on the soil of long-term application of the particular irrigation water proposed to be used, and thirdly for design of remedial treatment if needed.

The adjustment of the E.S.P. of a soil to come into equilibrium with the S.A.R. of an irrigation supply can be a very slow process due to the large quantity of cations held on the exchange complex compared with the relatively small concentration in the irrigation water. In fact, amelioration of an alkaline condition (as distinct from saline) in the course of normal irrigation, or by leaching with irrigation water, is unlikely to be rapid enough to be of practical significance, except under special conditions (e.g. presence of gypsum or lime in the soil). However, in the opposite circumstances in which the nature of the irrigation water is such that it slowly increases the amount of sodium on the complex this would cause serious alkalinity

over a long-term period, and historically has done so in some areas. Chemical and other remedial treatment of alkaline soils is discussed in the next section.

Soils problems on irrigation

In the following discussion a number of soils which present particular features or problems in irrigation development are described.

Saline and alkaline soils

Soils are classified with regard to salinity and alkalinity in accordance with the conductivity of the saturation soil moisture extract and the Exchangeable Sodium Percentage on the exchange complex. The classification is nominal only, as the performance of a soil from the agricultural viewpoint is influenced by other factors in addition to conductivity and E.S.P, including soil texture and the sensitivity of the particular crops to be grown. The classification is as follows:

Conductivity	Exchangeable Sodium	
Millimhos/cm	Percentage at 25°C	
Non-saline, Non-alkaline	Less than 4	Less than 15
Saline, Non-alkaline	More than 4	Less than 15
Saline, Alkaline	More than 4	More than 15
Non-saline, Alkaline	Less than 4	More than 15

The continued application of even relatively high-quality irrigation water in the absence of internal drainage sufficient to remove the incoming salts will inevitably

result, eventually, in a saline soil condition. This has occurred in a number of historic areas in which agriculture ultimately has had to be abandoned. A number of such areas still await reclamation.

A purely saline condition requires leaching only. If natural drainage conditions are inadequate to remove the leachate, internal drainage must be provided. Attempts to remove salt from the cultivated depth of soil by leaching laterally into furrows have not proved successful, as capillary action brings salt to the surface from the un-leached subsoil. The depth of leached soil must be greater than the height of capillary rise, which usually means more than a meter. In the simplest situation leaching is down to a watertable which is at considerable depth, (and which will remain so). Otherwise, internal drainage may have to be provided, either by tubewells which hold the watertable at sufficient depth below the surface ("vertical drainage"), by a perforate dpipe drainage network about at 2 m depth ("tube-drainage"), or by open drains of sufficient depth. Each solution has its limits and its problems. The tubewell system requires the existence of a sub-surface horizon, virtually an aquifer, of sufficient transmissivity to permit extraction of water at reasonable cost. Tube-drainage requires sufficient permeability of the soil horizon being drained to permit economically practical spacing of the tube network. Open drainage, which might appear at first sight to be the most straight-forward solution, particularly for developing economics, requires a depth and spacing of drains consistent with the permeability of the soils being drained (the open drains are required to function as internal drains, not as surface drains). In many cases such depth and spacing would be impractical, e.g. 3 m depth at 100 m spacing, in view of the often major difficulties of maintaining deep open drains, and the substantial surface area which they would occupy.

Tube-drains, open drains and tubewells may require pumping if gravity out-fall is not available. The principal problem of all three systems may be the disposal of the saline effluent. Where the salinity problem is local, the effluent may be returned to the irrigation system, or to a stream, where there will be adequate dilution. However, where the salinity problem is regional it may not be acceptable to discharge saline effluent into a river, or to re-cycle it into irrigation. Other means of disposal are by construction of an out-flow canal to the ocean, or by evaporation ponds. An ocean outflow canal is being constructed on a heroic scale in the Indus basin, and could eventually be required on an even more heroic scale, including major pumped-lift, in an adjacent area. Evaporation ponds are technically feasible but the surface area required can be considerable, as the evaporation rate reduces considerably (compared with fresh water) as the salinity in the pond rises. Desalination, now being adopted in the western United States, is not considered an economically practical solution for the foreseeable future in developing countries.

Where groundwater salinity has not yet risen to unacceptable levels watertable elevation may be controlled and natural leaching promoted by tubewell irrigation, including cultivator-owned shallow tubewells. However, in an area where soil salinity is already depressing crop yields, cultivators are unlikely to take up tubewell installation on a significant scale.

The most practical solution to a salinity problem in some areas (as also waterlogging) may be to reduce the rate of inflow of irrigation water into the area to an amount such that the watertable remains low enough for natural leaching to occur. Watertable elevation is determined by watertable gradient, which is influenced by rate of seepage from irrigation. Seepage from canals is also a

contributing factor, and this may be a reason for canal lining in some situations.

In some areas, an alternative solution to removing the saline condition is adopting appropriate cultivation practices and selection of crops. Frequently this is the only immediate course available to the small cultivator, in some cases with considerable success. The balancing act performed by cultivators in the lower Nile delta, depressing the salinity level with a paddy crop and taking a follow-on cotton crop before the salinity rises again is an example, but probably applicable only to their particular soil situation. The ultimate example of living with salinity is conversion from agriculture to pond fish culture, or prawn-culture, in such areas.

Reclamation of purely saline soils has its problems, but the treatment of saline-alkaline soils is complicated by two further factors. First, the permeability of the soil may already be very low, due to de-flocculation of the clay mineral, or it may become so as soon as leaching lowers the salinity. Second, as discussed earlier, alkalinity cannot generally be removed by simple leaching. Exchange of sodium on the exchange complex, by calcium, must also be achieved.

Reclamation of alkaline or saline-alkaline soils can range from the relatively simple to the virtually impractical. Drainability, with a sufficient degree of permeability and sufficient watertable depth to permit downward leaching of salts, including displaced sodium, greatly facilitates the process. Progressive application of gypsum (calcium sulphate) and leaching, or cultivation of paddy to provide leaching, may be all that is required.

However, where permeability is already very low, either because of dispersion of the soil due to alkalinity or due to the inherently fine texture of the soil, getting

water into the soil and getting the leachate out can present considerable difficulty. If dispersion is the problem the classic solution is to begin leaching with water of sufficiently high salinity to de-flocculate the soil (if such water is available), at the same time providing gypsum for displacement of sodium. After the latter process has proceeded far enough salinity may be reduced by leaching with water of low salinity. However, if texture is the problem (e.g. a heavy clay soil), rather than dispersion, leaching with high salinity water will not improve permeability, and a difficult drainage problem is presented.

In such circumstances solutions may be available to the small cultivator, with his low opportunity-cost labor, which would not be economically viable on a mechanized scale. An example is the practice of some cultivators in portions of the lower Nile delta. The surface soils are saline-alkaline, underlain by unripe near-impermeable silty clays. Watertable is high. As there is virtually no downward movement of water any leaching has to be laterally. The cultivators consequently dig ditches of 1.5 to 2 m depth at as close as 25 to 30 m spacing. There is sufficient lateral gradient into the ditch to provide appreciable water movement. Gypsum, brought from supply depots by pannier-laden donkeys, is ploughed in each year, and each year the ditches are in-filled with reclaimed surface soil and dug again in a new position. Progressively, and at great labor, the entire area of the holding is eventually trenched and reclaimed in this manner. This is obviously not a procedure which would appeal to cultivators everywhere. The equivalent mechanized approach, also practiced in the area referred to, and with limited success, is to employ a heavy tractor-drawn chisel plough and to sprinkle gypsum into the temporary slot opened behind the chisel. The slots, at some 2 m spacing, extend between open collector ditches at about 150 to 200 m. The hope is that each slot, in-Sued with gypsum improved soil, will provide a permanent conduit

for leaching from the area. Gypsum is ploughed in across the area as a whole. Mole plowing has also been tried in this area, as a means of providing temporary drainage, rather than the chisel plough slots. However, the drainage holes formed by the mole plough have very short life except in very special soil conditions. It is noted that the spacing required for permanent tube drains in the particular conditions referred to would be 10 m to 20 m, which would be economically unattractive.

A degree of reclamation of otherwise intractable heavy alluvial/marine clays has been provided in an area near Bangkok, by construction of raised beds. The beds, about 10 m in width, are separated by excavated water-ways, which are the source of the soil for constructing the beds. The water-ways serve both as drains and as irrigation supply, water being applied to the beds in this case by spray from a gasoline-driven pump mounted on a small boat which travels up and down the water-ways, propelled by jet reaction from the pump nozzle. After forming the raised beds the soil, initially in heavy clods, is left to mature by weathering for one or more seasons before cultivation. The raised-bed system, with bed surface about one meter above adjacent water-level, provides internal drainage, although to limited depth. The beds are devoted to raising of vegetables for the adjacent Bangkok market. The system is quite effective, but at the cost of heavy manual labor in forming the beds, and requires considerable skill in subsequent soil management. It is not a generally-applicable solution to that type of soil situation. To summarize, reclamation of alkaline soils can be a difficult problem, and may not always be practical. Diagnosis and development of appropriate treatment calls for special expertise in soils chemistry and drainage. Cultivator ingenuity and labor has been an essential part of the solution in some situations.

Expansive days

These are variously termed Black Cotton soils, cracking clays, or vertisols. They occur widely in areas of relatively limited monsoonal rainfall. They range from heavy clay to silty clay, the clay mineral being principally montmorillonite (clay content is commonly 20 to 40%). Calcium usually predominates on the exchange complex, and calcium carbonate nodules (kankar) often occur throughout the profile.

A notable feature of these clays is the high degree of expansion and shrinkage on wetting and drying, causing conspicuous cracking in the dry season. Cracks may be as wide as two centimeters, and up to one meter in depth. The soils, under irrigation, produce a variety of crops including food-grains, cotton, and sugar-cane. Problems have been encountered, however, with wet-land paddy due to deficiency in available phosphorus under saturated (anaerobic) conditions. The soil management problem sterns from the very sticky unworkable nature of the soil when wet, and its very hard intractable nature when dry. The range of soil moisture content under which conditions are suited to cultivation is narrow. In low-intensity rainfed agriculture the problem of cultivation is minimized, but it may be a limiting factor in introduction of intensive multiple cropping under irrigation. It is noted that certain of these clay soils, but by no means all, have the very beneficial characteristic of "self-mulching", i.e. shrinkage near the surface produces a network of very fine cracks and pea-size particles, a fine natural filth. In other areas the cracking is massive.

From the irrigation engineering viewpoint, there are two problems with these soils. One stems from the effect of expansion/contraction on structures. The

other, in some areas, is their extreme erosibility. The pressure which is exerted by such clays, if expansion is restrained, can be destructive. If lined canals are to be built, over-excavation and replacement with granular non-expansive material (if available) in the vicinity of the lining may be necessary. In some areas a horizon of suitable semi-granular non-expansive material (termed "murrum in India) occurs between the weathered parent rock and the over-lying day soil, but this is not the case everywhere, and haulage of non-expansive fill may be a major item of cost. Use of a reinforced concrete flume with free-standing walls, or supported on pedestals, may be resorted to, in order to avoid the expansion problem. In addition to expansive pressure, shrinkage cracking can present a threat to small and medium-sized hydraulic control structures, which may be completely by-passed by flow through massive shrinkage cracks. To avoid this problem unusually extensive cut-off walls may be required, or provision of a length of upstream lining (duly protected against expansive pressures).

The susceptibility of expansive clay soils to erosion varies, for no immediately apparent reason, from moderate to very great. With the most erosive clays, runoff from rainfall on a 1-2 % slope can cause heavy sheet erosion, the outflow being a dense slurry which can block drainage channels overnight. Lateral erosion due to runoff down the banks of an unlined canal can change its original trapezoidal section into a shallow saucer-shaped depression in one season. The only solution is to line the canal, posing of course the problem of expansive pressure on the lining. Roads in such clays are quite impassable in the wet season, unless given substantial surfacing with granular material. All soil conservation works, particularly contour bunding, must be fully protected against erosion, preferably with vegetative cover.

Gypsiferous soils

While gypsum is highly beneficial in the reclamation of alkaline soils, it can become a problem where it occurs in excess. The problem can be either agronomic, or technical relating to irrigation distribution.

Gypsum (hydrous calcium sulphate, $CaSO_4$ $2H_2O$) occurs in arid or semi-arid situations. In concentrations of up to 25% in the soil, and if in finely divided form, gypsum has little adverse effect on crop yields. Soils with up to 50% gypsum are in fact cultivated, although at reduced yields, in part due to fixation of phosphorus in such soils.

The problem in irrigation of gypsiferous soils stems from the solubility of gypsum. This can cause irregular settlement of irrigated fields, heavy leakage from unlined channels due to formation of solution paths down to the watertable, and disruption of lined channels. The smallest seepage from a lining, at a joint or crack, may cause a solution cavity to form behind the lining, resulting in eventual collapse of the lining into the cavity. The failure is progressive, differential settlement behind the lining causing cracking, with increased leakage and further solution settlement. The problem may be aggravated through attack on the lining by the sulphatebearing ground water.

An expedient adopted in some gypsiferous areas is to construct the channel as a reinforced flume, elevated on pedestals. The pedestals are located mid-way between the joints in the flume so as to be unaffected by solution due to joint leakage. Another system incorporates a heavy-duty plastic or composite lining behind the concrete inner lining, the plastic sheet forming the primary water

barrier. The latter must be proof against rodent and termite attack and must be sufficiently flexible to accommodate deformation due to minor settlement.

Acid sulphate soils (cat clays)

This is one of the most difficult types of soil from the water management viewpoint. It commonly occurs in tidal mangrove areas. The notable feature of the soil is the occurrence of pyrites (iron sulphide, FeS), formed by bacterial reduction of sulphates from sea-water or brackish water, under saturated anaerobic conditions. In reclamation of these soils, usually for rice cultivation, lowering the watertable can result in oxidation of the pyrites to form sulfuric acid, also consequential release of free aluminum ions which are toxic to the crop.

Water management under these conditions involves very careful control of watertable elevation, through regulation of irrigation and drainage, to avoid such oxygenation. Management of water levels to the required closed tolerances can be made the more difficult in such areas due to settlement of such organic soils when drained and also to tidal variation in drainage outfall levels.

Podzols

Podzols are a classic case of a soil which may be supporting a stable vegetative cover (commonly forest) in the natural state, but which is poorly productive when the natural cover is disturbed. The characteristic feature of podzols is leaching of the top-soil by humic acids, generated from rotting vegetative material on the forest floor. The acid leaching process breaks down all susceptible minerals, eventually including clays. The leachate transports the product down into the

subsoil, leaving essentially a washed fine silica sand topsoil, with humus cover.

The system is in fine-tuned ecological balance. Disturbance, particularly removal of the vegetative cover, can invite disaster. The virtual absence of clay mineral and the fine, often powdery, texture of the topsoil makes it highly susceptible to erosion. It is also of low fertility with very restricted potential for agricultural development.

Lateritic soils

Lateritic soils are also the product of leaching, but differ from podzols in that humic acids are not involved in the leaching process, and the break-down of soil minerals is not as complete. Lateritic soils occur extensively in upland tropical areas on acidic parent rock, including granite. They are of characteristic red-yellow color and granular in texture, with a small amount of clay mineral. They are readily erodible, and consequently may be of shallow depth (10 to 20 cm), particularly in undulating terrain. However, depth may be a meter or more in higher rainfall areas where weathering has proceeded more rapidly. The soil transitions into less weathered, fragmented, parent rock.

Lateritic soils have moderately low fertility and low moisture retention capacity. Particularly where of shallow depth they would be classified, by most criteria, as poorly suited to irrigation. However, such soils occur extensively in some areas, including the granitic portion of the Deccan, in central India Under rainfed conditions cultivation is precarious, usually limited to the monsoon season, and generally at subsistence level. Where water can be made available multiple cropping becomes possible and productivity is substantially increased. The

shallow depth and low moisture retention capacity remain a problem, however, necessitating a short irrigation interval. Land shaping for irrigation in such conditions requires considerable care, in order to avoid removal of topsoil.

An important factor in management of such soils under irrigation is the role of the subsoil, both in storage of soil moisture, which is available to plants by capillary rise or through root penetration, and as a potential contributor to deepening of the topsoil by mixing in the course of cultivation over the years. Work on agricultural research stations in areas of these soils has demonstrated the effectiveness of this process.

Dune sands

Due to the process of wind-loom movement of dunes ("saltation"), dune sands fall within a narrow range of particle size. Some 90% or more of a typical dune is sand, in the range of 0.1 to 0.5 mm. The remainder is fine silt, with a very small proportion of clay. Fertility and water retention capacity are low. Infiltration rate is very high, with consequent problems in irrigation application, also in leaching of fertilizer. This is obviously not a soil which would be given priority in selection of areas for irrigation development, if there were other options. In some situations, however, other options are not available, an example being the lower end of the Rajasthan Canal system in India. Fortunately the fine silt and colloidal material brought in with water from the supply canal, in the Rajasthan case, results in substantial improvement in the character of the virgin dune sand, and viable levels of productivity can be obtained. However, several factors remain, which make irrigation management in such an area difficult.

Sand is obviously highly susceptible to wind erosion. The same forces which formed the dunes will immediately begin to re-form dunes on levelled areas, if left unprotected. The most effective protection is a crop, or crop residue from a harvested crop. This implies that dune areas should be levelled only at a rate with which the cultivator can keep pace, i.e. keep under active cultivation. It also implies that, for an extended period, an area newly coming under irrigation will still have undeveloped dunes as islands within the already levelled and cropped portion of the area. From these dunes and dunes around the permanent perimeter of the irrigation area, hot wind-blown sand can destructively erode adjacent crops, particularly at the seedling stage. There is no simple solution to this problem in an area newly under development, as the only remedy involves planting of wind-breaks or secondary cover-crops on the dunes, and this may require a limited amount of irrigation by pumping and delivery by hose or movable sprinkler system. Such facilities are unlikely to be available to a small cultivator newly arrived in the area.

The very high infiltration rate of sand poses a problem in ensuring uniform distribution of water on the field. The solution adopted by some experienced cultivators is to divide a field (nominally a 50 m x 50 m basin) into narrow strips 2 m wide, by temporary ridges, and to direct the whole flow of some 2 ft^3/sec (56 liters/sec) into each such strip in turn, completing the delivery in a matter of three or four minutes. The imponded water then infiltrates uniformly. Field application efficiencies as high as 75% can be obtained on dune sands which have been under canal irrigation for several years.

Sprinkler irrigation is a classical method of water application in such high infiltration rate soils. It is employed in large scale irrigation of desert areas. It is

not, however, a solution readily available to the small cultivator, nor is it particularly efficient in areas of frequent high winds.

In the tertiary distribution system in dune-sand areas the problem is again wind-blown sand. An unlined tertiary, or water course, has two disabilities in such circumstances. First seepage losses are very high, compounding problems of rising watertable. Second, the channel can be filled and obliterated overnight in a sand storm. A lined channel can also be filled, but the in-filling sand can be removed and the channel restored to use. Clearing an unlined channel constructed in sand poses a problem as there is no evidence of when clearing has reached the original floor or sides of the channel; the original geometry of the channel is lost.

The use of covered lined channel, or pipe, can nominally avoid the problem of windblown sand. However, water from the supply canal carries sand and silt, which can deposit in the covered lined channel or pipe, as the flow velocities are necessarily small in this situation, due to low head and relatively flat gradient. A sectionalized removable cover on a lined channel would permit clearing of such a channel, but this procedure is not applicable with a pipe. A covered desilting cistern at the intake could be a solution, but its maintenance would need to be assured.

With regard to lining of small channels in dune sand areas, the lowest-cost solution, a trapezoidal section with sides supported by the fill, has been found troublesome, as the supporting sand may be eroded by wind, resulting in collapse of the linings. The alternative of a rectangular channel with structurally self-supporting sides is more satisfactory in this respect. Responsibility for cleaning of sand from small channels (water courses and minor canals) is a critical question.

In view of the very considerable length of channel involved, particularly wafer courses, it is highly desirable that such maintenance be carried out by the beneficiary cultivators. This does not present a problem in a well developed area with well organized cultivator groups.- However, it can be a considerable problem in the early stages of settlement when some cultivators have not yet taken up their allotments, and a cultivator at the downstream end of a channel kilometers in length may find that the channel is blocked upstream where it traverses as yet unoccupied holdings. A dune sand area can be a very hostile environment for a cultivator, particularly in the early stages of its development. The farmer deserves particularly close institutional support.