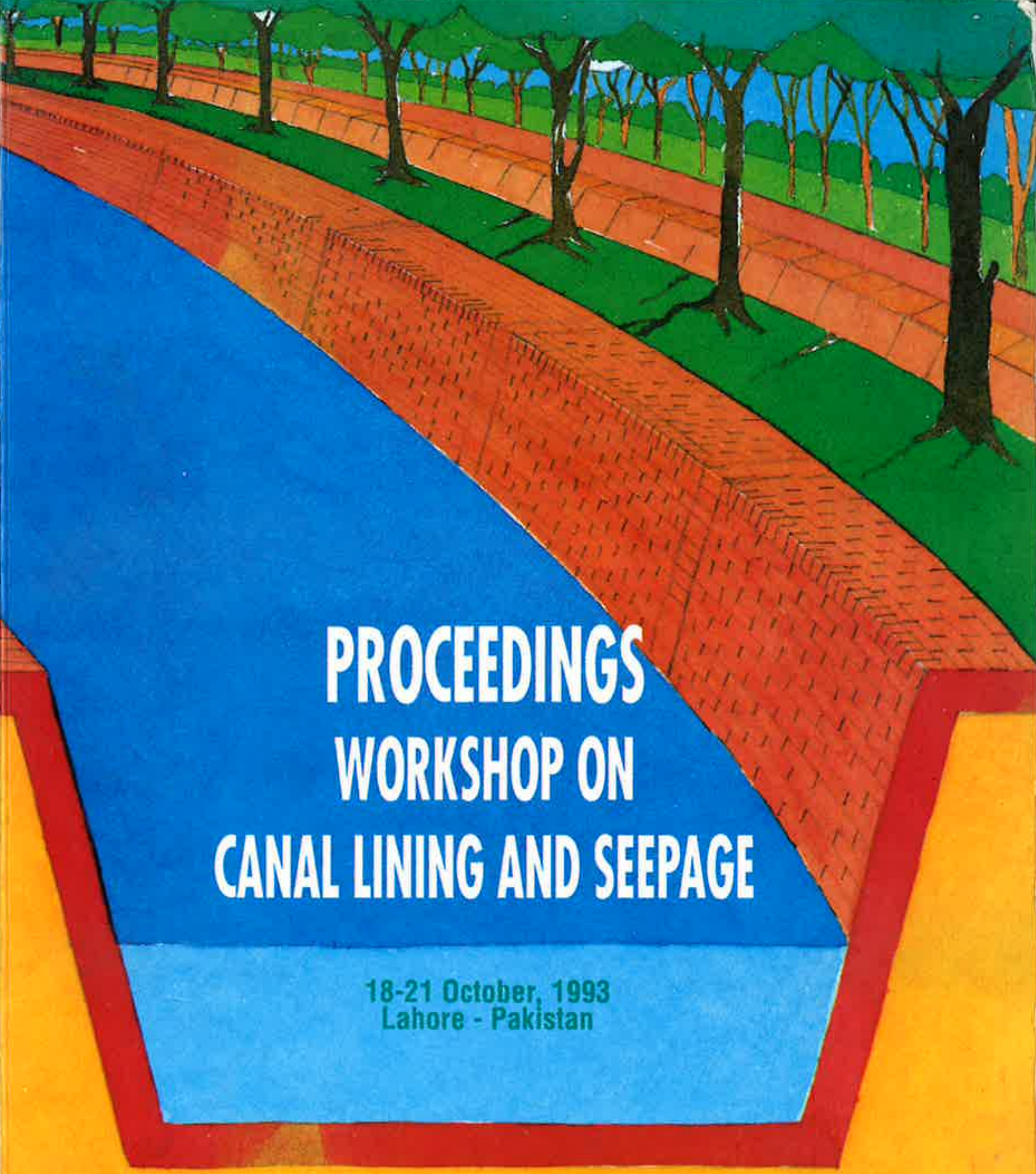

PROCEEDINGS
WORKSHOP ON CANAL LINING AND SEEPAGE

18-21 October, 1993
Lahore - Pakistan

International Waterlogging & Salinity Research Institute, Lahore - Pakistan

HR Wallingford, United Kingdom

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INTERNATIONAL WATERLOGGING AND
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PROCEEDINGS OF THE INTERNATIONAL WORKSHOP ON CANAL LINING AND SEEPAGE

OCTOBER 18 - 21, 1993

Editors

F. A. Zuberi
Dr. Muhammad Abid Bodla

LAHORE - PAKISTAN

1995

CONTENTS

FOREWORD

This publication contains proceedings of the International Workshop on "Canal Lining and Seepage" held at Lahore, Pakistan, October 18 to 21, 1993. About one hundred public and private irrigation management experts from across U.S.A., China, Egypt, Sri Lanka, Australia, U.K. and Pakistan participated in the various sessions of the Workshop. The Workshop, jointly organized by the International Waterlogging and Salinity Research Institute (IWASRI), Lahore, Pakistan and HR Wallingford, U.K., focussed on conferring global experience pertaining to canal lining and seepage. The deliberations addressed a wide range of issues extending from design, construction and maintenance to performance assessment and economic evaluation aspects of diverse conventional and new canal lining types and materials in addition to providing for evaluation and analysis of currently practiced seepage measurement techniques. Motivation for holding this Workshop had stemmed from widely experienced need to get the most out of existing irrigation infrastructure in order to increase agricultural productivity in a sustainable manner. In many countries of the developing world, irrigated agriculture continues to play a major role in achieving the objectives of food security, poverty alleviation and improvement in quality of life especially in the context of alarming population growth rates in these parts of the globe. While attempting to translate the desirable goal of agricultural growth into feasible and concrete development programs, improvement in efficiency and reliability of existing irrigation supplies becomes much more of an urgent need and requires implementation of measures to conserve this valuable resource base. The Workshop underscored that technological innovations and adaptations are important ingredients in bringing about such improvements.

Control on conveyance losses through lining irrigation channels, supplements drainage and enhances irrigation efficiency. Furthermore conveyance losses in saline groundwater zones are not retrievable for irrigation use, which prompts the need for water conservation through lining irrigation channels. However, the decision to line an existing unlined channel and choice among numerous lining adaptations is not so straightforward. Lining of perennial channels poses the problem of expensive diversion works, shorter effective life of lining than previously perceived and evidence from technical literature challenging the economic feasibility of huge investments on canal lining. The Workshop provided experts and mangers of the irrigation operational facilities with a forum to learn about and discuss these problems and issues. Papers introducing innovative lining designs and techniques including lining alternatives were also contributed by various authors. A total of 26 quality papers were presented by almost 44 authors and coauthors during six sessions of the Workshop. All registrants were encouraged to participate in the group discussion sessions which were especially designed to deliberate on problems and issues pertaining to various aspects of canal lining and seepage. Summaries of these group discussion sessions are also included in this volume.

It is believed that these Proceedings will serve the pertinent engineering profession as an important reference tool that will challenge water mangers to take full advantage of the experience and expertise currently available in the areas of canal lining and seepage to do a better job of development and research.

Editors

F.A. Zuberi

Dr. Muhammad Abid Bodla

ACKNOWLEDGEMENTS

The Editors would like to thank the Technical and Organizing Committees of the Workshop for their support and encouragement. Special thanks go to HR Wallingford, UK for their invaluable support from the inception of this Workshop to final publication of the proceedings. The Editors and the Organizing Committee would like to express their profound appreciation for the support given by Mr. Shams-ul-Mulk, the then Member (Water) and now Chairman, WAPDA and would wish to congratulate him for providing for an excellent initiation of the Workshop as keynote speaker. Dr. K. Sanmuganathan, Head ODU, HR Wallingford, UK and Mr. F.A. Zuberi, General Manager (IWASRI) should also be congratulated for imparting useful information and guidelines to the Workshop participants in their Introductory and Welcome Addresses.

The Workshop could not have been a success without well-qualified, conscientious Session Chairmen, Facilitators and Reporters. Sincere thanks are extended to the distinguished authors who offered their time to produce quality papers. Mr. Philip Lawrence of HR Wallingford, UK deserves special mention for bearing the responsibility of soliciting the contacts with authors participating from overseas.

The Editors are grateful to Mr. Muhammad Mauj Mustajab and Mr. Muhammad Shauq Shahab, Stenographers for skillfully undertaking the difficult and exhausting task of retrieving the proceedings of the Workshop from video tapes and typing many draft and final documents. Thanks are also due to Mr. Jamshed Javed, Tracer for reformatting the figures provided by the authors. Finally, the success of the Workshop from initial organization, through the Workshop itself, to final publication is due in large part to the hard work and tireless efforts of Mr. Muhammad Siddiq Ch., Mr. Imtiaz Ahmad, Mr. Muhammad Javed, Dr. Tahir Qazi, Mr. Abdul Hafeez Ch., and Mr. Ghulam Abbas Anjum of the IWASRI Workshop Organizing and Technical Committees.

Muhammad Abid Bodla

Dr. Muhammad Abid Bodla

WORKSHOP
ON
CANAL LINING AND SEEPAGE
LAHORE - PAKISTAN
18-21 October, 1993

PROGRAMME

MONDAY, 18 October, 1993

SESSION 1: INAUGURAL

10:30-11:00	Arrival of Participants	
11:00-11:05	Recitation from Holy Quran	Hafiz Abdul Hameed, Research Officer, IWASRI, Pakistan.
11:05-11:15	Welcome Address	F.A. Zuberi, Director General, IWASRI, Pakistan.
11:15-11:45	Introduction to the Workshop	Dr. K. Sanmuganathan, Head (ODU), HR Wallingford, U.K.
11:45-12:00	Inaugural Address	Shams ul Mulk, Member (Water), WAPDA, Pakistan.
12:00-13:30	**Lunch**	

SESSION 2: UNSTRUCTURED

Afternoon	Perusal of Workshop Material	All participants

TUESDAY, 19 October, 1993

08:30-10:00 **SESSION 3: OVERSEAS EXPERIENCE WITH CANAL LINING**

Chairman: **F.A. Zaidi, Joint Secretary, MOWP, Pakistan.**
Reporter: **Michael Patto, CTA/IWASRI, (UNDP), Pakistan.**

Canal Lining Experience in China	Lin Huashan and Jin Yongtang IWHR, Beijing, China.
Canal Lining and the Egyptian Experience	Dr. F.El Shibini, Director, WDISRI, Egypt.

	Report on Canal Linings used by the Bureau of Reclamation	Thomas E. Mitchell USBR, USA.
10:00 10 30	**Tea/Coffee**	
10:30-12:00	**SESSION 4: PAKISTAN EXPERIENCE WITH CANAL LINING**	
	Chairman: Dr. K. Sanmuganathan, HR Wallingford, U.K. **Reporter:** Dr. Theo M. Boers, NRAP/IWASRI, Pakistan.	
	Lining of Irrigation Channels "The Punjab Experience"	Mansoob Ali Zaidi, Superintending Engineer, I&PD, Punjab, Pakistan.
	Lining of Distributaries and Minors	Shuja Ahmed Junejo, Superintending Engineer, I&PD, Sindh, Pakistan.
	North West Frontier Province Experience in Canal Lining	Raqib Khan, Superintending Engineer, I&PHED, NWFP, Pakistan.
	Balochistan Minor Irrigation and Agricultural Development Project - Approach to Canal Lining.	Abdus Salam Khan, Chief Engineer, I&PD, Balochistan, Pakistan.
12:00-13:30	**Lunch/Prayer Break**	
13:30-15:00	**SESSION-5: GROUP DISCUSSIONS:**	
	Facilitators	1. Muhammad Ehsan, General Manager, NESPAK, Pakistan. - Overseas Experience 2. Hammond Murray Rust, Senior Irrigation Specialist (IIMI), Sri Lanka. - Pakistan Experience
	Reporters	1. Dr. Ata-ur-Rehman Tariq, (CEWRE), UET, Pakistan. - Overseas Experience 2. Allah Bakhsh Sufi, Senior Engineer, IWASRI, Pakistan. - Pakistan Experience
	Conclusion from country experience papers	All participants
15:00-15:30	**Tea/Coffee**	

15:30-17:00	**SESSION 6: DESIGN AND SEEPAGE MEASUREMENTS**	
	Chairman: **Dr. F.El Shibini, Director, WADISRI, Egypt.** **Reporter:** **Dr. Muhammad Nawaz Bhutta, IWASRI, Pakistan.**	
	A Country Paper on Canal Lining, the Egyptian Experience	Yehia Abdel Aziz MPWWR, Egypt.
	Recent Experience of Lining on Small Channels in Punjab Province with Particular Reference to Irrigation Systems Rehabilitation Project	Muhammad Ehsan, Nasar Iqbal Dodhy and Muhammad Sarwar Sial NESPAK, Pakistan.
	Seepage Measurement Techniques and Accuracy	J.A. Weller and P. McAteez, HR Wallingford, U.K. (presented by Philip Lawrence, HR Wallingford, UK).
	Seepage Loss Measurements on Chashma Right Bank Canal	Dr. Muhammad Siddique, Faiq Hussain Pasha and Ahmad Masud Choudri, ISRI, Pakistan.
	An Overview of Canal Lining Experience in Pakistan.	Dr. Nazir Ahmed, Consultant, Pakistan.
17:00-17:30	**Tea/Coffee**	
17:30-18:30	Video/Slides	Informal Presentation

WEDNESDAY, 20 October, 1993

08:30-10:30	**SESSION 7: PERFORMANCE OF LINING**	
	Chairman: **Lin Huashan, IWHR, Beijing, China.** **Reporter:** **Dr. Muhammad Mehboob Alam, IWASRI, Pakistan.**	
	Influence of Surface Permeability on Concrete Durability	Meng Zhen Quan, Beijing Hydraulic Science Research In., China.
	Role of Design and Construction Techniques	S.N.H. Mashhdi, NDC, Pakistan.
	Studies on Performance of Various Lining Materials	Dr. Irshad Ahmad, Ch. Bashir Ahmed and Haq Nawaz Butt IRI, I&PD, Pakistan.
	Canal Lining Performance Parameters in the Chashma Right Bank Canal Stage-I Irrigation System	Zaigham Habib and Carlos Garaces-Restrepo IIMI-Pakistan.

	Role of Maintenance: Experience from Pakistan	Dr. Bagh Ali Shahid, Abdul Sattar Shakir and Dr. Muhammad Abid Bodla IIMI-Pakistan/IWASRI.
	The Role of Maintenance in Extending Lining Service Life	J.C. Skutsch, HR Wallingford, UK.
	Alternative Materials and Construction Techniques for Lining Tertiary Level of Irrigation Canals	D.R. Birch and N.J. Lockett OFWMP, Halcrow, Balochistan, Pakistan.
10:30-11:00	**Tea/Coffee**	
11:00-12:30	**SESSION 8: GROUP DISCUSSIONS:**	
	Facilitators	1. Ian Simmens, Halcrow, Pakistan. - Design. 2. Brig. Khurshid Ghias, WAPDA, Pakistan. - Measurement. 3. J.C. Skutch, H.R, U.K. - Construction. 4. Thomas E. Mitchell, USA. - Maintenance.
	Reporters	1. Dr. M. Mehboob Alam, IWASRI, Pakistan. - Design. 2. Dr. Muhammad Siddique, ISRI, Pakistan. - Measurement. 3. Abdul Hafeez, IWASRI, Pakistan. - Construction. 4. Zaigham Habib, IIMI-Pakistan. - Maintenance.
	Conclusions from design and performance paper	All Participants
12:30-14:00	**Lunch/Prayer Break**	
14:00-15:00	**SESSION 9: ECONOMICS OF CANAL LINING**	
	Chairman: **Javed Saleem Qamar, General Manager, WAPDA, Pakistan.** **Reporter:** **Ali Akbar Naqvi, Director Economics, WAPDA, Pakistan.**	
	Financial and Economic Analysis of Canal Lining in Pakistan	Muhammad Shafique, WAPDA, Pakistan.

	Changes in Hydraulic Performance and Comparative Costs of Lining and Desilting of Secondary Canals in Punjab, Pakistan	Hammond Murray Rust and Edward J. Vender Veld, IIMI, Sri Lanka.
	Economics of Canal Lining - An Evaluation Method	F. Chancellor, HR Wallingford, UK.
15:00-15:30	**Tea/Coffee**	
15:30-17:30	**SESSION 10: FIELD VISIT**	
	Visit to IRI Research Station and to field	IRI, Pakistan.

THURSDAY, 21 October, 1993

08:30-09:15	**SESSION 11: GROUP DISCUSSIONS:**	
	Facilitators:	1. F. Chancellor, HR, UK. - Overseas Experience
		2. Ata-ur-Rehman, NESPAK, Pakistan. - Pakistan Experience
	Reporters:	1. Muhammad Shafique, WAPDA, Pakistan. - Overseas Experience
		2. Ghulam Muhammad Khokhar, WAPDA, Pakistan. - Pakistan Experience
	Conclusions from Economics Session	All participants
09:15-10:30	**SESSION 12: LINING ALTERNATIVES AND NEW MATERIALS**	
	Chairman: **Muhammad Idrees, General Manager, WAPDA, Pakistan.** **Reporter:** **Dr. Muhammad Irshad, IRI, Pakistan.**	
	Seepage Mitigation Using Soil Clay and Algae	P. Rengasamy, A.J. McLeod and S.R. Ragusa, CRCSLM, Australia (presented by Michael Patto, IWASRI/UNDP, Pakistan).
	Precast Parabolic Canals Revelation and Revolution in Pakistan	A. Laycock, Swabi SCARP, NWFP, Pakistan.
	Unlined Canals: The Grateful Earth	Haigh M., Jones C. and C.J.N. Davey MMP, Pakistan.

	Alternative Canal Lining Applications	Thomas E. Mitchell, USBR, USA.
10:30-11:00	**Tea/Coffee**	
11:00-12:00	**SESSION 13: GROUP DISCUSSIONS:**	
	Facilitators:	1. M. Badruddin, IIMI-Pakistan. - New Materials and Methods. 2. Y.A. Aziz, MPWWR, Egypt. - Alternative and New Materials. 3. Thomas E. Mitchell, USBR, USA. - New Materials and Methods.
	Reporters:	1. M. Saleem Bashir, IWASRI, Pakistan. - New Materials and Methods. 2. Dr. M. Mehboob Alam, IWASRI, Pakistan. - Alternatives and New Materials 3. Shafiq-ur-Rehman, IWASRI, Pakistan. - New Materials and Methods.
	Conclusions from Alternatives and New Methods Session	All participants
12:00-13:30	**Lunch/Prayer Break**	
13:30-15:00	**SESSION 14: REVIEW - I**	
	Chairman: **Dr. K. Sanmuganathan, Head, ODU, HR Wallingford, U.K.** **Reporter:** **Dr. Muhammad Abid Bodla, IWASRI, Pakistan.**	
	Review of Group Sessions	All participants
15:00-15:30	**Tea/Coffee**	
15:30-16:45	**SESSION 15: REVIEW - II**	
	Chairman: **Shams ul Mulk, Member (Water), WAPDA, Pakistan.** **Reporter:** **Philip Lawrence, H.R. Wallingford, U.K.**	
	Research Agenda	All participants
16:30	Closing Remarks	Shams ul Mulk, Member (Water), WAPDA, Pakistan.

Finalized after the Workshop

WELCOME ADDRESS

F.A. Zuberi
Director General (IWASRI), WAPDA, Pakistan.

Bismillah-irrahman-irraheem

Mr. Shams ul Mulk, Member (Water), WAPDA, Dr. K. Sanmuganathan, Head Overseas Development Unit of HR Wallingford, U.K. and foreign and local delegates to the Workshop on Canal Lining and Seepage

It is a great pleasure for me to extend a welcome to you all on the inauguration of the Workshop on Canal Lining and Seepage which is organized by International Waterlogging and Salinity Research Institute (IWASRI) of Pakistan in collaboration with HR (Hydraulic Research) Wallingford UK. The presence here this morning of a galaxy of scientists and engineers with varied experience and specialization in the field of canal lining and seepage, signifies the importance of the subject and the interest you have in this important subject.

In Pakistan, 25 to 30% of the water diverted from rivers for irrigation is lost from the canal system. With increasing demands for water, and no immediate prospect of providing additional storage, the case for reducing canal seepage loss is obvious. Ambitious canal lining programmes are being launched in Pakistan, particularly in the Punjab, and similar programmes have been initiated in India. China and Egypt are concerned with water savings and lining is included as a measure to reduce seepage in many canal modernization programmes. Although these programmes are proceeding, basic questions concerning the durability and cost effectiveness of canal lining as a method of seepage reduction have not been addressed in a holistic manner. There is evidence that the effective life of canal lining constructed in third world countries may be short, around five to ten years; much less than the twenty or thirty years usually assumed in economic analyses of the lining projects. Further, Pakistan pumps about 55 billion cubic meter (45 MAF) of ground water every year and only about 17 million cubic meters (14 MAF) is replenished from rainfall. If seepage from canals is to be reduced, then methods of artificially recharging the aquifer may have to be considered in some places.

The purpose of this Workshop is to bring together senior engineers, administrators and experts from Pakistan and selected overseas countries to focus on the broad question of canal lining and seepage, assess their perceptions and concerns and, through this process, evolve a research agenda. There will be two outputs from the Workshop. Firstly, an agreed programme of work that needs to be undertaken to resolve the complex issues associated with lining. Secondly, the invited papers and a summary of the discussions and conclusions will provide an invaluable record of experience on lining and seepage in Pakistan, and the other participating countries, which will be widely disseminated through the IPTRID network of the World Bank.

I am pleased to see that the Irrigation Departments of the three provinces are represented. We are sorry that the fourth province could not make it. Federal Ministries of Water & Power and Planning, WAPDA, the research organizations and consultants (both foreign and local) are also taking part. To provide an international perspective, invited engineers and experts from China, Egypt, USA and UK are also participating. We had invited experts from India also but I am sorry to note say that they have not been able to arrive as yet.

Ladies and Gentlemen, we are most fortunate this morning to have the gracious presence of Mr. Shams ul Mulk, Member (Water), WAPDA. Sir, I would like to thank you, most sincerely, for sparing the time to be with us to inaugurate this Workshop. Your presence here shows your keen personal interest and deep concern about canal seepage and the resultant waterlogging & salinity problem which is the toughest problem besetting our agricultural development. The firm resolve of the Government of Pakistan to tackle it by the most appropriate and economic means, will be needed to face the future challenges.

Here I will like to accord a special welcome to our colleagues from abroad. They have taken the trouble to journey to Pakistan to participate in this Workshop. I hope that your stay with us, in this historic city of Lahore, will be a pleasant one and that you will have a fruitful exchange of ideas and experience with the scientists and engineers of Pakistan and other participating countries.

I will also like to make use of this opportunity to briefly introduce International Waterlogging and Salinity Research Institute (IWASRI) of Pakistan. IWASRI was created by Government of Pakistan in 1986 with the primary objective of acting as prime national organization for the management and sponsorship of research on waterlogging & salinity and water management. Since its creation, IWASRI has conducted and managed research on various topics concerned with waterlogging, salinity, water management and environmental issues. IWASRI has also conducted a number of national and international symposia, seminars and workshops to share knowledge and experience and to exchange views on the vital aspects of the problem. This Workshop is one such example of that.

On behalf of IWASRI and HR Wallingford, I thank you all for your participation in this Workshop which aims to be a forum for the presentation of new ideas, knowledge and techniques on the problems connected with canal seepage which continue to cripple our agricultural economy.

Again I would like to welcome Mr. Shams ul Mulk and you all to this Workshop and hope you all contribute to making it a successful and memorable event.

Thank you very much.

INTRODUCTORY ADDRESS

Dr. K. Sanmuganathan
Head Overseas Development Unit, HR Wallingford, U.K.

Good morning, ladies and gentlemen,

My task this morning is to try to outline why we the IWASRI and HR Wallingford decided to organize a Workshop on Canal Lining and Seepage. Seeing how full this hall is I have to admit we must have chosen the right subject, shouldn't we! I work for a research institute HR Wallingford. Yes we have changed our name! We used to be Hydraulics Research, now we are HR Wallingford because every one knows us as people from Wallingford and we specialize in all aspects of civil engineering hydraulics from water resources, irrigation, drainage to river tidal and coastal engineering topics.

Personally I head a group we call it the Overseas Development Unit of around 25 of us and our task is to study water related problems with particular reference to 3rd World countries. In our work, in addition to investigating specific tasks that our clients ask us to investigate, we work on thematic issues that are common to many different countries such as the question of seepage and canal lining. Our outputs mostly in the form of papers, reports, software, manuals etc., are always directed at outlining methodology that can be used by 3rd World professionals under 3rd World conditions and this dictates the way we work.

By way of illustration I may refer to the manuals and software that we have developed to help design, for example, sediment control structures so that their performance can be predicted quantitatively and with confidence. Or for example, I may refer to a management information software that we have developed that assists irrigation professionals in the 3rd World in operating the schemes effectively particularly during water shortage conditions. With their permission, I would like to quote two other instances, for example an environmental checklist that we have developed in association with the International Commission on Irrigation and Drainage which is designed to help project initiatives to take appropriate measures right from the outset as regards environmental concerns, right from the project conception, instead of thinking of environment as an alien discipline only to be considered after finalizing the design primarily to satisfy the funding agency requirements. Another example of the type of products we produce, I do have a reason for listing them, is the minor irrigation design software, for example, that we have developed to assist institutions, with inadequate technical manpower. Particularly, as is often the case in Africa, so that designs of small schemes can be carried out in a cost effective manner without sacrificing quality. In planning on these thematic work, we attempt to follow a set pattern of development as a sort self discipline in order that the results are indeed relevant to the actual field problems and more importantly that the 3rd World professionals can readily see the relevance to their problems. This normally starts with wide ranging consultations.

Some six years ago we organized a research colloquium in Wallingford to ask ourselves the question, what are the research issues? We had international participation at least I can see Mr. Badruddin, who represented Pakistan and who is here with us today. Our biennial regional symposia that we organize in Asia and in Africa is another example, the last one being in Beijing in China last May.

We organize at least one Workshop an year, some of them formal while the others informal but always directed at keeping our researchers close to the professionals in the field with the view to identifying appropriate research question and that always comes first in our agenda. This is normally followed once you have identified a question by field observation to help define the specific research problem precisely. Then this subsequently is followed by conceptual formulation of a possible solution, analysis, field testing (always field testing) and finally preparation of appropriate software manual or call it what!. We find this sequence extremely effective in disciplining ourself first and also ensuring that our products are relevant to the management of the water environment particularly in the 3rd World.

It is in this context having identified seepage reduction and canal lining as an important aspect of 3rd World irrigation today, we for our part like to see this Workshop help us identify important research issues that the profession feels need resolution. During the 1950's, 60's and 70's even, there was intense activity in constructing irrigation and drainage infrastructure in the 3rd World. Irrigation was seen as a vehicle for development, providing food, rural employment, poverty alleviation, call it what! However, during the 80's the pace of development has slackened partly because nearly all the readily developable sources of water and land resources have been used and partly because there has been an element of disillusionment with irrigation.

The promised benefits of the earlier projects never appear to materialize, at least not in the quantities originally anticipated in the design. Finance ministries are now less keen to allocate resources to irrigation and so are the international funding agencies. It has become harder and harder to convince administrators that investment in irrigation does pay adequate dividends. We now need to, much more than before, quantify improvements in performance and relate them to investment in an acceptable and reliable manner. Thus performance has become a key word in our vocabulary. Another set of constraints that affects us is brought about by the shortage of the water resources. Some thirty countries are expected to face severe water shortage by the turn of the century. In the 3rd World, water use for agriculture overs around the 85 to 90 percent mark. With increased urbanization and industrialization, other uses are beginning with some justification to clamour for their fair share.

The view that agriculture is using disproportionate amount of available water resources was very evident, during the 1992 Dublin sessions for example, or even the Earth Summit later on, in Rio. The need to avoid wastage of water has become a dominant theme in talking about water development. One way this is being attempted and Mr. Zuberi gave instances of that, is through lining of canals both to improve operational efficiency and to reduce seepage losses. Lining of canals has become almost synonymous with modernization of irrigation today. It is, as Mr. Zuberi said, more or less universally accepted that lining of canals is an effective means of saving water. However, to establish the economic viability and sustainability of lining, to establish that lining does indeed brings about the predicted benefits over the assumed time period through appropriate measurements, is I think a difficult task. One has to say that a number of questions remain unanswered. What are they? Among them which of them need priority? That in my view, I hope is the task before us for the next three days. It is conceivable that we may collectively conclude that sufficient knowledge of all relevant parameters to formulate appropriate policy decisions and no specific investigation is necessary. Well, at the end of day while that would be an acceptable conclusion, we the organizers do not feel that as a likely outcome.

Let me illustrate why. Let me read from a paragraph from a project completion report done recently relating to a project that involved a cost of about 300 million US$ of which 82% of the expenditure was devoted to lining cost and other modernization works in canal reaches and construction of lined watercourses. This component was originally expected to produce some 77% of the anticipated benefits of the project. The para commenting on the achievement goes something like this, "...the project achieved its main specified objective of canal and watercourses lining (100% completed). There was a delay in achieving this and other minor objectives which doubled the length of the project period. There is some doubt about the actual amount of water saving taking place." This has been resolved so far as possible whilst completing this report which has been done by looking at the increased area irrigated and it goes on to say "...it is unlikely that a fully accurate figure can ever be isolated because of the number of parameters involved; rainfall, river flows, cropping pattern, farmers choice in allocating water etc., justifying 300 million dollars of investment". This is soon after the project was completed. I wonder what sort of paragraphs we can write ten years afterwards, for example.

However, that is the purpose of this Workshop. Let us during the next 3 days compare notes, compare our experience, exchange our information and hopefully identify both for ourselves as a research organization and for you as professionals working in different aspects of lining programme, identify a set of issues if there are some, that need resolution. In trying to achieve that, we have attempted to structure the Workshop to give ample time for discussions. There are formal presentations also but they have been limited. They are there to prompt discussions. In no way, are they intended to be comprehensive coverage of all relevant topics. We hope you will supply that. We have allocated this afternoon for all of us to peruse through the submitted papers. From tomorrow morning onwards, it shall be assumed that all participants have read all the papers. The presenters are being asked to highlight only the important points when they make their presentation. The time is being limited. In every session at least one-third of the time will be devoted to discussions and your session chairmen are being requested to enforce that. I hope you will help them.

In addition, every day small group discussions are being arranged whereby different aspects of the subject matter dealt with during the day will be discussed in details by small groups. The outcome of these group discussions will be summarized and presented to you on the last day to comment, add, prioritize or disagree.

A digest of these deliberations alongwith the papers edited where relevant, to incorporate your observations will be published. I have no doubt that with your active participation during the next three days, this volume will prove to be a memorable one. It is with this objective in view that in addition to the eminent proficiency here in Pakistan from all over Pakistan, from all walks of life, IWASRI and HR Wallingford have with the assistance of the British Overseas Development Administration arranged for participation from China, India, Egypt and USA. In addition we are fortunate that a number of Professionals from IIMI are also with us. I think that the necessary ingredients for a successful workshop are present. Let us make use of it.

Thank you.

INAUGURAL ADDRESS

Shams ul Mulk
Member (Water), WAPDA, Pakistan.

Bismillah-irrahman-irraheem

I thank the organizers of this Workshop, IWASRI and HR Wallingford. I thank all the participants who have taken the trouble of being here today, especially the guests who have travelled from abroad to join us. I wish to thank IIMI, UNDP and other participating organizations who have been here this morning. These are the opportunities one gets rarely to be in the company of such distinguished people, engineers and other professionals, not only from Pakistan but from overseas and to talk to them of the concerns that we in the developing countries have.

The rationale of holding this Workshop, its basis and the motivation have been explained by Dr. Sanmuganathan and by Mr. Zuberi and I am not going to touch these in any greater detail. However, I do like to mention the issues with which we are confronted in our irrigation and drainage sector that continues to play very dominant role in the economy of Pakistan. We have by now the largest contiguous irrigation network in the world. We all know that this great national asset is not producing optimally, that this tremendous resource is beset with very major problems and issues. It is not only large as you all know, it is a complex system. It is complex in the sense that we have one contiguous system yet nine different agro-climatic zones with our main storages lying in the extreme north and a very large transmissive aquifer underlying the Indus plains. The groundwater quality varies from potable to twice the salinity of sea water and the aquifer is being exploited partly for supplementing irrigation supplies and partly for water table control through mobilizing additional salinity, the disposal of which poses another problems to us. So it is a complex system.

When supplies are affluent and demands are low as it had been the position with us so far, we do not need to reach the limits of our knowledge as it is not really a matter of survival. It definitely calls our attention to the issues of economics, financial viability, technical standards and professional ethics but it is not a matter of survival really. But one can foresee the world rapidly changing from that scenario to a different scenario where the supplies would become limited and demands radically enhanced. As I keep on telling my colleagues, in fifties the per capita water available in Pakistan was 5,000 cubic meters, it is now 1,600 cubic meters and is estimated to fall to 800 cubic meters in another 15 to 20 years. With that Pakistan will have slided from a water affluent country to a water scarce country and 15 to 20 years is not too long a period because when you think of water development projects, institutional improvements, and improving operational and maintenance standards, they take that long. If we are to be faced with a situation of dire scarcity, in a period of 15 to 20 years, then we have to start taking steps now. We have to recognize our responsibilities about it. This takes us to the question of efficiency of water usage, because for all countries in the world and especially for a country like Pakistan where presently about 97% of our total water is used in irrigated agriculture which, as Dr. Sanmuganathan said, was termed as and it is truly so, "high volume low value activity" at the Dublin Conference. Now it was so because perhaps the other sectoral uses of water were not yet really identified, for instance water uses for environment protection. I very seriously think that the occasions would arise in future where for the saline effluent disposal you will need water for the dilution. While the uses are multiplying and their volumes are increasing, the resource is the same. Besides, population is increasing and therefore we must adopt measures to save water.

Future development will mostly depend on whatever we can save from existing uses. In Pakistan 105 MAF is presently consumed and the additional allocation under water accord to the provinces is only 12 MAF. Our groundwater aquifer is at the brink of its ultimate extraction capability. We really need to reduce our pumpage in certain areas. At the same time I will warn you against reaching any hasty conclusions. In the areas which are underlain by useable aquifer, whatever is lost from the system goes to the underground reservoir that is built up by these seepage losses. This underground reservoir does not evaporate, it does not silt and it does not require any long conveyance system to take water to the farm and therefore provides a very valuable resource. What it means is that the losses which incur from the system and become the source of recharge to the useable aquifer, are not losses. But where we have an aquifer with suspect water quality or where the extraction is not sustainable on a long term basis, it is perhaps there that we must think of preventing losses from the irrigation network. I still use the word perhaps because these are the issues on which we must deliberate. These are the issues on which perhaps no final view can be expressed, unless they become the subject of deliberations, debate, consideration and arguments.

Further, we must think of the potential options for us to save water, and obviously lining is something which comes straight-away. Simultaneously we must take into consideration the evidence from literature which indicates instances where effectiveness of lining for seepage control lasted for 3 to 5 years only. So the argument is that whereas huge investments were made, time was consumed and yet the system was no better than it was before if the idea was of seepage control. This was an issue we picked up in IWASRI and I held detailed discussions with Mr. Zuberi and proposed that we must look into it in greater details. We must know why are we lining the canals. Is it for hydraulic efficiency or we want to achieve a better value of roughness coefficient "n"? Is that the only reason or is it the seepage or the both, or is it the slope? Whatever it is, if you decide the objective then the design must be made in such a manner that the envisaged goal is achieved on a sustainable basis. I am not going to invest to get relief for three years only as there is hardly any money to be spent for such temporary remedies. Something you do must be sustainable and durable. We can count a number of areas where the existing knowledge is somewhat sketchy, spotty or has gaps in it. I am very grateful to the organizers of this Workshop as they have picked up this concern.

Having once decided the purpose for which lining is to be installed there arise a lot many research issues that are involved. How to achieve the objectives in a cost effective manner? Unfortunately, monitoring is mostly absent in our plans. Except for the fact that some visible problems were noticed with the lining itself, we did not have a very well documented experience of how effective it has been. Let us try to fill the existing gaps in the information that we have. I suspect that perhaps the gaps will continue. However, I think as a consequence of this Workshop we may come up with the idea of really instituting a good monitoring programme designed to check and evaluate effectiveness of the implemented projects in achieving the targeted objectives.

Certain things are very visible, for example economic benefits as you see them in the fields. You need to have only data collected. But as Dr. Sanmuganathan indicated earlier, there are certain effects which perhaps are very difficult to get measured. Now if we are dealing with the benefits which are unquantifiable then it raises very basic economic issues as to how do you justify a particular component? How do you go for a major reconstruction, rehabilitation or modernization programme without being really able to evaluate its ultimate results. My opinion is that problems are generic only in their description but not in their solution. We have problems which could be described generically around the world but how to respond to that problem would be different in Pakistan than in the United States of America. Indeed it will be different in one zone of the country compared to the other zones and different in one project area than the other in the same zone. Therefore we need site specific solutions. We need solutions which have validity to address the problem exactly in the manner in which that problem exists in the area where that problem is located. So we must develop methodologies and procedures to address the problem exactly in the manner it exists, exactly in the area where it is located to avoid accommodating sub-optimality that could be imposed in the project right from the day one and that sub-optimality would continue to remain through out the project life which one should never accept.

Quality of work is another issue which is especially very relevant to the lining. I think whatever may be the designs and specifications, unless it is constructed exactly in accord with the envisaged quality standards we will face the same problems. You may have designed lining as a completely impervious barrier against water seepage but unless it is appropriately constructed obviously we are not going to achieve desired objectives. We must also develop methodologies of quality control which should be feasible under variable conditions in different places. I can tell you this that having decided the objective, having given the design to a very competent group of engineers, having written the specifications in exact accord with the philosophy and the discipline of the design, everything can be defeated by bad quality work. Water retaining structures do not allow you any deviation. They are very unforgiving. So that is why I suggest that quality issue is of major importance.

Dr. Sanmuganathan did refer to sediment management. I think it is not directly related to this particular issue but it is related in a different way as I remember that when we were carrying out the engineering studies for Ghazi Barotha Project where we have a lined canal of about 50,000 cusecs capacity, I invited the attention of the panel of experts to two questions:

1. What is the rationale of using a particular value of "n" on this canal?

2. What are the prospects of the sediment deposition in this canal as the moment sediment deposition takes place the value of "n" changes adversely.

Where sediment management is an area deserved of consideration, I think it is not an issue for this Workshop. I think these areas need to be discussed in the better account at some other place at another time. I think I have spoken longer than what I was expected to speak and it is not only this that I would like to confine myself to that but I would not like to usurp the time reserved for the lunch. So I hope that you will continue to stay in this Workshop, that you will give your experiences, you will debate them thoroughly and at the end of day when I hopefully will be with you again, we would have reached certain conclusions not necessarily of agreement. There could be areas where we would continue to disagree because these are the areas where the current state of the art does not provide specific answers. Even if we are able to identify the areas where we feel there is a gap, it will be a great achievement. Because once having identified the gaps we can then proceed to fill it up by research, laboratory research, field research, pilot research and so on, so forth.

Gentlemen, I thank you for coming here to day for listening to me with attention. I thank the participants, I thank the guests and I thank the Organizers.

Thank you very much.

TECHNICAL SESSION: OVERSEAS EXPERIENCE WITH CANAL LINING

CANAL LINING EXPERIENCE IN CHINA

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ABSTRACT

By introducing several kinds of canal linings and their applications in China, this paper focuses on the recent development in these areas. Particularly, in lift water region, different types of low pressure pipelines have been widely used as the alternatives of canal linings. Because of the serious frozen heave damage to concrete lining, diverse protection methods are studied in China and a qualified method, the combination of concrete with polystyrene laminate or plastic membrane, and its applications are also shown in the paper.

GENERAL

Owing to the great variation in climate, soil and economic conditions in China, diverse canal lining methods are used. These methods include lime-soil mixture lining, soil cement lining, masonry lining, membrane lining and concrete lining.

Lime, as an abundant local material, has been used in construction of buried canal/pipe for a long time. Lime-soil mixture lining has the advantages of low cost and acceptable effect of seepage control. Because of the weak frozen tolerance, it is limited to be used in medium and small size canal in mild climate areas. To reduce its drying shrinkage and crack, sand and gravel are added into the mixture for improvement. Usually cement mortar or lime mortar are applied on the lining surface to improve the impermeability.

Soil cement lining is a lining method which is suitable for the usage in the areas of lacking in sand and gravel materials. Its application is also limited in the mild climate regions. In most cases, the cement content is about 8% to 12% and water content is between 20% and 35% (Ministry of Water Resources, China, 1991). Only sandy soil or sandy loam can be made for the lining mixture.

Masonry lining is a traditional lining method in China. Its history might go back to 2,000 years ago. High stability, good frozen and wearing resistant ability and using local materials make it possible to be widely used in the areas with abundant stone. However, masonry lining has the disadvantages of low seepage control, high roughness, high cost and great handwork. To improve its impermeability, grouting clay mortar or lime mortar, providing lime-soil mixture layer or membrane underneath masonry have been used and the results show that the seepage loss was greatly decreased.

Membrane lining is impermeable, light in weight and easy to pave. It has been widely used since 1950s as the development of the plastic industry. To extend its service life, soil, soil cement, lime-soil mixture, concrete or masonry are taken as its protection layer. The practical uses show that plastic membrane can last more than 20 years under the buried condition.

Concrete lining is the most common canal lining because of its good seepage control, small roughness, easy construction and long service life. The recent work was focus on reducing cost, improving seepage control, developing mechanical construction method and frozen damage prevention techniques.

Among these kinds of linings, membrane lining and concrete lining have the widest adaptability and have become the most important canal lining practices in China. Further discussion on their recent development are given as follows.

MEMBRANE LINING

Lining Materials

Two kinds of membranes are used as lining material, namely plastic membrane and linoleum.

Plastic membrane has wide varieties in its materials as the development of plastic industry. Linear low density polyethylene (LLDPE), low density polyethylene (LDPE) and polyvinyl chloride (PVC) are the most common ones. Since LLDPE is greater in tensile strength and elongation rate, it is the first choice for choosing plastic membrane as lining material. However, PVC membrane is more suitable for the areas with heavy growth of plants like reed except in cold areas. The plastic membrane with dark color and 0.18 mm to 0.22 mm in thickness is recommended as lining membrane (Ministry of Water Resources, China, 1991). Linoleum is made of asphalt mastic and glass fiber textile. It has the advantages over plastic membrane in the resistibility of aging, cracking and penetrating.

Linoleum, as a membrane material, still has the ability of deformation under the condition of -26° C. Its thickness is required to be 0.64 mm to 0.65 mm. Therefore, it demands greater transportation cost on materials than plastic membrane.

In general, choosing plastic membrane is the first priority in membrane lining engineering.

Protection Layer of Membrane Lining

The choice of protection material of membrane lining depends on the availability of local materials and flow velocity of canal. For plain soil protection, flow velocity in canal is limited below 0.7 m/s for clay and 0.45 m/s for sandy loam (Jian Gong *et. al.*, 1991). For other kinds of protection, such as masonry, concrete slab or soil cement mixture, intermediate layer is required between the protection layer and membrane. Lime-soil or soil cement mortar is recommended as intermediate materials for mild climate areas and sandy cement mortar for cold areas.

Durability of Plastic Membrane

Durable or aging problem is often worried about plastic membrane lining. Under open condition, plastic membrane is aged very quickly. But the situation is different for buried ones. The plastic membrane samples under 300 mm plain soil protection in Dongbeiwang of Beijing were tested and the results are shown in Table 1 (Jin Yongtang, 1988), in which recognize that the strength of membrane was slightly increased after 18 years but toughness was declined.

Table 1. Behavior Changing of Buried PVC Membrane for 18 Years.

Color	Thickness (mm)	Tensile Strength (MPa)		Ratio of Elongation (%)		Sampling Time
		Latitude	Longitude	Latitude	Longitude	
Red	0.12-0.14	18.9	24.4	261.3	224	1965
	0.13-0.15	32.6	33.2	8-40	10-190	1983
Blue	0.14-0.15	18.1	24.2	261.3	264	1965
	0.14-0.15	27.1	33.2	4-8	40	1983

This proved that plastic membrane may undoubtedly be used more than 20 years under buried condition.

CONCRETE LINING

Lining Materials

The cost of concrete lining is relatively high. To reducing its cost, utilizing local aggregate materials and applying admixture are the essential improvements.

In shorting aggregate area, the transportation cost of aggregate may amount to 10% to 20% of the total lining cost. Using local available materials to replace standard aggregate or using admixtures may greatly reduce the cost. Of course, this replacement should not result in that the declination in lining quality exceeds the permitted limitation. The experiment and engineering practices (Jian Gong *et. al.*, 1991) show that adding 20% to 30% of pulverized fuel ash or 15% to 20% loess may meet the design requirement of seepage control; using fine or very fine sand may make the strength of concrete reaching at 13.7 MPa to 24.2 MPa under adequate mixture ratio; and using fresh shale gravel or mudstone gravel can make concrete at the strength of 19.6 MPa and sandy stone gravel at the strength of 7.35 MPa to 9.81 MPa.

Lining Method

Both prefabricated and cast-in-situ methods are used in concrete lining. For large-sized canal, cast-in-situ is still at handwork level in the field. Mechanical method is being developed. Prefabricated concrete lining is the prevailing method by making concrete slabs in size of (400mm × 600mm or 500mm × 700mm) × (40mm or 60mm) in factory, then moving them to the field and placing them by mortar. The reason that concrete slab is small in size is for the convenience of moving and placing by handwork. Combination methods of cast-in-situ in canal bottom and prefabrication in slopes have been put into practice. This combination, especially for large-sized slabs which are installed by mechanical moving and lifting equipment, makes the construction period shorter than that of the cast-in-situ method and canal lining surface smoother than that by the prefabricated way.

For medium and small size canals, "U" shape canal (as shown in Figure 1) is recommended because "U" shape has better hydraulic characteristics and occupies less land area. Moreover, "U" shape concrete lining has the advantage of integrity in structure, which makes it suitable for the area with frozen heave damage problem. To construct "U" shape concrete canal efficiently, a simple but efficient cast-in-situ machine (as shown in Figure 2) has been developed. This kind of machines can construct "U" shape canals ranging from 400 mm to 1,800 mm in diameter.

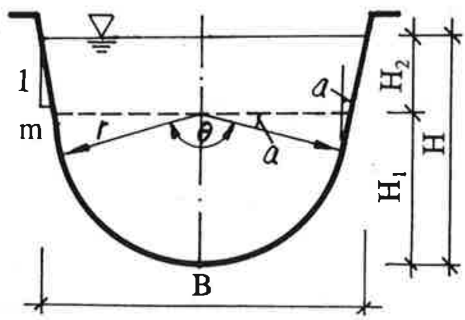
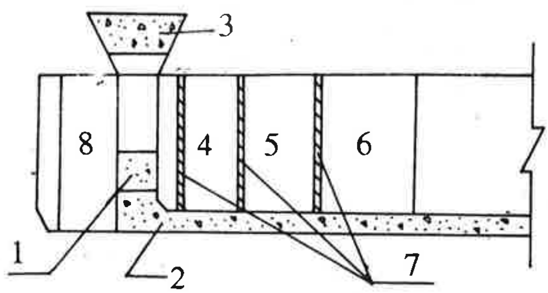


Figure 1. "U" Shape Canal.



1. Throat; 2. Entrance; 3. Hopper;
4. Vibrator; 5. Vibrating soothing; 6 Model;
7. Vibrating Disconnecting; 8. Guider.

Figure 2. "U" Shape Cast-in-situ Lining Machine.

The construction rate by the machine is 10 times higher than that by only handwork. Alternatively, a new simple machine to make prefabricated "U" shape concrete flume is developed recently. The distinguishing feature of this machine is to make the flume by vibrating a flat slab first and then bending it into designated "U" shape. In this context, concrete can be vibrated easily and thoroughly in flat. Therefore, the flume with high quality and thin thickness (only 25 mm to 30 mm in thickness) can be made efficiently. Bending process also causes the curved part possessing a higher strength. The construction rate of a 7-person work team by this machine is as high as 180 to 200 m/day for the flume in size of 500 mm in diameter.

LINING IN LIFTING WATER AREA

In lifting water for irrigation areas, low pressure pipeline as an alternative of canal lining has mushroomed for recent years in China. The statistics show that more than 3 million ha of farms have been equipped with low pressure pipeline delivery water irrigation system for 10 years. This rapid development is due to the advantages of low pressure pipeline in saving of land occupation, in fitting of field topographic undulation and in free of frozen damage.

Several kinds of newly developed pipes accelerate the progress. They include thin PVC pipe (2 mm to 3 mm in thickness for the pipes with diameter of 4 inch to 6 inch), corrugated PVC pipe, prefabricated plain concrete pipe and a combination pipe which consists of a plastic membrane tube and a concrete or lime-soil mixture envelope (Jin Yongtang, 1988) (as shown in Figure 3).

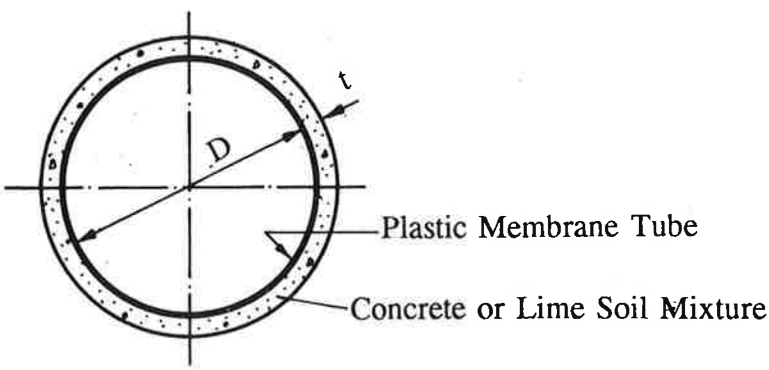


Figure 3. Combination Pipe of a Plastic Membrane with Concrete or Lime-Soil Mixture Envelope

The combination pipe couples the advantages of impermeability and smoothness of plastic membrane and saving the cost by using local materials of concrete or lime-soil mixture. It has been used in 67,000 ha of irrigated farms.

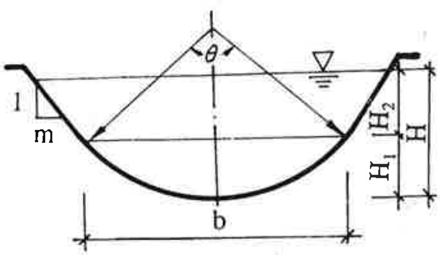
FROZEN DAMAGE PREVENTION IN CANAL LINING

Frozen damage to the concrete canal lining is a serious problem in northern part of China. A great effort has been put into studying its alleviation or prevention method. Some progresses have been made and shown below.

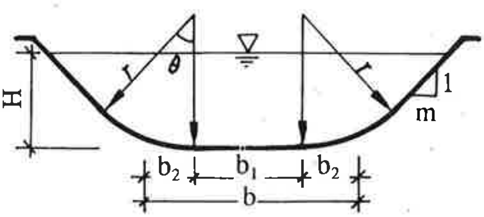
Lining Structure to Assuage Frozen Damage

For masonry or concrete lining in gentle frozen heave area, combination of canal base treatment and following structure improvements are recommended:

- In small-sized canal, choosing integrity lining structure as "U" shape or are cross section;
- In medium or large-sized canal, selecting trapezoidal cross section with are bottom or choosing trapezoidal cross section with curved toes of slopes for wider bottom canal, as shown in Figure 4 (Ministry of Water Resources, China, 1991), or choosing wedge slab, central thickened slab, "II" shape slab and rib team and slab construction, as shown in Figure 5 (Ministry of Water Resources, China, 1991).



(a) Trapezoidal cross section with arc bottom

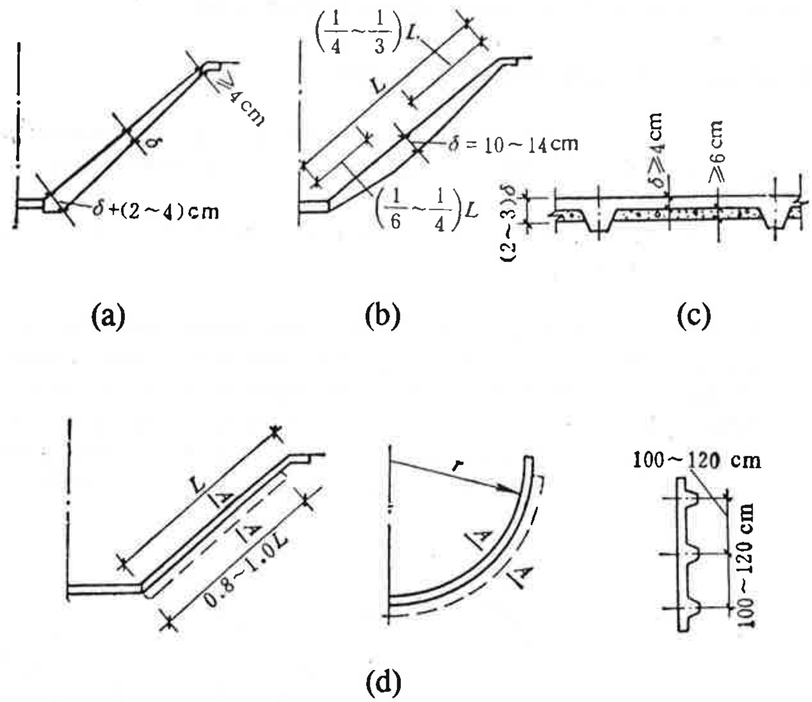


(b) Trapezoidal cross section with curved toes of canal slopes

Figure 4. Favourable Cross Section of Canal of Alleviate Frozen Heave Damage.

Lining Materials to Prevent Frozen Damage

To reduce seepage rate is a good way to alleviate the frozen heave. Many field experiments show that the combination lining by providing membrane underneath the concrete lining may reduce the seepage to 1/15 of concrete lining and frozen heave value to 35% to 55%. Of course, this measure will not work under the condition with recharging water sources to the bed besides the canal.



(a) Wedge slab;
(b) Central thickened slab;
(c) "Π" Shape slab;
(d) Rib team and slab.

Figure 5. Diverse Concrete Lining Structures to Soothe Frozen Heave Damage.

Providing insulator is a satisfactory way to prevent frozen heave by preserving the soil temperature under the lining. Polystyrene is an adequate insulator. Its experimental usage in lining engineering started in 1985. The experiments in Shanxi Province, north China, concluded that furnishing 40 mm polystyrene laminate at lower part and 20 mm at upper part of south slope (shade slope) under concrete lining, as shown in Figure 6, is an economical and effective way to prevent frozen heave.

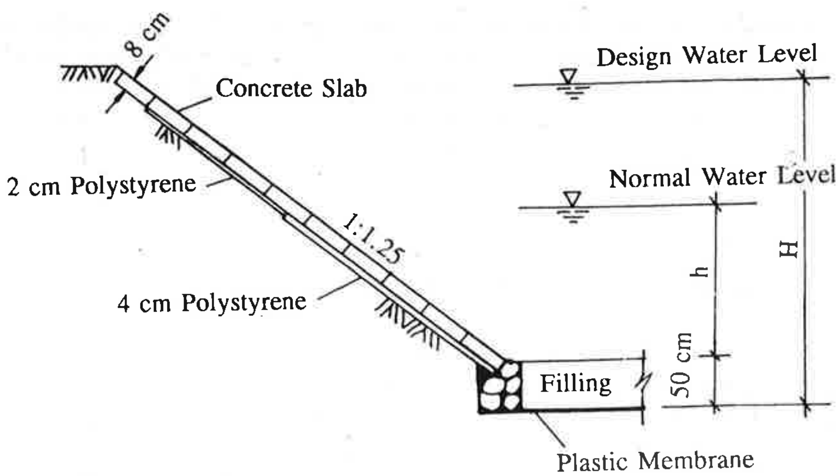


Figure 6. Combination Lining to Prevent Frozen Damage.

For selecting the adequate thickness of polystyrene laminate, the following equation (Dong Qinrui, 1989) is suggested.

$$h_b = \lambda_b \left(\frac{H}{\lambda_s} - \frac{h_c}{\lambda_c} \right)$$

where h_b and h_c are the thicknesses of insulator and concrete slab respectively, in cm;
λ_b, λ_c and λ_s are the thermos transmitting factors of insulator, concrete and soil respectively, in J/(m.s. °C);
H is the equivalent thickness of soil in thermos transmission, in cm.

$$H = 100\sqrt{\frac{Pa}{\pi}} \ln \frac{A_o}{T_o}$$

where A_o is the mean temperature variation, in °C;
T_o is the mean temperature in a year, in °C;
P is the period of temperature variation, P = 365 days;
a is the temperature transmission factor, in m^2/day.

The calculated value from the equations is the maximum thickness needed for the insulator in the south slope of canal. In the other parts of canal with solar radiation, the thickness may be reduced according to the distribution of the radiation. This freezing prevention method has been verified in the Project of Diverting the Yellow River Water into Qingdao City, Shandong Province, north of China.

CONCLUSIONS AND DISCUSSIONS

Diverse canal lining methods would still be used in near future from the availability of canal lining materials. However, membrane lining and concrete lining would be the predominant ones. In small-sized canal, "U" shape concrete lining, both cast-in-situ and prefabricated, is proved to be the successful linings and will be prevailing in future. In lifting water area, low pressure pipeline will replace open channel to be an effective water conveyance system. In large-sized canal, both prefabricated and cast-in-situ concrete linings need a lot of labours. Although they are acceptable under the low labour cost at present, efficient mechanical lining method may be more reasonable as the development of industry and economy and the increase of labour cost. Combination of membrane and concrete lining not only greatly decreases the seepage rate but also alleviate the frozen heave damage. It is recommended to be used in north regions. In the seriously frozen heave areas, special prevention measures should be taken in lining structure or lining materials to prevent damage. Polystyrene laminate is a good insulator to preserve the lining from frozen heave and practices show that the results are convincing. Further study may switch to reducing its cost or developing other low cost insulator.

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CANAL LINING AND THE EGYPTIAN EXPERIENCE

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ABSTRACT

Seepage losses from the Nile, main and branch canals forms considerable part of the total outflow downstream High Aswan Dam (55.5 billion m^3/year). Seepage from the Nile goes to the shallow aquifer where it can be pumped while the canals network (40,000 km total length) and drains network (17,000 km) recharges the deep and shallow aquifers and most of the drainage water goes to the sea (about 12 billion m^3/year). The old canals exist in the clay cap of the Nile valley, while most land reclamation developments take place in sandy soils at the valley fringes sloping upward. It deemed obvious that lining in new lands is mainly to control canal seepage and at certain places to prevent low quality drained return flow from irrigation schemes in the uplands to enter a canal. For drains, lining is mainly a protective measure for groundwater from contamination. It is a fact that water in Egypt is the limiting factor for agriculture developments, and hence raising the conveyance efficiency through proper lining techniques and materials is a must for water conservation policy. This paper discusses in brief the history of lining of canals in Egypt, objectives and problems, and focusses on some lining research studies conducted by the WDISRI as well as some case studies considered of prime concern to the subject. Future recommendations using synthetic materials, geotextiles and gabions are discussed.

INTRODUCTION

Egypt covers an area of one million Km^2 in the north east corner of Africa, which is mostly deserts. The climate is typical of arid and semi-arid regions with very limited rainfall and extreme temperatures during long summer periods. Water resources mainly comprise the river Nile of Africa (55.5 billion m^3/y downstream of Aswan Dam), shallow groundwater aquifer (2.6 billion m^3/y) rechargeable from the Nile, deep groundwater in the north desert (0.5 billion m^3/y) and limited winter rainfall along the coastal strip (about 1 billion m^3/y), which is not all effective.

Irrigated agriculture was and still is the backbone of Egypt's economy. Water allocated for agriculture is 49.7 billion m^3/y in 1990. It is estimated to become 59.9 billion m^3/y in the year 2000, i.e. 85% of Egypt's total water resources.

The Nile basin extends from Aswan south to the Delta north, a distance of almost 1000 km. The agriculture lands in the country form 3 to 4% of the total area and the rest of the area consists of deserts. The country's population is almost 60 million hence the water per capita is less than 1000 m^3/y, and the agriculture land per capita is less than 0.13 acre.

The irrigation network (canals and tributaries) is about 40,000 km, and the drains network is about 17,000 km. The soil in the Nile valley is mostly heavy clay, where at the fringes of the basin it is sandy soil. All land reclamation developments take place in desert sandy soils of high porosity (Figure 1, 2, 3 and 4).

CANAL SEEPAGE STUDIES

Beni Magdoul canal is one of the distributary canals taking off from Mansouria main canal. It was lined in 1977 by concrete cast in situ with thickness of 10 cm. The total length of the canal is 2990 m, and serves 800 Fed. The canal is operated for continuous flow. Nahia canal, another distributary in the area is an earthen canal. Its length is 4500 m and serves 1100 Fed. The canal operates for rotational flows: (4 days on and 8 days off).

Seepage Loss Estimation Using Ponding Method

Two canal ponding tests were carried out which are shown in Figure 5.

> The first was on a 278 m long concrete-lined stretch of Beni Magdoul canal. Soil is generally a mixture of clay and sand. Test was run for 54 hrs.
>
> The second was on a 245 m long unlined section of Nahia canal. Soil is clay and the test was continued for 75 hrs. Dams at both end of the reach were constructed from sand faced with clay.

The two tests were repeated in 1992 but for longer time periods. It should be noted that ponding test is useful where seepage is likely to be small. The seepage rate is determined from the rate of water loss and the wetted surface area. Two commonly employed methods for seepage rate calculation are:

(a) Falling water levels are either recorded at the start and end of the test, or at regular intervals. Corrections are made throughout for leakage through structures, rainfall, evaporation and wind effect etc.

(b) Constant level-water level remains unchanged by adding water to replace what is lost continuously throughout the test. A portable flow measurement structure such as, weir, flume, orifice is used to record inflows.

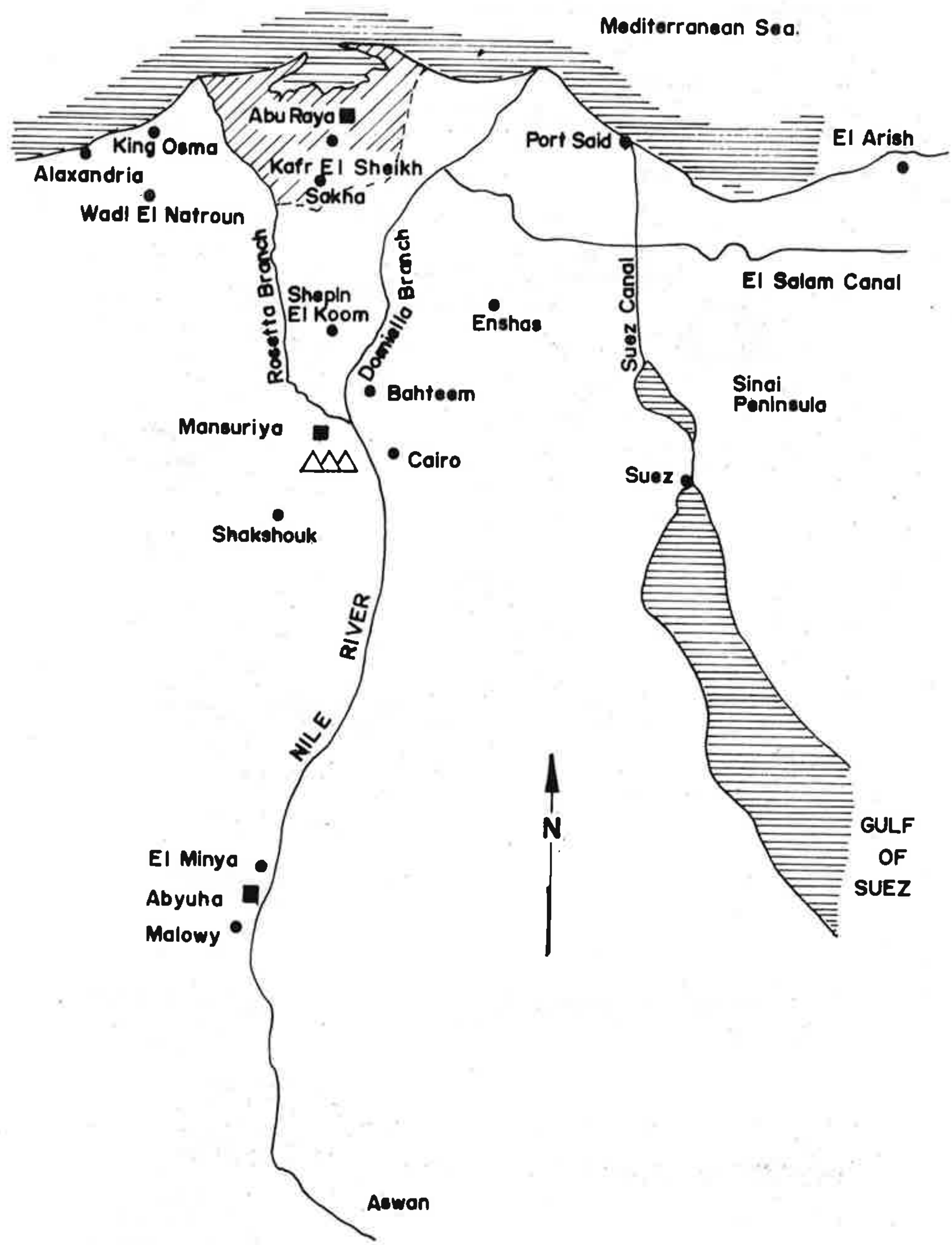


Figure 1. The Nile River in Egypt.

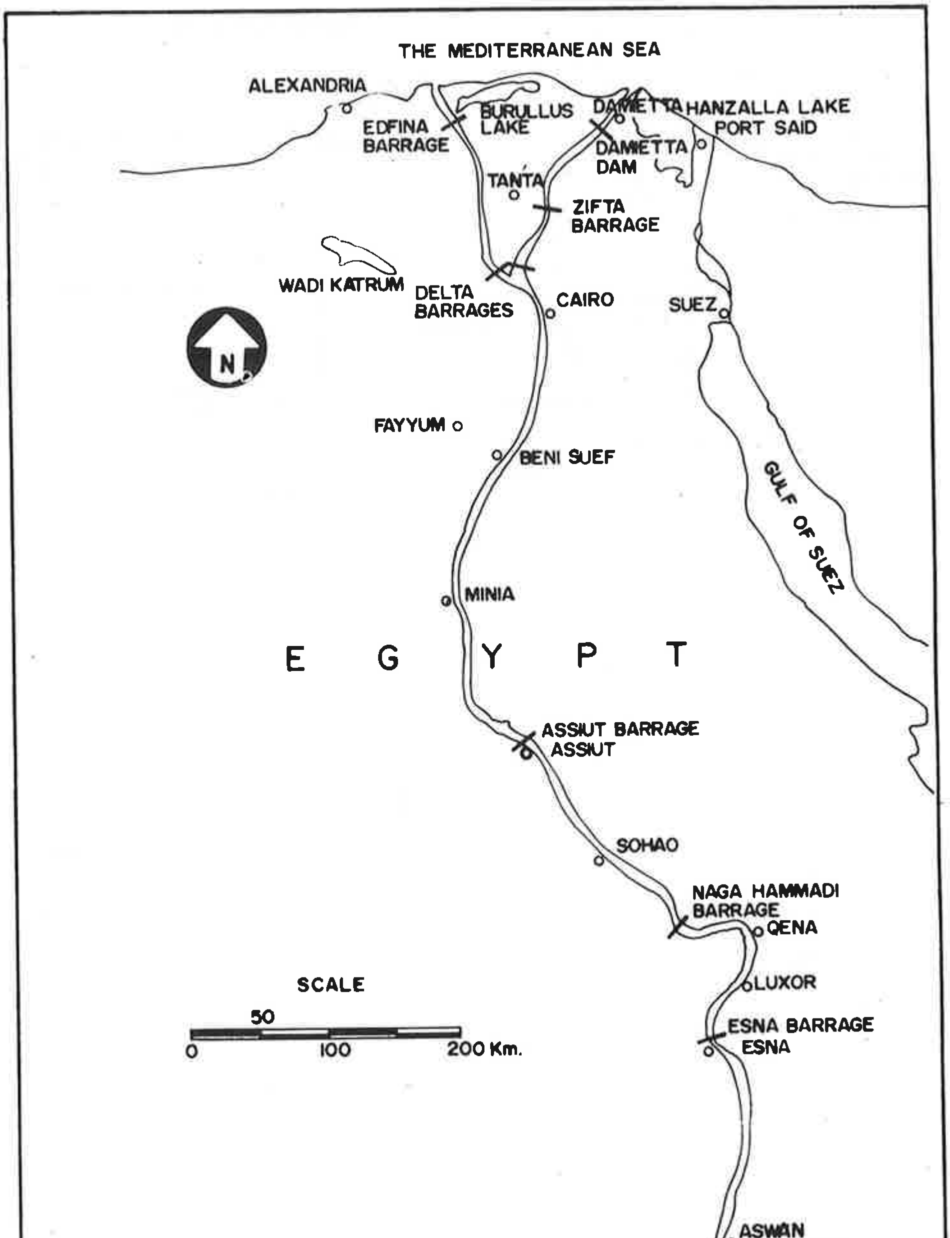
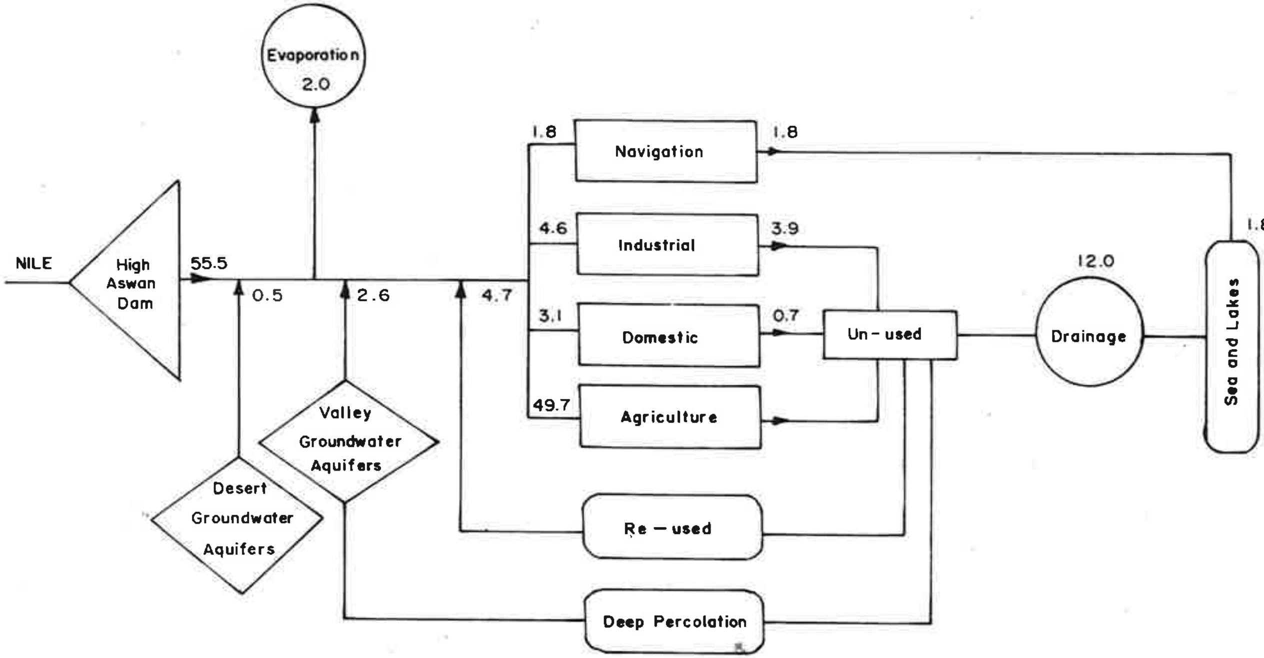
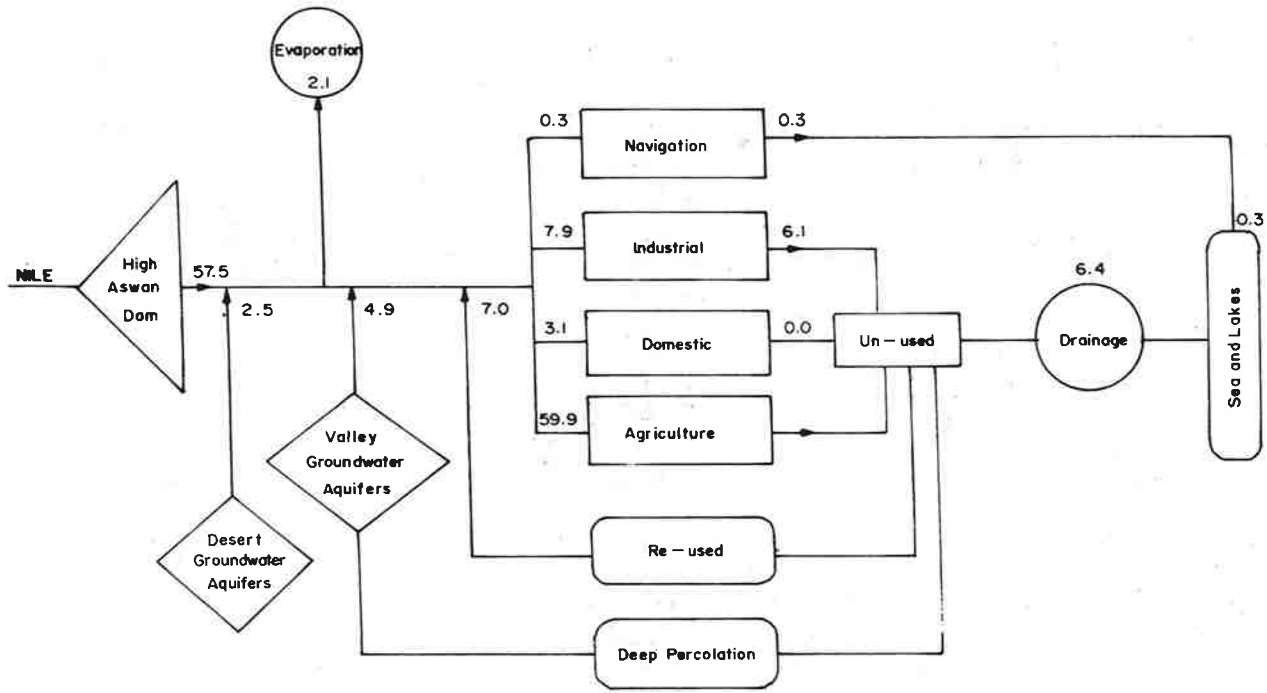


Figure 2. Engineering Works in the Nile Valley.



NOTE: Numbers are billion m^3/year

Figure 3. **Water Availability and Use in Egypt, 1990.**



Note: Numbers are billion m^3/year

Figure 4. Water Availability and Use in Egypt, 2000.

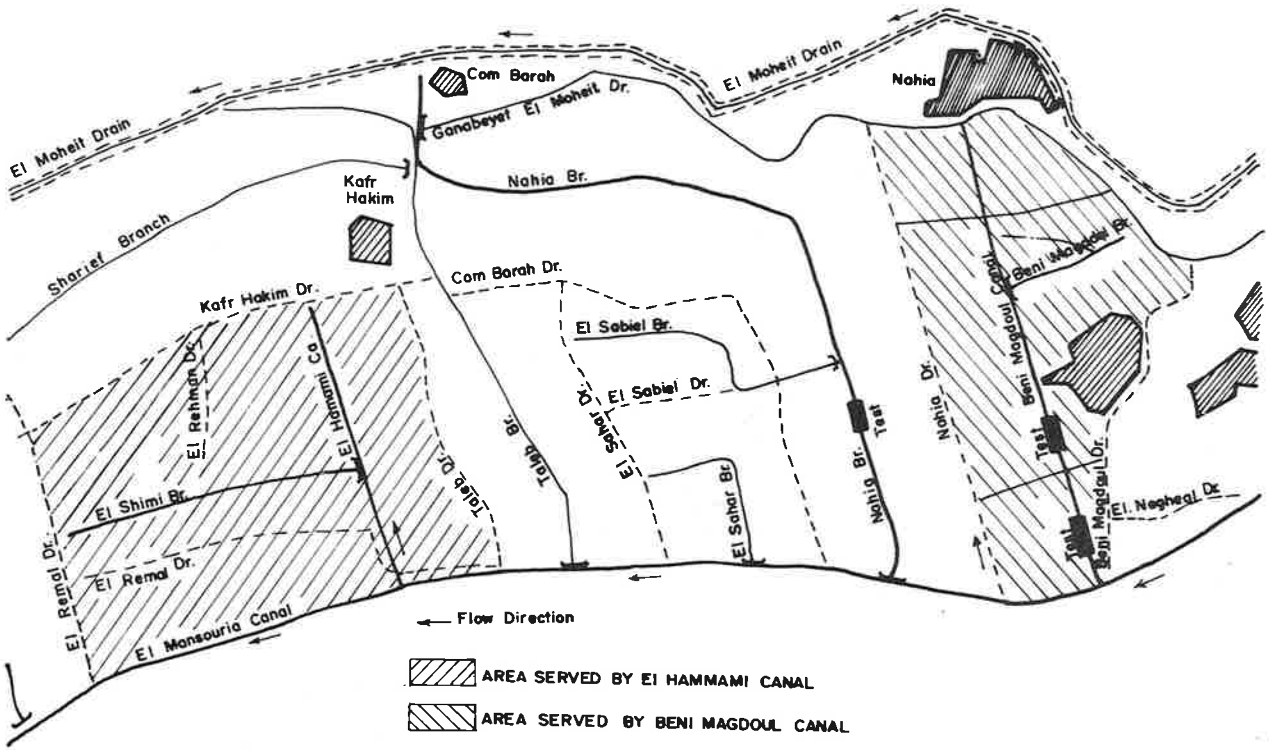


Figure 5. Location of Tests sites on Nahia and Beni Magdoul Canals.

In Beni Magdoul a hybrid test of the two methods was made. The reach was first filled to a level 1 cm above full supply level (FSL), and the level was recorded hourly until it dropped 1 cm below FSL, at which point the reach was filled again to its initial level. Hence seepage head was maintained fairly constant. The measured seepage loss is based on kraatz (1977) because he relates seepage to the wetted perimeter and hence to the canal size.

$$S_t = \frac{W_1(d_1 - d_2)\ L_1 + W_2(d_1 - d_2) + \ldots}{P_1 L_1 + P_2 L_2 + \ldots} - e$$

Where S_t	=	seepage in m^3/m^2/time interval/hrs.
d_1	=	depth of water at start of measurement in m.
d_2	=	depth of water at end of measurement in m.
W_1, W_2	=	average width of reach at sections 1,2 in m.
L_1, l_{-2}	=	Length represented by sections 1,2 in m.
P_1, P_2	=	average wetted perimeter in m.
e	=	evaporation in m/day.
t	=	time interval between measurements in hrs.

Assuming no rainfall or any other inflow.

A sample of test result for the 245 m reach, Nahia Canal Time of test 75 hrs, soil type, clay, design discharge 550 litre/sec., evaporation 0.007 m/day, seepage 0.010 m^3/m^2/day and estimated volume lost during the test was 88 m^3.

CANAL LINING EXPERIENCE IN EGYPT

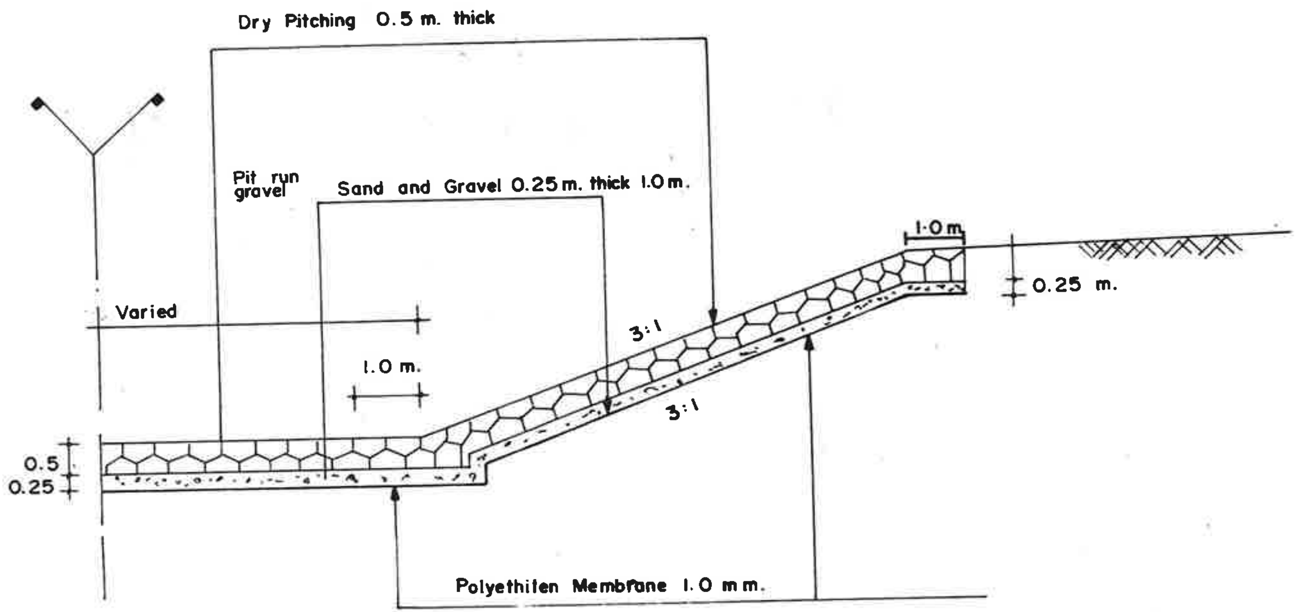
Lining of El-Bustan Canal

El-Bustan Canal is lined from its reach of 39 km to 55 km. Polyethylene membrane of 1.0 mm thickness under 0.25 m thick compacted layer of sand and gravel is used to line this section (Figure 6).

Lining of El Nasr Canal

EL Nasr Canal is located west of Nubaria, and it serves for irrigation and navigation. Construction of the canal included two phases (Figure 7):

a) Excavation, filling and to stabilize the layer underneath the lining material.



SCHEMATIC SKETCH OF EL. BUSTAN CANAL LINING FROM KM .39 TO KM .55 WHERE THE CANAL IS DRY AND ABOVE LAND LEVELS.

Figure 6. El-Bustan Canal Lining Sketch.

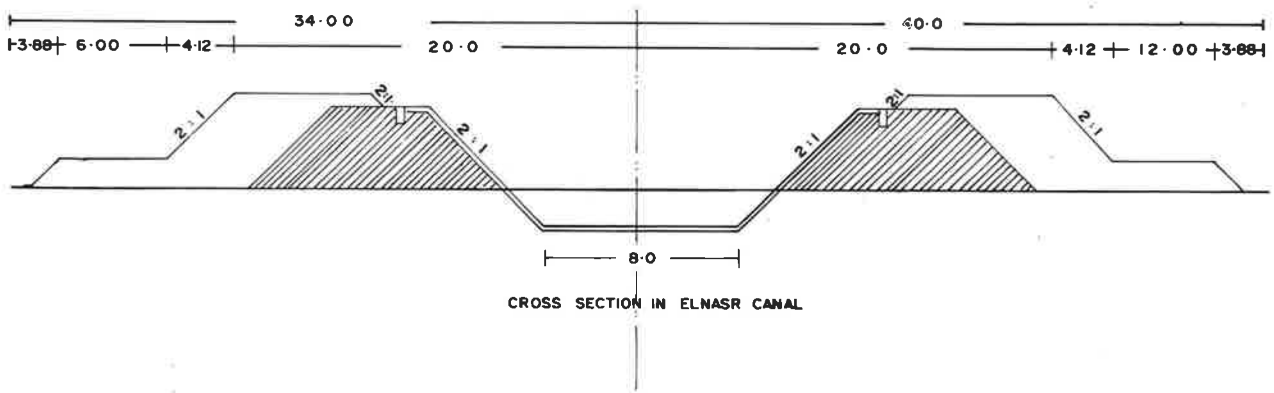


Figure 7. El-Nasr Canal Lining Sketch.

b) Concrete lining, joint and curing.

The first phase, consists of earth works:

- Excavation and filling of the canal cross-section, berms and embankments.

  The impermeable stabilized layer under the lining concrete cover. Its function is mainly to reduce water seepage and prevent concrete cover from slipping. Its use is essential if the natural land levels is below the designed levels of the berms and canal bed. Also if the soil underneath is expansive soil and contain percentage of calcium sulphate (Gypsum).

The soil used underneath the concrete lining has the following properties:

- Pure sandy soil/silty sandy soil/clayey sandy soil.
- The optimum water content and maximum dry density were determined by the proctor test.
- The liquid and plastic limits were determined to check the acceptable range.
- The specific gravity of the granular soil should not be less than 2.5.
- Dissolved salts should not exceed 2% and chalk not to exceed 40%.
- Gypsum not to exceed 5% in order not to affect cement.

Lining procedure was in three stages:

- Concrete curing.
- Forming the joints followed by its filling.

Special lining protection from seepage water.

- From Km.27 to 55.4, two trenches were dug at the bottom of lining 1.0 m from the toes (0.5x0.5m). This is to intercept seepage from lands.

- The two trenches were filled with soil filters.
- P.V.C. non-returnable valves were installed in a staggered pattern every 12 m along the canal center line. However it did not work due to sediment clogging.
- From Km.55.4 to 82 collector drains were made to drain excess water to the main drains.

THE USE OF SYNTHETIC MATERIALS IN CANAL LINING

Geotextile and related materials have been widely used for canal lining during the last few years (Figure 8). Egypt at present produces PVC.

They are usually made from only four synthetic polymers: *Polyamide, Polyester, Polyethylene* and *Polypropylene*. Two main types of fabrics used for Geotextile are:

a) Wovens
b) Non-Wovens

Woven geotextiles, are manufactured using weaving techniques.

Non-woven, are formed from filaments or fibers arranged at random and bonded together into a planer structure. This could be *Thermal* bonding, *Mechanical* bonding or *Chemical* bonding.

Manufacturing processes may produce:

Mats - generally between 10 and 20 mm thick with heat bonded nodes of a regular pattern.

Nets - consist of two sets of parallel stands which cross each other at a constant angle (60° - 90°).

Grids - regular holes in the sheet is gently heated and then stretched, in one direction *uniaxial* or two directions *biaxial*.

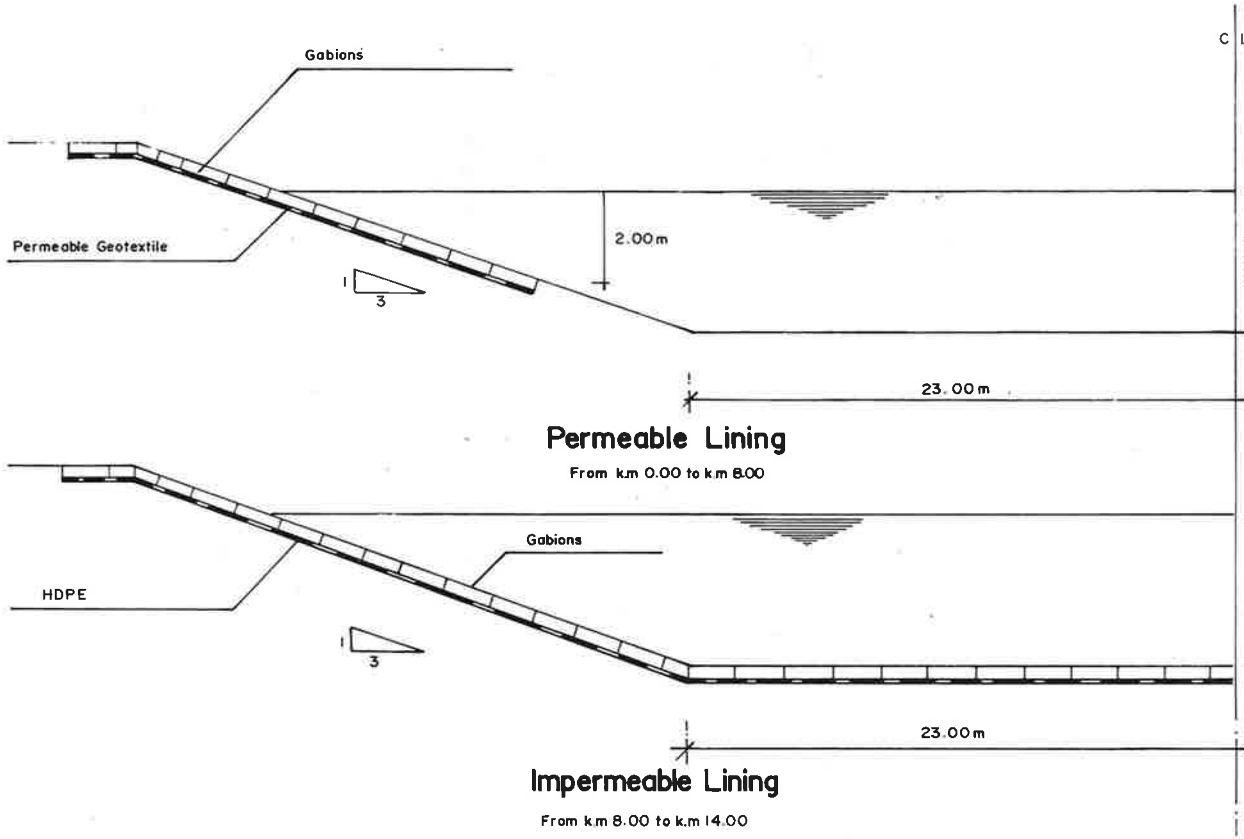


Figure 8. Typical Sections Showing Permeable and Impermeable Linings.

GEOCOMPOSITE MATERIALS

Functions are:

a) Separation.
b) Filtration.
c) Drainage.
d) Reinforcement.

Different test methods have evolved throughout the world. The Institute of Civil Engineers intends to publish "Specification for the Use of Geotextiles and Related Materials".

Index tests on parent materials are used for the following purposes:

1. Identification.
2. Quality control.
3. Comparison of manufacturer's products.
4. Some design analysis.
5. Specification writing.

Test conditions must be controlled to ensure consistent results:

1. The relative humidity of the testing lab.
2. The ambient temp. of the lab. and test samples.
3. The duration of the test.
4. The boundary conditions.

PHYSICAL PROPERTIES

Five index tests:

1. Mass/Unit Area BS 87/36561 minimum of 10 specimens, each 100 mm^2.

2. Nominal thickness/Dimensions BS 87/36562 geotextile sample is placed on a plane reference plate under pressure 2 KN/m^2. A vernier gauge measures the distance between the reference plate and pressure plate.

3. Apparent Pore size distribution by dry sieving BS 86/45317. Sieving dry spherical solid glass beads then measuring the amount retained by the fabric sample.

4. Percent open area determination for woven geotextiles US Water Ways Exp. Station AD-745-085. A small section of the Fabric is inserted into a projector and the magnified image traced on to a sheet of paper. Open spaces can be measured and expressed as a percentage of whole area.

5. Percentage contact area core/geotextile, a method developed by the University of Strathclyde. The protruding elements of the core of a geocomposite material are painted with ink and compressed on a sheet of plain paper.

REFERENCES

Kraatz (1977). Irrigation Canal Lining, FAO.

REPORT ON CANAL LININGS USED BY THE BUREAU OF RECLAMATION

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ABSTRACT

"Report on Canal Linings Used by the Bureau of Reclamation," summarizes over 90 years of experience the Bureau of Reclamation (Reclamation) has in lining irrigation canals in the United States of America. Reclamation has experimented with many materials for canal liners, but presently the main lining materials Reclamation uses are concrete linings, compacted earth linings, or buried plastic linings. Reclamation continues to experiment with lining materials and lining placement techniques as new lining materials are developed.

HISTORY

The following is a brief history of canal linings and canal lining studies performed by the Bureau of Reclamation (Reclamation). Also included is a statistical compilation of different types of linings expressed as a percentage of the total Reclamation canals constructed.

A. Lower Cost Canal Lining Program - The low cost canal lining program was initiated in June 1946, and for 16 years various canal linings were studied. During those 16 years, 2,993 miles of various types of canal linings were installed on Reclamation canals. A summary of the types of linings and lengths of installation used during the low cost canal lining program are shown in table 1. Table 2 shows a statistical compilation of total lengths and types of linings used on Reclamation canals until 1993.

B. Recent experience: 1986 to 1993 - Since 1986, Reclamation has constructed approximately 225 miles of new canals and rehabilitated approximately 28 miles of existing canals. Flows in these canals range from 3,000 cubic feet per second (cfs) to 90 cfs. Of these total lengths of canals, only 7 miles of canal were unlined because the in place conditions made lining not necessary. In one length of canal the Plasticity Index of the in place soil was greater than 12, making lining unnecessary, and in another case the canal transported water through an area of high groundwater making lining unnecessary.

Table 1. **Quantities of Canal Linings Placed on Reclamation-operated Canals (1946-1962).**

TYPE OF LINING	SQUARE YARDS	MILES
EXPOSED LINING		
Asphaltic concrete (hot and cold mix)	276,000	42.0
Asphaltic macadams	11,000	0.8
Asphalt surface membranes (prefabricated and constructed-in-place)	81,000	10.3
Other exposed asphalt linings (mortars, blocks, and slabs)	8,000	0.7
Portland cement concrete (unreinforced)	23,690,000	1,077.5
Portland cement concrete (reinforced)	9,738,000	419.9
Portland cement mortar (pneumatically applied) (shotcrete)	1,919,000	167.6
Soil cement	37,000	3.7
Other exposed linings (concrete blocks, plastic and rubber surface membranes, etc.)	8,000	6.8
BURIED MEMBRANE LININGS		
Asphalt (hot-applied)	5,839,000	333.1
Asphalt (prefabricated)	24,000	2.1
Bentonite	300,000	19.6
Plastic	22,000	1.2
EARTH LININGS		
Thick compacted earth	12,152,000	566.2
Thin compacted earth	1,885,000	74.3
Loosely placed earth blankets	3,207,000	174.9
Bentonite-soil mixture	108,000	6.1
Soil sealants (chemical, petrochemical and sediment)	535,000	41.2
MISCELLANEOUS		
Includes resurfacing of existing linings, their undersealing and grouting, and the construction of cast-in-place concrete pipe in lieu of lining	144,000	45.8
TOTAL	59,980,000	2,993.8

Table 2. Percentages of Types of Linings on Reclamation Canals.

TYPE OF LINING	FROM 1946 TO 1962 (3,000 MILES)	1963 TO 1993 (1,650 MILES)	TOTAL USBR CANALS (6,850 MILES)
Concrete (reinforced, unreinforced, shotcrete, etc.)	56%	55%	57%
Buried Membrane			
Hot asphalt	11%	-	5%
Plastic	0.00004%	8%	2%
Other	0.007%	-	2%
Compacted earth	19%	37%	28%
Other	14%	-	8%

The linings used on these canals were approximately 140 miles of earth lining, 40 miles of polyvinyl chloride (PVC) membrane lining, 56 miles of unreinforced concrete lining, 5 miles of reinforced concrete lining, 2 miles of shotcrete lining, and 3 miles of specialty nontraditional linings. Reclamation has also worked with various water districts in the United States to study specialty nontraditional linings that these districts have used for special applications.

SELECTION OF TYPE OF LINING

Linings most prevalent at the present time are unreinforced concrete, thick compacted earth, and buried PVC geomembrane. Figures 1 through 4 are a series of flow charts that may be used as an aid for laying out concrete or earth canal systems. It should be emphasized that these charts are for general layout or design of canal systems and engineering judgment must be exercised when special considerations arise. The majority of the charts devoted to earthlined sections may be used for buried membrane sections. Figure 5 shows the freeboard requirements for the various linings.

LINING

COMPACTED EARTH

Lining Material
P. I. = 12 MIN., L. L. = 45 MAX.

Use only for
Q > 1.4 cms

THICKNESS OF EARTH LINING

d	t_1	t_2
0.6 or less	0.3	0.9
0.6 to 1.2	0.45	1.2
1.2 to 1.8	0.6	1.8
1.8 to 6.1	0.6	2.4
> 6.1	0.9	2.4

FREEBOARD FOR EARTH LINING

Q	H
≤ 6	0.15
6 to 10	.189 (log Q) + .003
10 to 600	.252 (log Q) − .06

For explanation of symbols see Figure 4

Note: These charts may be used for general layout and/or design, but engineering judgement should be used if unique or special conditions arise.

UNREINFORCED CONCRETE

THICKNESS OF CONCRETE LINING

Q	t
0. to 15	65
15 to 45	78
45 to 100	90
100 to 215	102
215 to 600	115

CONTRACTION JOINT SPACING

Transverse		Longitudinal	
t	C-C	P	C-C
65	3	< 6	None
78	3.7	≥ 6	Maximum spacing same as Transv. C-C
90	4.3		
102	4.5		
115	4.5		

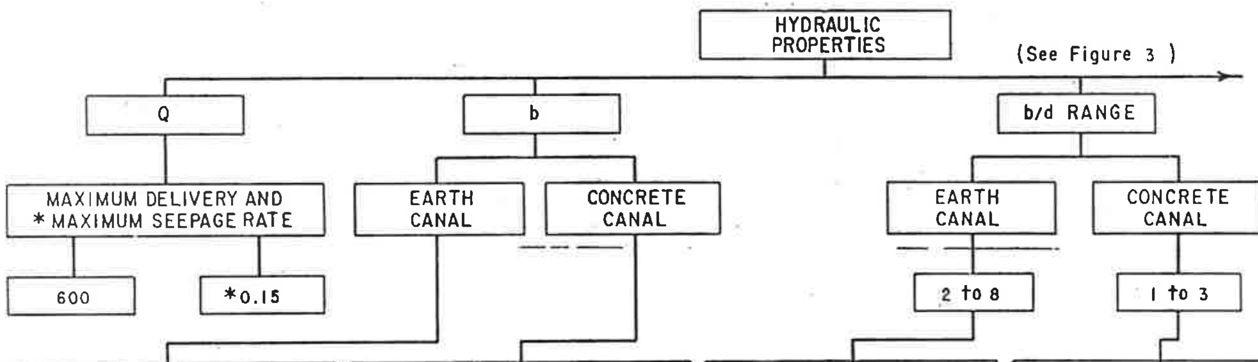
WIDTH OF LIP (L)

Q	L
0 to .85	100
.85 to 8.5	150
> 8.5	200

FREEBOARD FOR CONCRETE LINING

Q	H
≤ 1.0	0.15
1.0 to 3	.12 (log Q) + .15
3 to 10	.23 (log Q) + .10
10 to 40	.34 (log Q) − .01
40 to 600	.36 (log Q) − .05

Figure 1. Canal Design Charts - Physical Properties.



Q	b
1.5 to 3	1.99 (log Q) + 1.55
3.0 to 7	3.26 (log Q) + 0.94
7.0 to 13	4.83 (log Q) - 0.38
13 to 25	5.97 (log Q) - 1.05
25 to 40	12.00 (log Q) - 9.48
40 to 70	15.84 (log Q) - 15.63
70 to 130	19.71 (log Q) - 22.77
130 to 210	29.77 (log Q) - 44.03
210 to 300	44.54 (log Q) - 78.34
300 to 440	60.72 (log Q) - 118.42
440 to 600	93.54 (log Q) - 205.17

Q	b
≤ .1	0.3
0.1 to .4	0.6
0.4 to 0.85	0.9
0.85 to 1.7	1.2
1.7 to 2.8	1.5
2.8 to 7	1.8
7 to 20	0.99 (log Q) + 0.97
20 to 50	3.14 (log Q) - 1.84
50 to 80	6.86 (log Q) - 8.15
80 to 120	13.06 (log Q) - 19.96
120 to 190	19.04 (log Q) - 32.39
190 to 280	25.53 (log Q) - 47.19
280 to 400	38.73 (log Q) - 79.49
400 to 600	61.90 (log Q) - 139.77

Q	b/d Minimum
1.4 to 2.8	2
2.8 to 14	2.5
14 to 28	3
28 to 71	3.5
71 to 141	4
141 to 212	5
212 to 283	6
283 to 425	7
425 to 600	8

Q	b/d Minimum
0.014 to 0.71	1.0
0.71 to 14	1.2
14 to 71	1.3
71 to 141	1.5
141 to 212	1.8
212 to 283	2.0
283 to 425	2.5
425 to 600	3.0

For Explanation of Symbols see Figure 4

Note: These charts may be used for general layout and / or design, but engineering judgement should be used if unique or special conditions arise.

* Maximum allowable seepage rate before lining is required $(m^3/s/)/m^2/day$

Figure 2. Canal Design Charts - Hydraulic Properties 1.

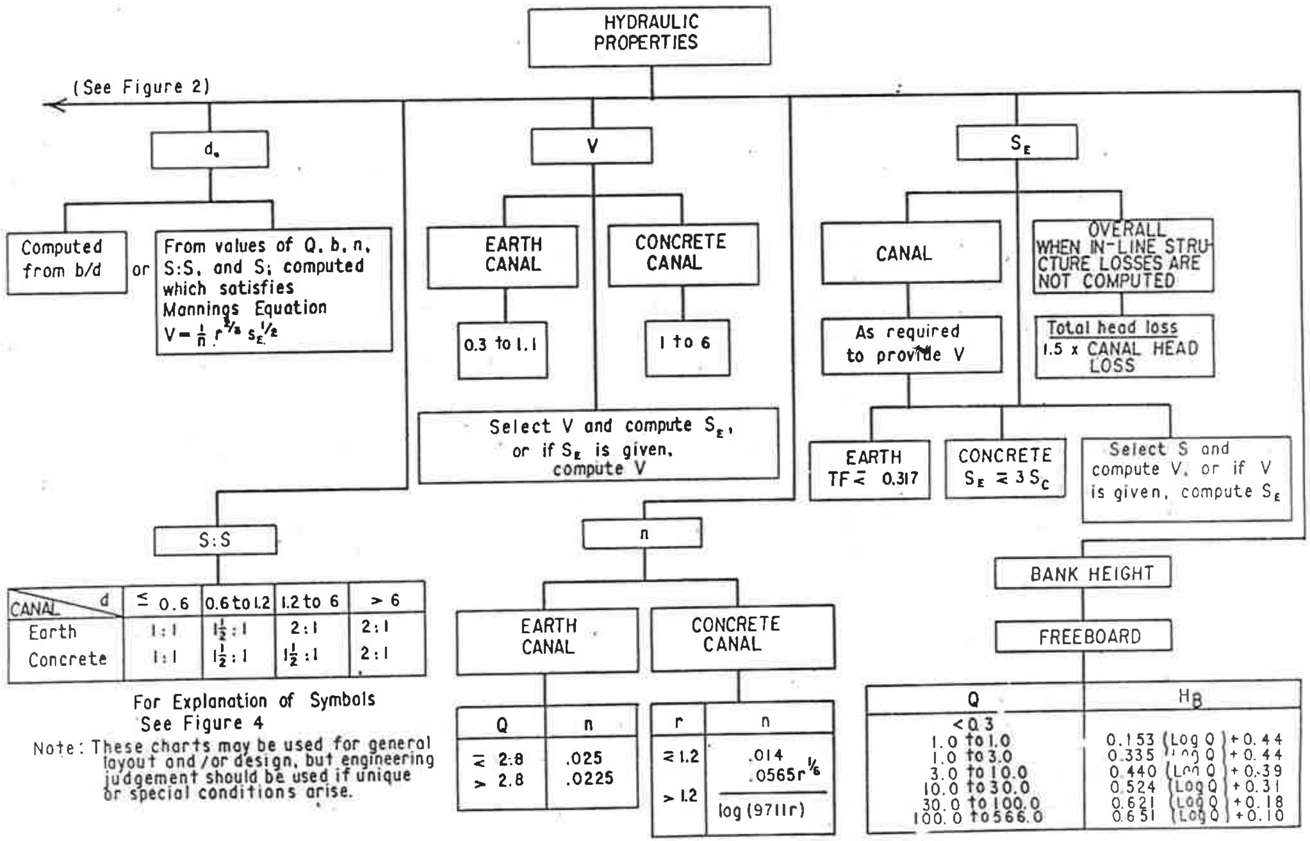
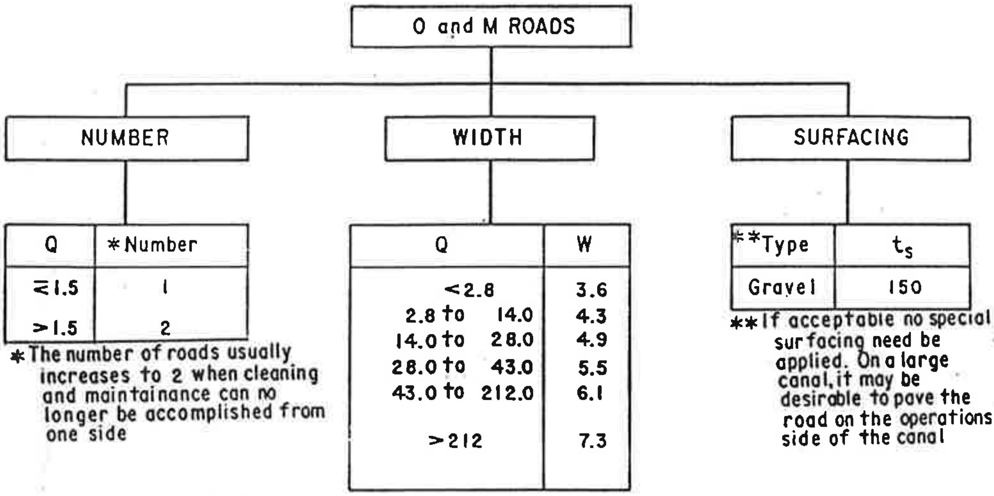


Figure 3. Canal Design Charges - Hydraulic Properties 2.



Explanation of Symbols:

- d = Normal depth (m)
- NWS = Normal water surface
- t = Thickness of concrete lining (mm)
- t_1 = Vertical thickness of earth lining at invert (m)
- t_2 = Horizontal thickness of earth lining along sideslopes (m)
- b = Canal bottom width (m)
- Q = Canal design capacity (cms)
- V = Canal Velocity (m/sec)
- r = Hydraulic radius (m)
- n = Mannings "n"
- S_E = Energy slope
- S_C = Critical energy slope
- S:S = Canal sideslopes (Horizontal/Vertical)
- H_E = Height of earth lining above NWS (m)
- H_C = Height of concrete lining above NWS (m)
- H_B = Height of bank above NWS (m)
- L = Width of lining lip (mm)
- P = Perimeter of concrete lining (m)
- C-C = Center to center spacing of contraction joints
- TF = Tractive force (1000 ds) (Kg/m^2)
- W = Width of O and M Road (m)
- t_s = Thickness of gravel surfacing (mm)
- L.L = Liquid Limit
- P.I. = Plasticity Index

Figure 4. Canal Design Charts - Operation and Maintenance Roads.

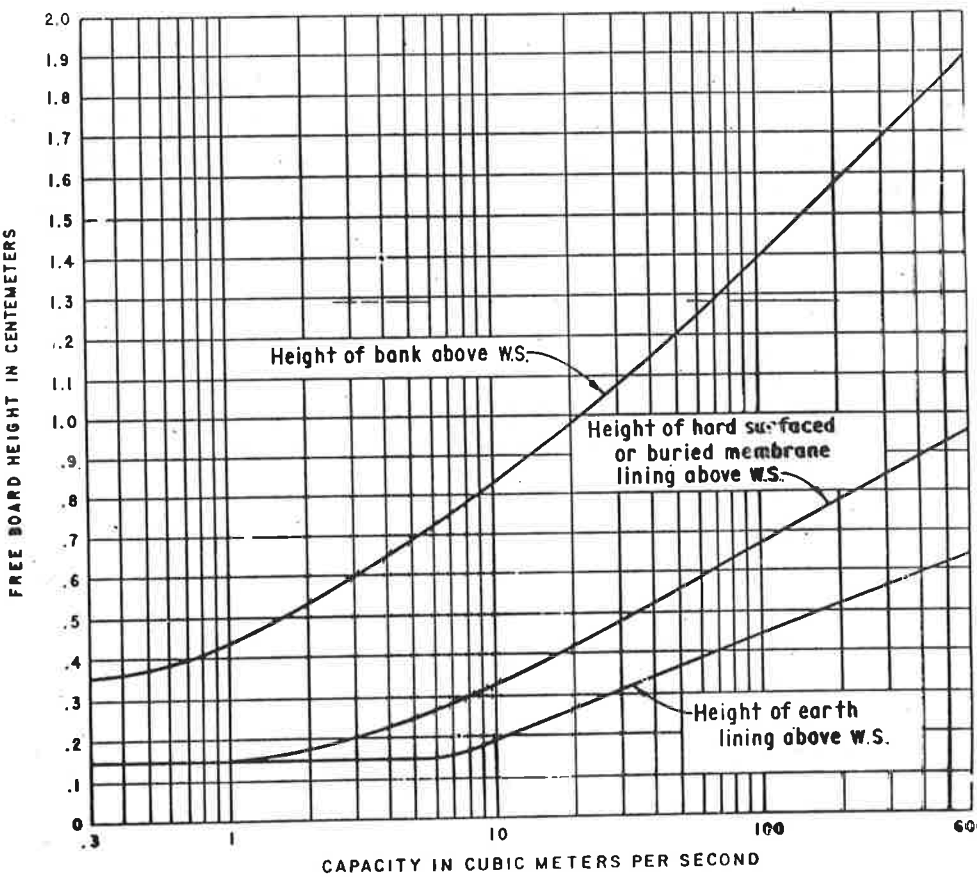


Figure 5. Freeboard and Bank Height for Canal Sections.

It is the policy of Reclamation to line open channels to conserve water and secure other benefits. There are many factors that could influence the type of lining chosen, and no single type of lining can be recommended for all lining requirements. A full economic evaluation should be conducted which would include an evaluation of land and water values along with estimates of construction costs and operation and maintenance costs for the various lining options considered. In addition to economics, other factors such as location, climatic conditions, construction considerations, environmental concerns, operational and maintenance concerns, experience gained on existing systems, and general sound engineering judgment must be considered before a final choice is made. General Reclamation criteria for each type of lining are discussed in the following sections.

CONCRETE LINING

Concrete lining has been successfully used on many Reclamation projects. Figures 6 and 7 show typical sections and details for both reinforced and unreinforced concrete lining, while Figure 8 shows lining thickness requirements vs. canal capacity.

Concrete lining has certain hydraulic and structural characteristics that tend to make it a desirable alternative at many locations. Higher flow velocities can hinder silt deposits and some kinds of aquatic growth. Furthermore, concrete lining has better hydraulic characteristics along with steeper allowable side slopes, usually 1½:1, resulting in a smaller canal prism which will reduce the right-of-way required for construction. Since less land is required, this can reduce right-of-way cost. Concrete is also a common construction material and may be the most economically available lining in some locations. Contractors are generally familiar with construction methods and equipment used for concrete lining. Concrete produces a barrier which generally gives it a low rate of seepage, presents an impenetrable barrier against burrowing animals, and significantly reduces weed growth in the canal prism. Finally, from a safety standpoint, concrete lining may be reinforced in high hazard areas giving it added structural capabilities, and this factor alone may preclude using other types of lining.

Many different methods have been used to provide as watertight a system as possible at the construction joints in concrete lining. Current Reclamation policy is to use PVC strips placed in the lining or elastomeric sealant placed in preformed grooves, these alternatives are shown on Figure 9. If alternative No. 3 is chosen for the transverse joints, care must be taken to provide a large enough radius between the canal invert and the side slopes to ensure proper placement of the strip. Spacing criteria for contraction joints are shown on Figure 1. If canals with elastomeric sealant are left unwatered for a long period of time, the sealant may deteriorate by exposure to the sunlight.

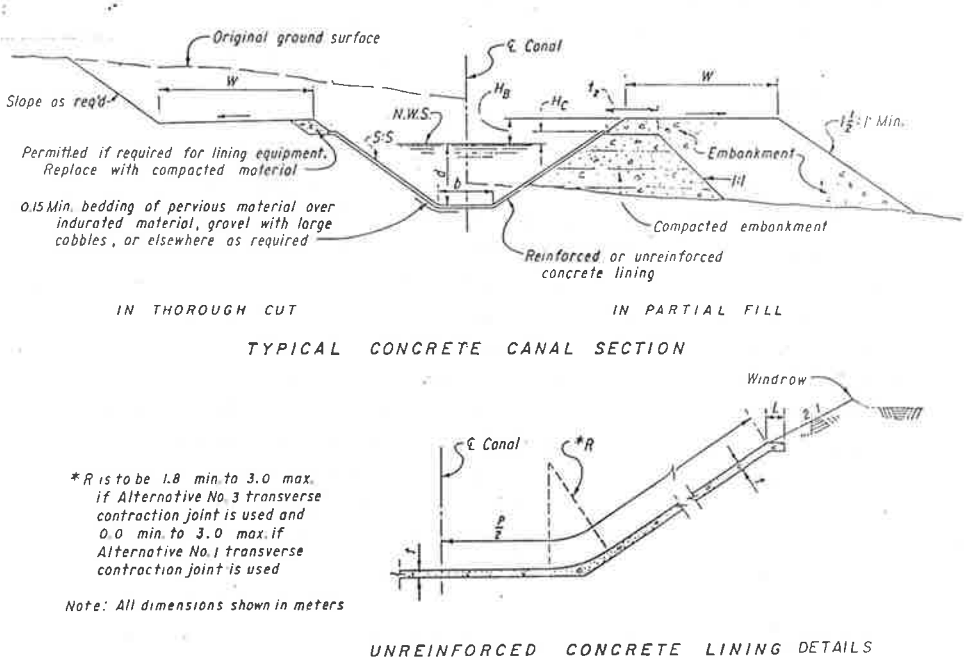


Figure 6. Typical Concrete Canal Section and Unreinforced Concrete Lining Details.

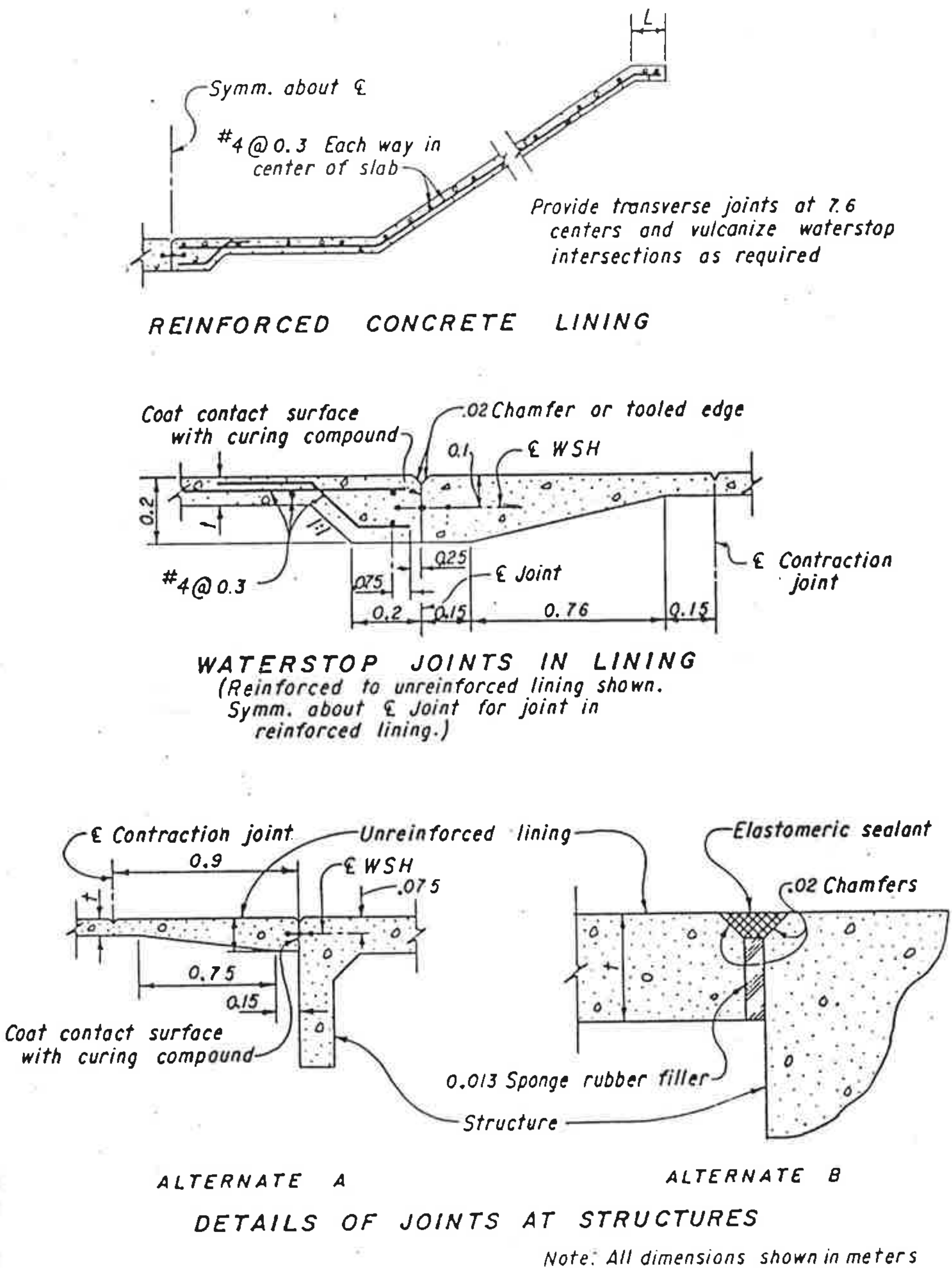


Figure 7. Reinforced Concrete Lining and Miscellaneous Details.

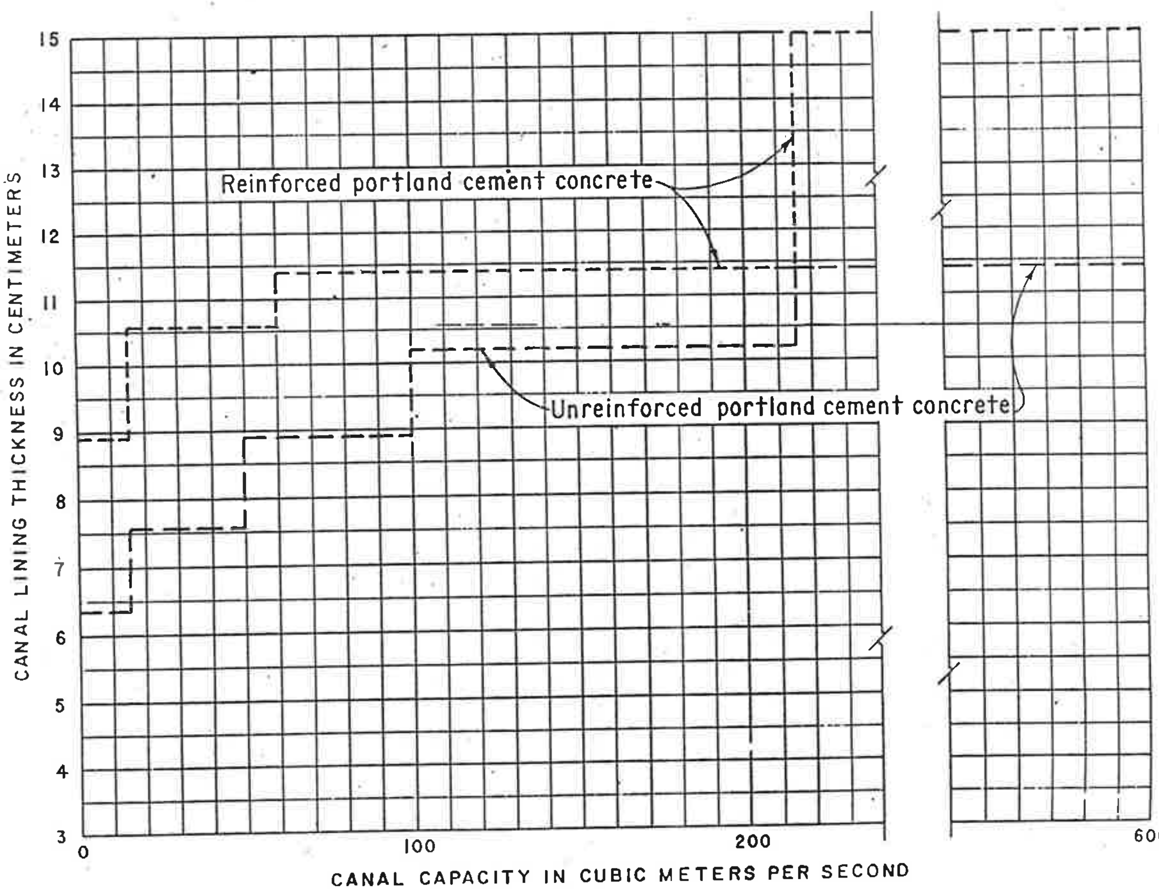
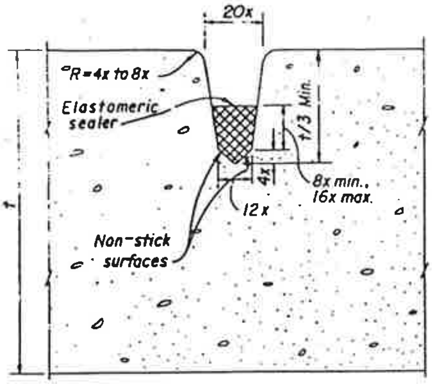


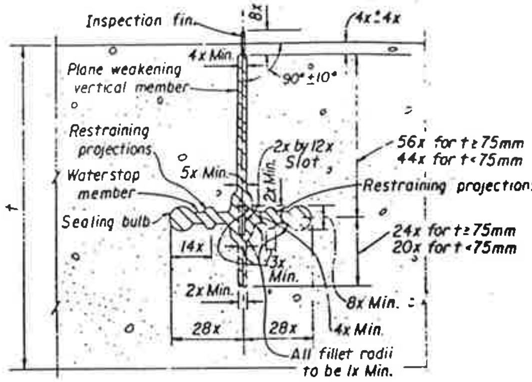
Figure 8. Thickness of Hard-Surfaced Lining for Use in Canals.



LONGITUDINAL OR TRANSVERSE JOINT

ALTERNATIVE No. 1

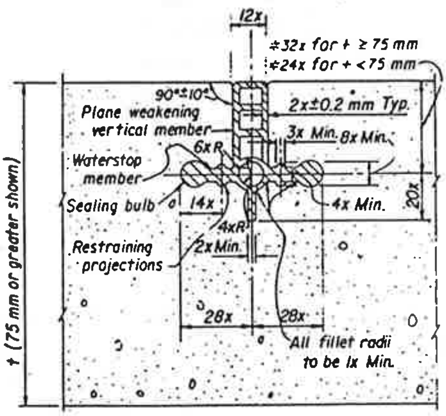
(ELASTOMERIC SEALER)



LONGITUDINAL JOINT ONLY

ALTERNATIVE No. 2

(POLYVINYL CHLORIDE STRIP)



TRANSVERSE JOINT ONLY

ALTERNATIVE No. 3

(POLYVINYL CHLORIDE STRIP)

** 32x Plane weakening vertical member to have 3 equal cells and 24x plane weakening vertical member to have 2 equal cells.*

NOTES

All dimensions shown in millimeters (x=0.793875 mm).

A longitudinal joint of one alternative may be used with a transverse joint of another alternative provided a reasonably close fit is obtained at intersections.

NOTES PERTAINING TO ELASTOMERIC ALTERNATIVE:

Grooves for Alternative No. 1 shall be formed and concrete curing compound in the grooves shall be removed by sandblasting. The bottom surfaces of the groove shall have a non-stick surface (teflon tape, etc.) or place a back-up rod or other filler in the bottom of the groove to prevent bond between these surfaces and a the elastometric sealant.

NOTES PERTAINING TO PVC (POLYVINYL CHLORIDE) ALTERNATIVE:

Diameter of sealing bulb shall be at least twice the thickness of the waterstop member.

Shape of the restraining projections is not defined.

Shape of the plane weakening vertical members above and below the center bulb for Alternative No. 2 and below the center bulb for Alternative No. 3 is not defined, except that the members shall be sufficiently rigid to insure installation in the specified shape and position.

Weight of the PVC strip shall be a minimum of 460 g/m for the 56x Alternative No. 2 strip, 420 g/m for the 44x Alternative No. 2 strip and the 32x Alternative No. 3 strip, and 390 g/m for the 24x Alternative No. 3 strip.

Where PVC strip is used in the longitudinal direction, cut 75 mm out of the top of the plane weakening vertical member at intersections and place transverse joint through slot.

Figure 9. Typical Lining Contraction Joint Details.

Higher velocities and steeper side slopes present a greater hazard to humans or animals that enter the canal when water is flowing. Safety ladders, as shown in Figure 10, must be installed to allow exit by humans. Animal escapes may be required in areas of deer concentrations. Fencing required to restrict access by people, livestock, and/or deer can vary from four-strand barbed wire fence for livestock to a 6-foot chain link fence topped with barbed wire.

There are some special foundation considerations for the concrete lining to perform satisfactorily. Concrete lining can be damaged by expansive earth foundation materials; therefore, special foundation preparation, such as overexcavation and replacement with suitable material or lime treatment of the in place expansive material, may be required during construction. Thin concrete lining must have a smooth, uniform foundation. Small continuous foundation ridges as small as ½ inch in height will typically cause a crack in the lining. Low density material that has historically never been wet usually has the potential for collapse upon saturation. These areas should be treated by removal and recompaction or by prewetting. Cracks in the lining should be repaired as soon as possible to keep water from reaching potentially troublesome foundation material. Reclamation has some limited experience of treating low density loessial material by a method of silt injection to consolidate the loose material. Soil stabilization by silt injection, may be used after construction as problems develop in areas that were not identified prior to or during construction.

Hydrostatic pressure in the soil behind the concrete lining can cause the lining to uplift and crack. Improper storm drainage that allows water to enter behind the lining or cracks in the lining that could introduce enough water to create a localized high groundwater or a naturally occurring high groundwater will cause this damage if the water surface in the canal drops faster than the pressure behind the lining can be reduced. Damage due to hydrostatic back pressure can be mitigated by restricting operational fluctuations and/or by installing an underdrainage system. Underdrain systems that drain by gravity to natural low areas along the canal, or to a pump sump if no natural low areas are available, have been the most reliable at protecting the lining where hydrostatic back pressure or groundwater exist. Figure 11 shows details of a typical gravity drainage system. It is important to provide a properly designed filter around the underdrain pipe to preclude the possibility of piping earth material into the underdrain pipe if a large leak develops in the canal lining. The outfall of these drainage systems should be monitored for a radical change in flow or turbidity in the flow. If either of these occurs, then the valve at the outfall should be closed and the leak should be found and repaired. A flap valve weep drainage system, similar to that shown on Figures 12 and 13, may also be very effective but is not recommended in hard freeze locations.

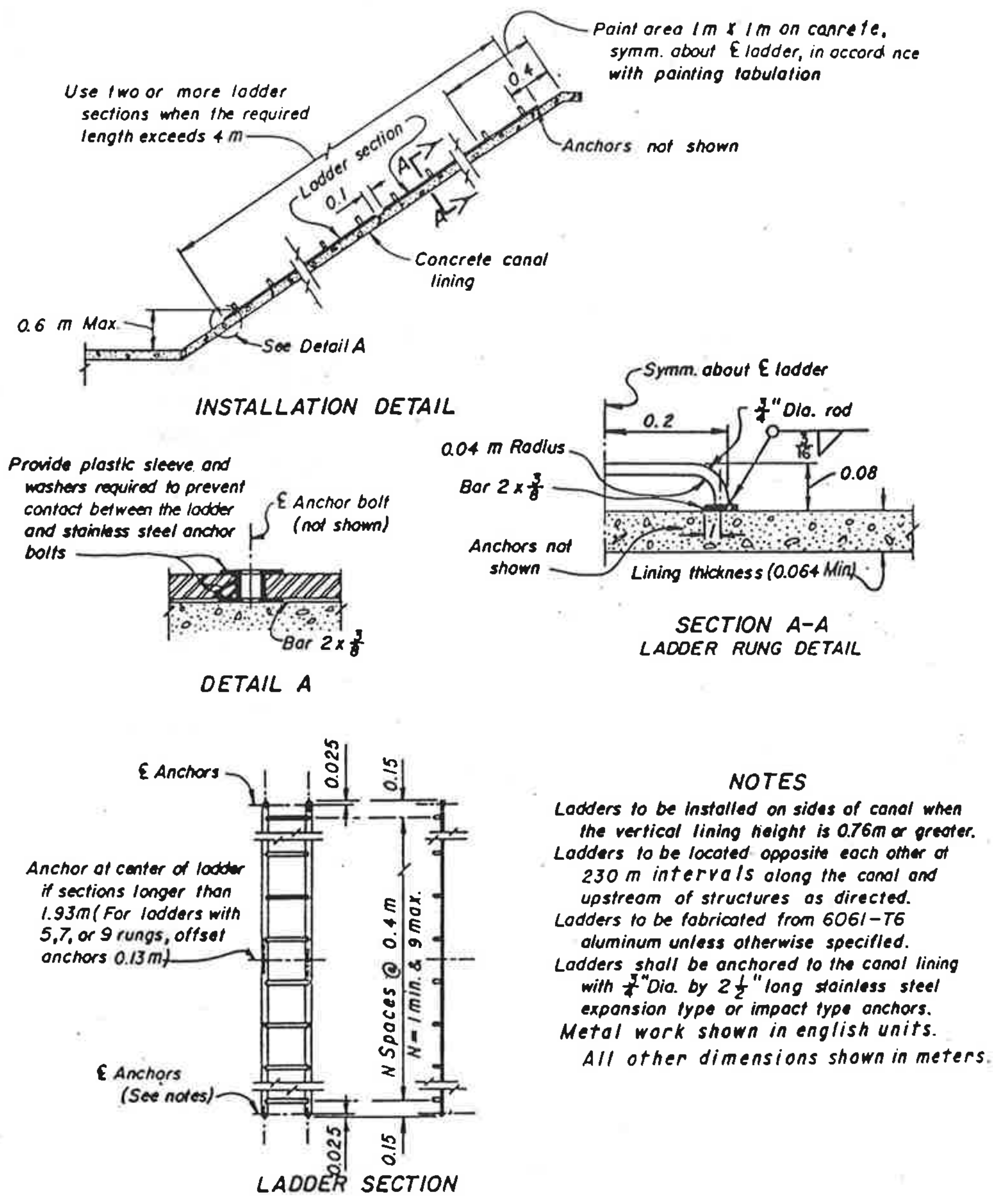


Figure 10. Safety Loaders for Concrete Lined Canals.

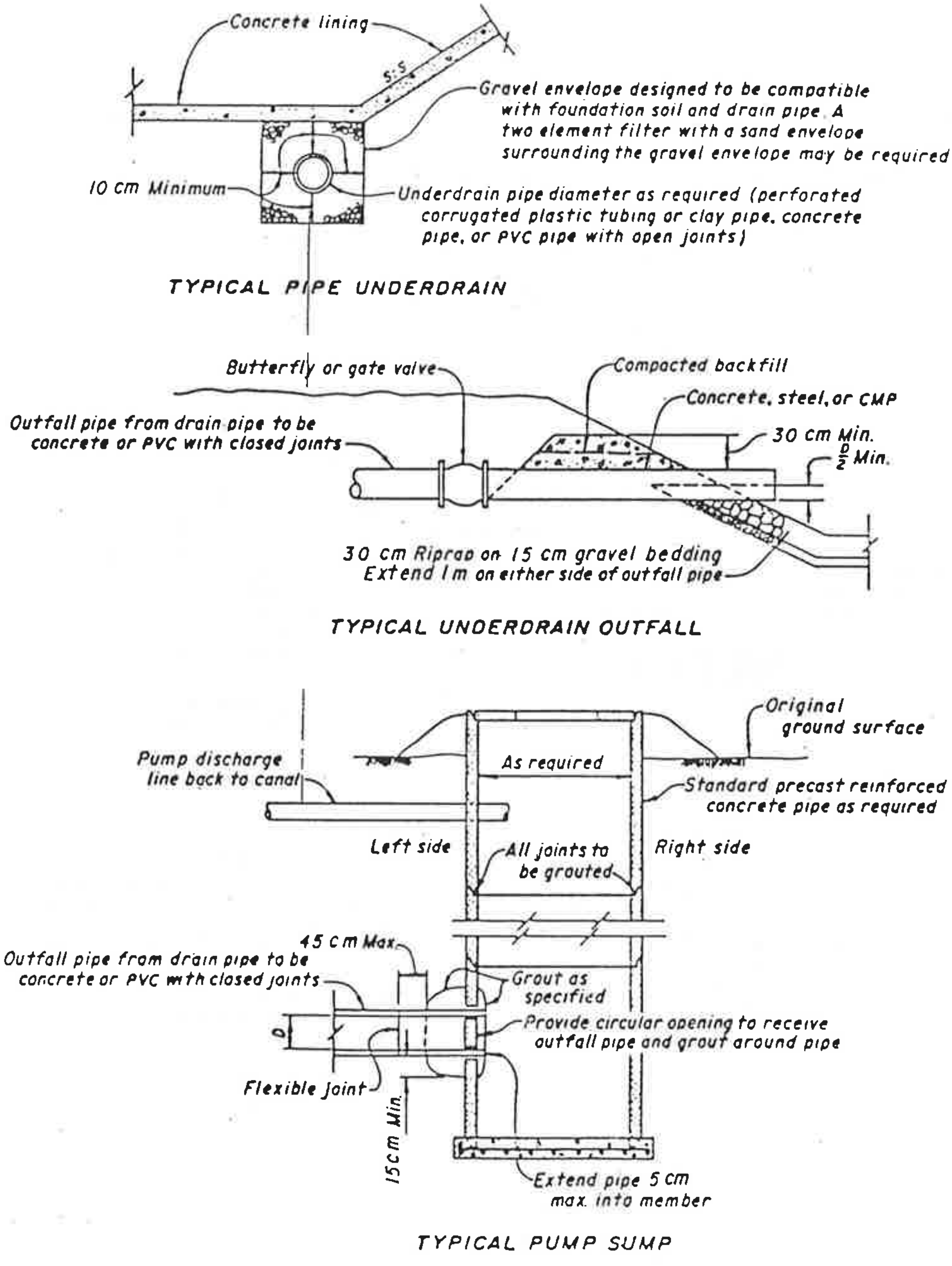
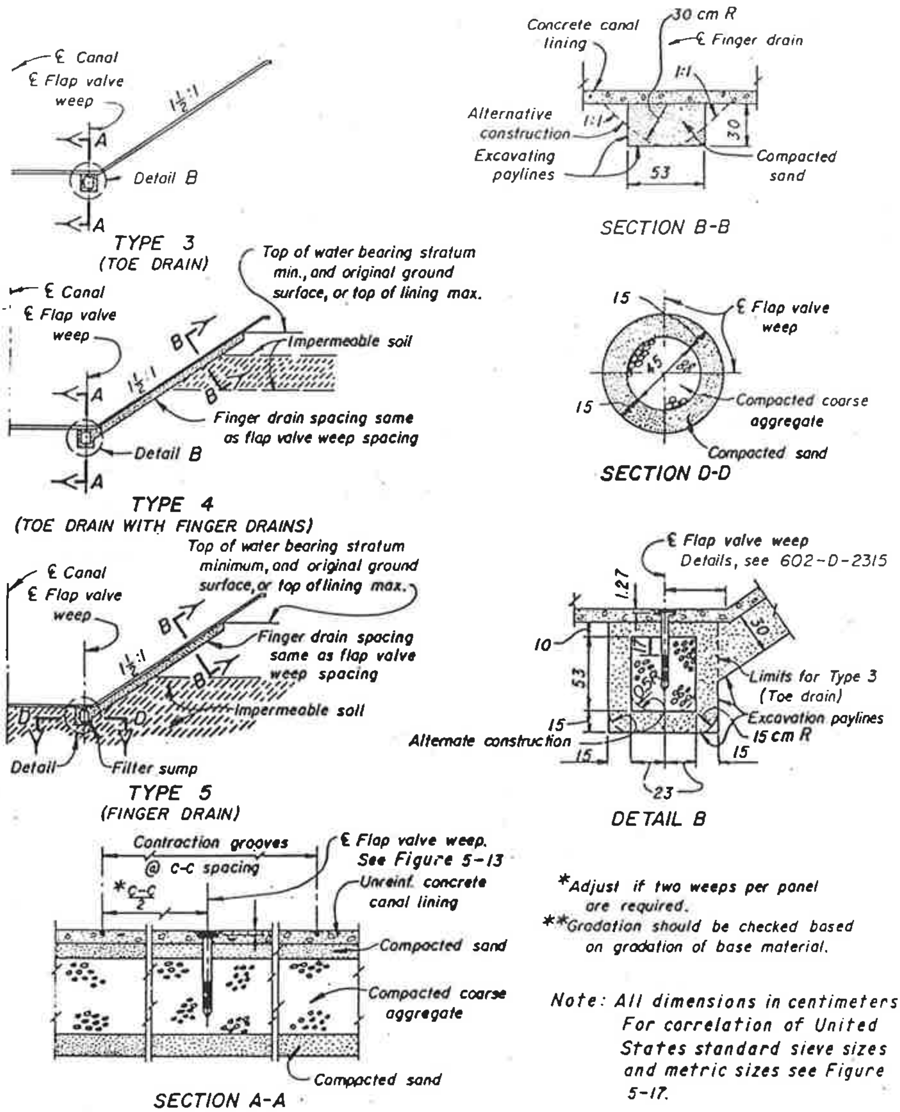


Figure 11. Gravity Underdrainage System for Concrete Lining.



**GRADATION OF FILTER MATERIAL

FILTER MATERIAL	PERCENT (BY WEIGHT) RETAINED ON STANDARD SIEVE						
	#30	#16	#8	#4	3/8	3/4	1 1/2
Sand	95-100	50-80	20-50	5-15			
Coarse Aggregate				95-100	50-80	20-50	0

Figure 12. Flap Value Weep Underdrains for Concrete Lining.

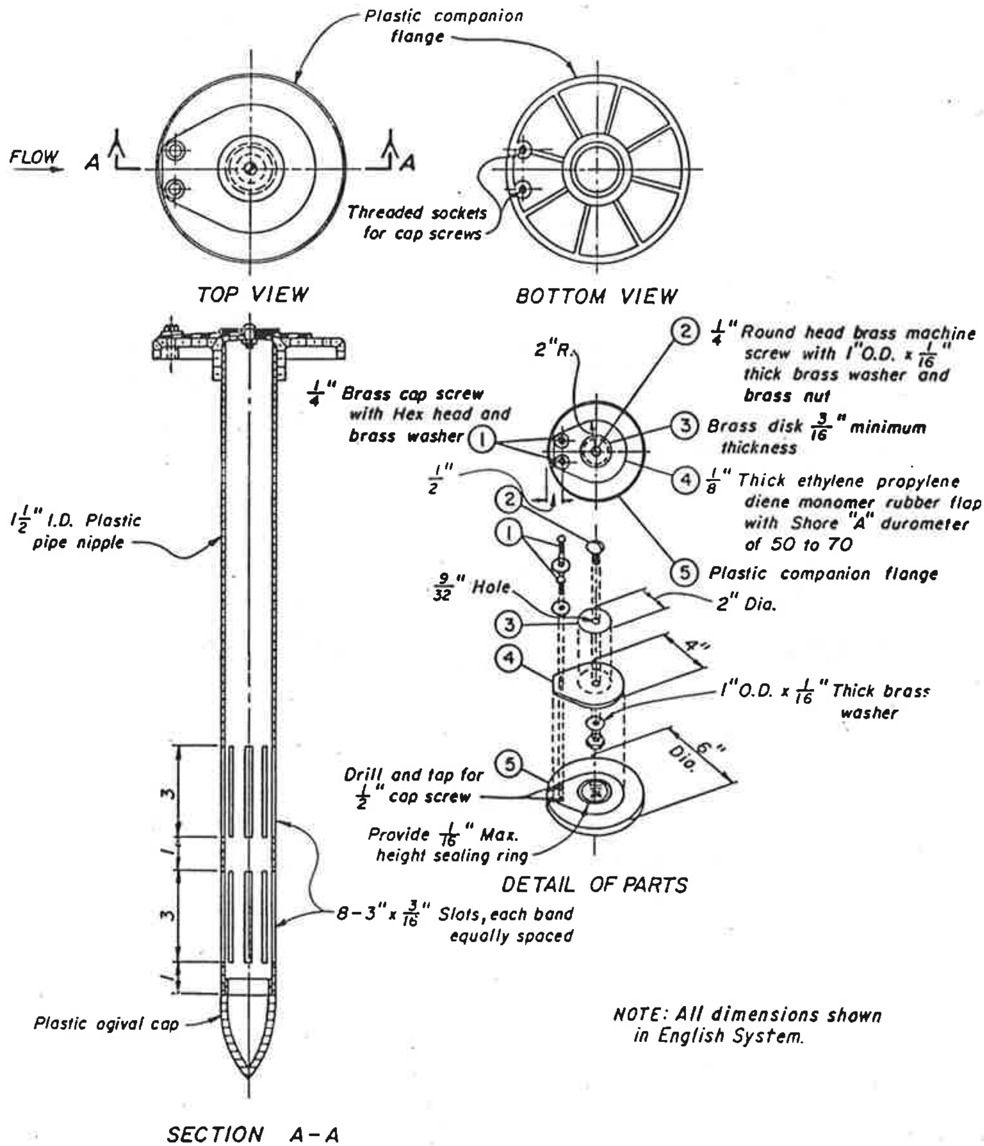


Figure 13. Flap Valve Weep Details

The flap valve weeps must be back flushed after they are inserted through the fresh concrete lining to flush out any concrete that may have entered through the slots during installation. When the flap valve weeps are installed in the Type 5 finger drains, as shown on Figure 12, special precautions are required to ensure the flap valve weep are located within the gravel envelope. The flaps must be aligned with the direction of flow as shown on Figure 13 to minimize the adverse effect of trash and sediment on the operation of the flap. It is also recommended to place the flap valve weep assemblies only in the invert of the canal, as the flaps tend to twist when open and at times do not close properly if installed on the canal side slope.

Exposure to the varying weather conditions presents special problems for concrete lining. In colder climates frost heave can damage concrete lining, flap valve weeps can freeze, and the freeze-thaw cycles can deteriorate the lining. Special care should be taken if the canal is constructed on a silt material since an ice crystal formation adequate to damage thin unreinforced concrete lining may develop even with no free water surface present. A moisture content in silt as little as 2 percent greater than optimum can lead to frost damage to unreinforced concrete lining.

COMPACTED EARTH LINING

Thick compacted earth linings of gravel and sand with clay binders or poorly graded gravel-sand-clay mixtures with a minimum thickness of 2 feet are excellent linings for canals. A table rating these and various other earth materials for suitability as a lining material is shown in Figure 14. Typical sections for compacted earth lining are shown on Figure 15. If suitable materials are locally available then this type of lining should be considered because compacted earth makes an excellent lining and will usually be economically competitive. Compacted earth lining can withstand colder temperatures without as great of damage as concrete lining as it has a greater ability to tolerate frost heave, although a reduction in the compaction may occur due to frost action. No special equipment or technology is required for construction of compacted earthlined canals, which usually results in competitive bidding, and if constructed properly, compacted earth lining will have a seepage rate comparable with good concrete lining. Compacted earth can also tolerate greater water surface fluctuations without as great of damage as concrete lining. It generally does not require as much foundation preparation as concrete lining and certain expansive materials may be tolerated near the prism. Low density material will have to be addressed in a similar manner as was done with concrete lining. Since side slopes are flatter and velocities slower, compacted earthlined sections are less hazardous to people and animals that enter the canal.

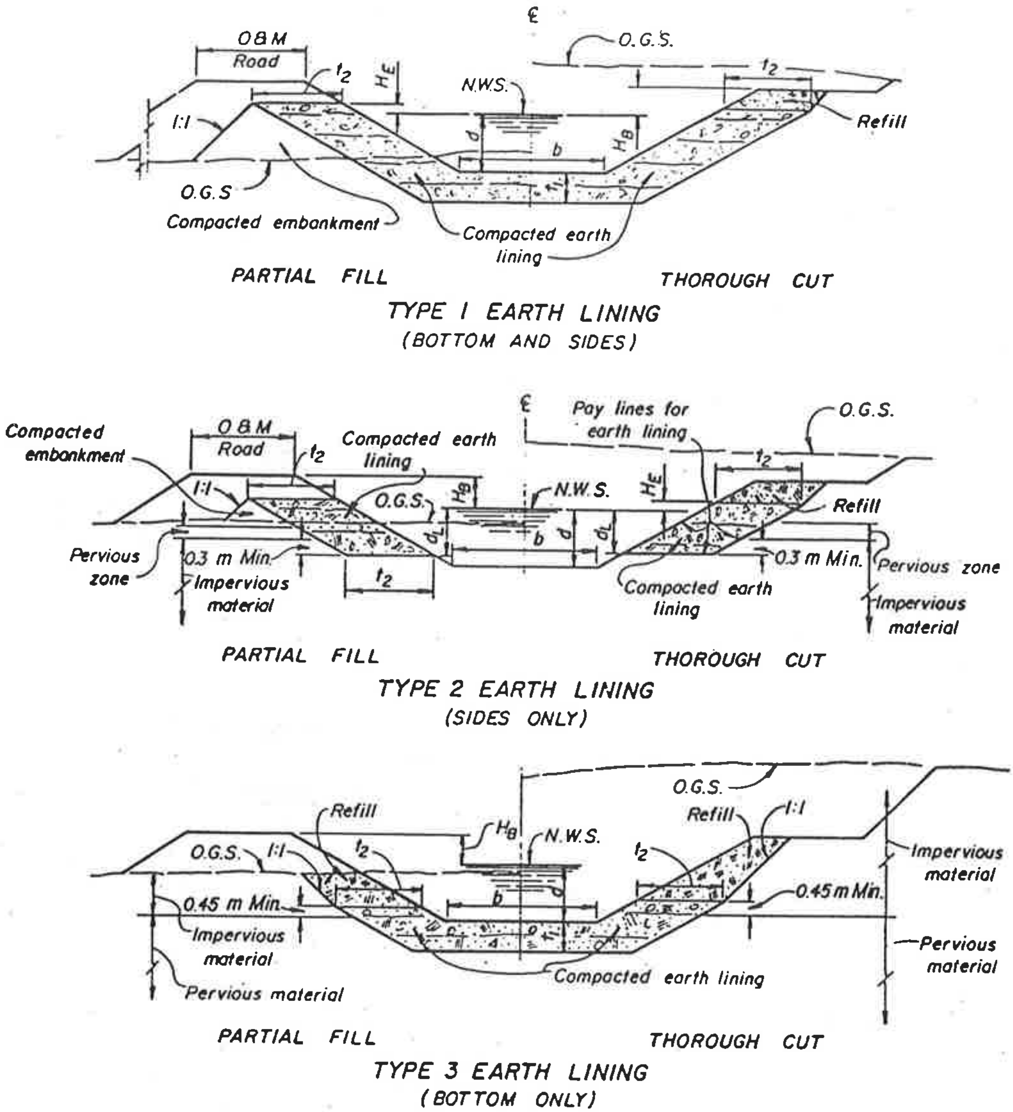
Major Divisions of Soils			Typical Names of Soil Groups	Group Symbols	Soil Properties: Permeability	Soil Properties: Shearing Strength	Soil Properties: Compacted Density	Suitability for Canals: Erosion Resistance	Suitability for Canals: Compacted Earth Lining
COARSE-GRAINED SOILS More than half of material is larger than No. 200 sieve size	GRAVELS More than half of coarse fraction is larger than No. 4 sieve size	CLEAN GRAVELS (Little or no fines)	Well-graded gravels, gravel-sand mixtures, little or no fines.	GW	14	16	15	2	–
			Poorly graded gravels, gravel-sand mixtures, little or no fines	GP	16	14	8	3	–
		GRAVELS WITH FINES (Appreciable amount of fines)	Silty gravels, poorly graded gravel-snad-silt mixtures	GM	12	10	12	5	6
			Clayey gravels, poorly graded gravel-sand-clay mixtures	GC	6	8	11	4	2
			Gravel with sand-clay binder	GW-GC	8	13	16	1	1
	SANDS More than half of coarse fractions is smaller than No. 4 sieve size	CLEAN SANDS (Little or no fines)	Well-graded sands, gravelly sands, little or no fines	SW	13	15	13	8	–
			Poorly graded sands, gravelly sands, little or no fines	SP	15	11	7	9 Coarse	–
		SANDS WITH FINES (Appreciable amount of fines)	Silty sands, poorly graded sand-silt mixtures	SM	11	9	10	10 Coarse	7 Erosion Critical
			Clayey sands, poorly graded sand-clay mixtures	SC	5	7	9	7	4
			Sand with clay binder	SW-SC	7	12	14	6	3
FINE-GRAINED SOILS More than half of material is smaller than No. 200 sieve size	SILTS AND CLAYS	Liquid limit less than 50	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity	ML	10	5	5	–	8 Erosion Critical
			Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	CL	3	6	6	11	5
			Organic silts and organic silt-clays of low plasticity	OL	4	2	3	–	9 Erosion Critical
	SILTS AND CLAYS	Liquid limit greater than 50	Inorganic silt, micaceous or diatomaceous fine sandy or silty soils, elastic silts	MH	9	3	2	–	–
			Inorganic clays of high plasticity, fat clays	CH	1	4	4	12	10. Volume Change critical
			Organic clays of medium to high plasticity	OH	2	1	1	–	–
HIGHLY ORGANIC SOILS			Peat and other highly organic soils	Pt	*			**	

(The No. 200 sieve size, 0.074 mm, is about the smallest particle visible to the naked eye)

(For visual classifications, 4.8 mm may be used as equivalent to the No. 4 sieve size)

* Numbers above indicate the order of increasing values for the physical property named.
** Numbers above indicate relative suitability (1 = best).

Figure 14. Soil Suitability for Earth Lining.



NOTES

. uning material requires a protective cover of gravel or riprap to prevent scour or erosion, excavation pay lines shall be extended to provide for the designated thickness of lining plus the gravel or riprap cover.

If a pervious zone containing mostly course material is encountered and requires a graded filter to prevent loss of lining material, excavation pay lines shall be lowered on sides or bottom to provide for the designated thickness of lining plus the filter.

Figure 15. Typical Earth Lining Sections.

Compacted earth lining has different considerations than concrete lining for satisfactory performance. First, it must be designed for a slower flow velocity to prevent erosion. If the lining chosen tends to be erodible, gravel armoring of the side slopes or a beach belt in the operating zone may be required.

Cleaning of the canal prism must be done with care to prevent removing lining material or disturbing the armoring or beach belt, and control of aquatic growth in the canal prism and weeds on the adjacent bank is more difficult. Finally, a sudden failure due to burrowing animals is a potential problem since the earth lining is not a barrier to these animals.

BURRIED PLASTIC LINING

Buried plastic PVC material is gaining more acceptance as a lining material. In the United States, PVC is used because it is the most economical to install. A typical section for buried plastic lining is shown on Figure 16. Tests on various buried membranes date back to the 1950's; however, the use of this type of lining did not gain in popularity until the mid 1970's when manufacturing techniques made heavier plastic sheets at a more competitive price. Better quality control has also enhanced its acceptance.

In many ways the buried plastic lined canals covered with earth and/or sand and gravel are similar to compacted earthlined canals. The finished prism is similar to the compacted earthlined prism except the side slopes may be flatter. Cleaning of the canal and control of aquatic and weed growth poses a similar problem to cleaning of thick compacted earthlined canals. If weed growth is considered a possibility, an approved soil sterilant should be applied to the subgrade. Care should be taken to not apply sterilant outside the lined area if landscaping or grasses are to be established later.

Several characteristics make PVC lining desirable. It can be placed during colder periods of weather. It is especially adaptable for the rehabilitation of existing earth canals, and it is the least affected by frost heave or expansive material in the proximity of the canal prism. It can also tolerate greater water depth fluctuations than any other type of lining if the cover material over the plastic is specifically designed for this. Where these types of conditions exist, buried plastic lining should be considered.

The subgrade should be relatively smooth and free of sharp rocks, roots or other objects which may puncture the membrane. Dragging the subgrade with a heavy machine type chain or an old tractor track may produce an acceptable foundation.

If this method does not provide an acceptable foundation, a covering of 3 to 4 inches of sand or fine textured soil may be placed on the subgrade prior to placing the membrane.

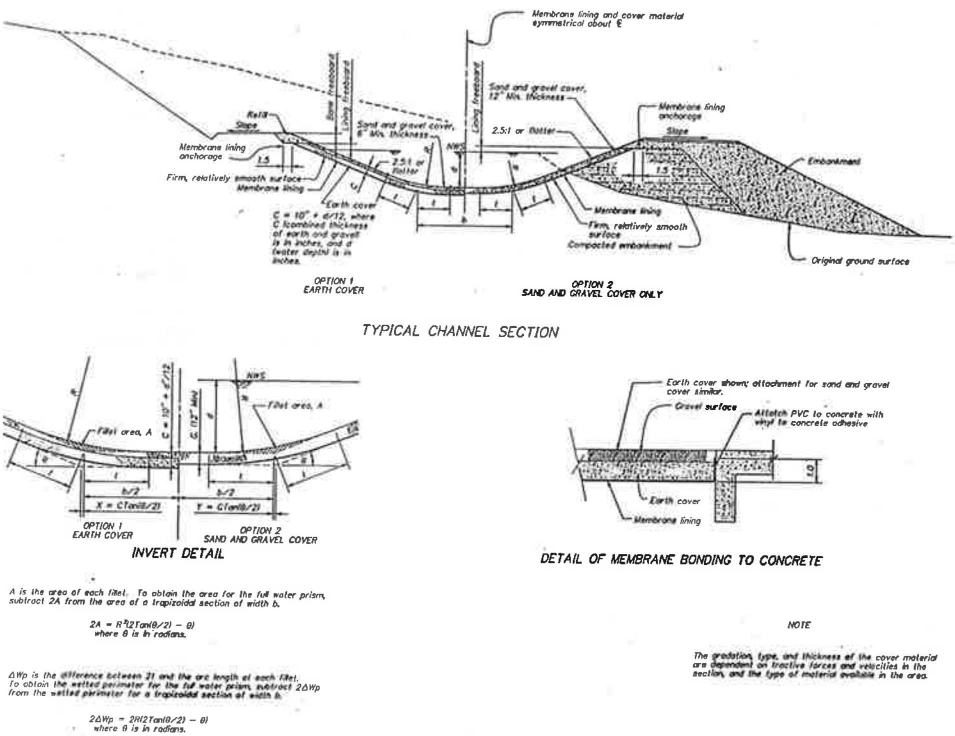


Figure 16. Typical Buried Membrane Lining Section.

The cover material design is important for the success of buried plastic lined canals. Either an earth cover topped with sand and gravel or a cover of only sand and gravel should be used.

To make this type of lining viable, a sand and gravel source within an economical haul distance is required. Although a full cover of sand and gravel is preferred, an earth cover topped with sand and gravel may be used if economics preclude using sand and gravel for the entire cover. Advantages to using sand and gravel for the cover material are a one step construction process and a more stable finished product on the side slopes. The use of pit run gravel that fits the gradation limits shown on Figure 17 and is located near the canal site can significantly reduce the cost of this type of lining. There also must be sufficient depth of cover to protect the membrane from punctures from cattle or deer crossing the dry canal. For stability the side slopes should be 2½:1, or flatter, depending on location and conditions.

OPERATIONAL CRITERIA

As a guide for beginning canal operations, the water surface fluctuation limits given below are considered tolerable for the upper 2 feet of the designed normal water surface. However, uncertainties arising from variable operating conditions dictate that these limits be approached with caution. Canal operators should be alert to ensure that the manner in which the canal is operated does not have adverse effects on operation of the turnouts, or cause distress in the canal lining or banks.

The water surface rise limitations are to prevent possible undesirable changes in turnout discharges. The water surface drawdown limitations are to prevent undesirable changes in turnout discharges, to protect the concrete lining from damage by external hydrostatic pressures, and to prevent the earthlined sections from sloughing.

> **Water surface rise** - The rise in the canal water surface should not exceed 6 inches in any 1 hour. The 6-inch rise may be taken in less than 1 hour, but the total vertical movement of the water surface must not exceed 6 inches in the 1-hour period. Experience shows that filling should not exceed 18 inches in any 24-hour period.

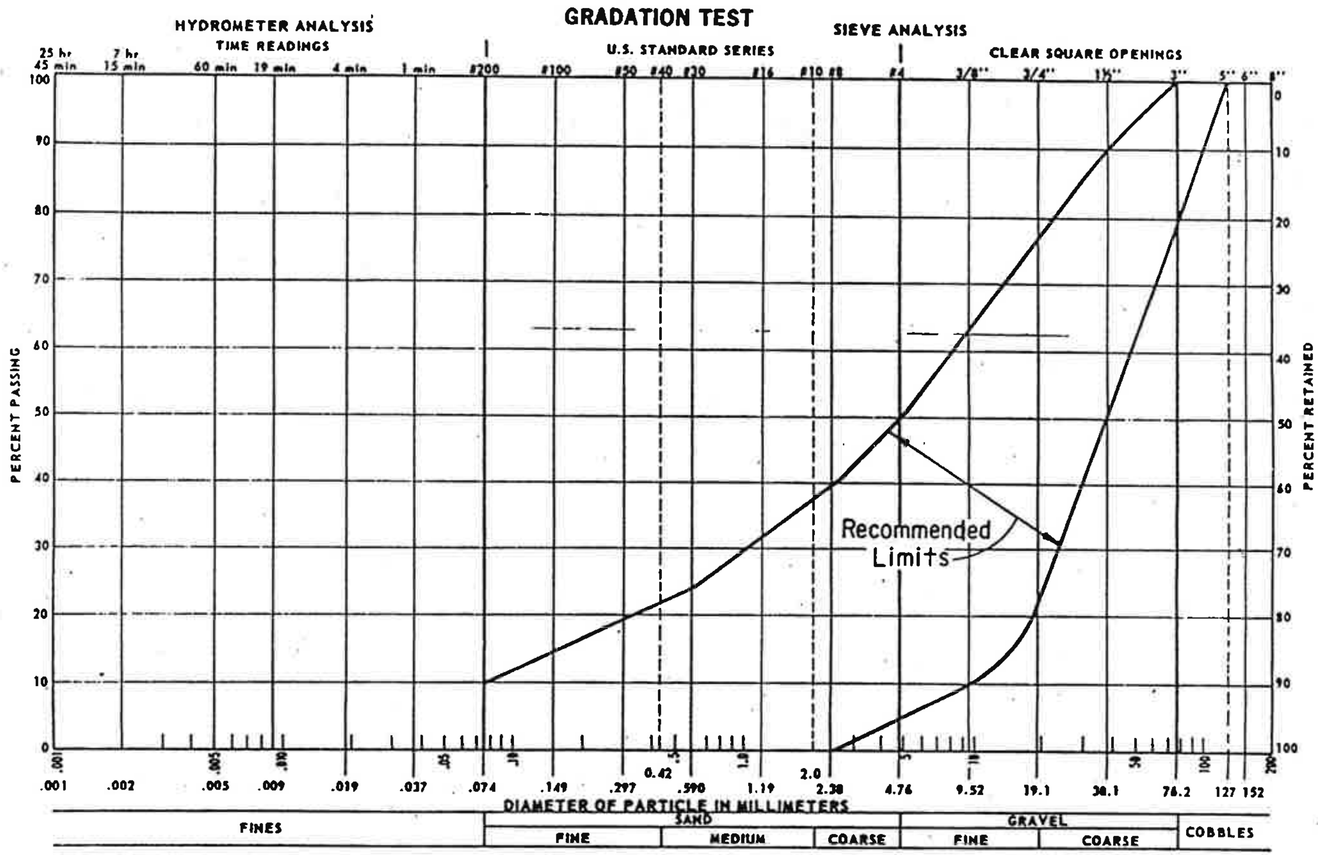


Figure 17. Buried Membrane Lining Cover Material Gradation.

Water surface drawdown - Drawdown shall not exceed 6 inches in any 1- hour period (may be taken at any rate), 12 inches in any 2-hour period, and 18 inches in any 24-hour period.

NONTRADITIONAL LININGS

Reclamation continues to investigate alternatives to traditional types of linings and methods of placing lining. Reclamation has also learned from water districts that have experimented on materials for new types of linings. Many new materials have specific applications that may justify their added expense or specialized application.

BOTTOM-ONLY LINING

In some special situations soil conditions are such that seepage is primarily vertical. Under such conditions, a bottom-only lining may be attractive. If a completely watertight lining is not necessary, and the small amount of seepage from the side slopes can be tolerated, bottom only lining may be a cost effective way to reduce seepage. Soil conditions which exhibit the vertical seepage pattern are found in loessial soils in some areas of Kansas and Nebraska. Field studies were conducted at three locations by the Kansas-Nebraska Projects Office, Grand Island, Nebraska. For these studies 10-mil PVC was installed only in the canal invert. Results of the field studies are listed below.

CANAL LOCATION	Q ft^3/s	* B ft	SEEPAGE LOSS $FT^3/FT^2/DAY$ BEFORE LINING - AFTER LINING		PERCENT REDUCTION
Farwell Main Canal	290	18	0.56	0.27	52
Franklin Canal	230	14	1.01	0.45	55
Upper Meeker Canal	284	16	1.13	0.56	50

SHOTCRETE OVER GEOSYNTHETIC

Reclamation has designed lining for approximately 1 mile of canal with shotcrete over a geosynthetic on the Towoac Canal for the Dolores Project in Colorado. This method of construction was chosen for several reasons. First, one mile is too short a reach of canal to economically use a custom built lining machine. Second, this project was a canal rehabilitation where the canal was only out of service for a short time in the year, and this method was chosen to complete this work in this short time. Finally, this area is on a steep hillside with silty material, and it must be extremely watertight to prevent any failures. An underdrain was even added to collect any seepage before it entered the embankment.

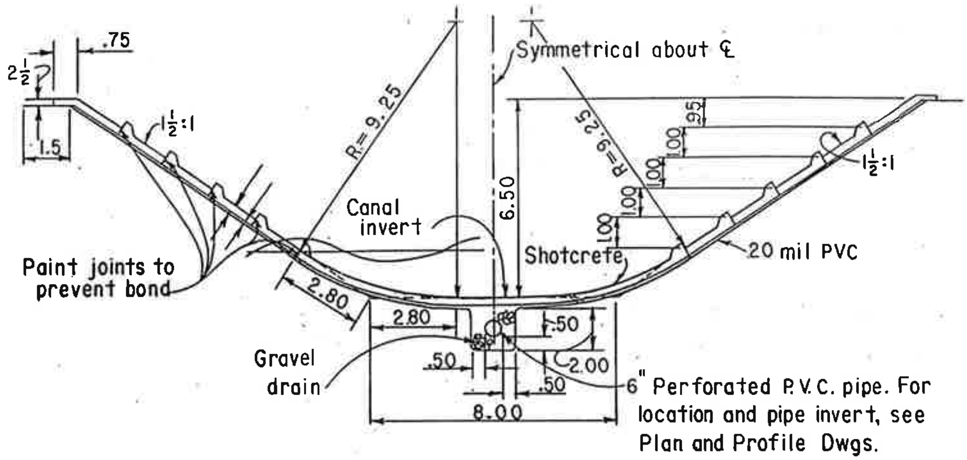
Figure 18 shows details of this type of lining. Certain construction considerations are required for the PVC. After the canal subgrade is prepared by excavating, trimming and dragging, 20-mil PVC is installed on the subgrade. A prefabricated drainage composite is installed directly on the PVC lining.

The drainage composite is manufactured with the symmetrical nodal configurations on one side so that the flat backside can be installed directly on the PVC lining, and a nonwoven, needle-punched geotextile is bonded to the nodal configuration. The shotcrete is then applied to the needle-punched geotextile. This is required so the shotcrete will not slump on the 1½:1 surface. Several longitudinal open joints and transverse open joints every 30 feet are provided to allow drainage of water between the shotcrete and the PVC lining. The shotcrete is pneumatically applied concrete placed directly onto the needle-punched geotextile. It has a 3,000 pound per square inch strength, and a wet-mix process was used to better control the composition of the mixture. Only the accelerator is allowed to be added to the mixture at the nozzle. The allowable slump for the shotcrete is 3 inches.

STABILIZING SOILS

Soils are stabilized for any combination of the benefits of reduced permeability, increased tractive force, and increased stability leading to steeper side slopes on canal prisms. The most common methods of stabilizing soils are mechanical stabilization and chemical stabilization.

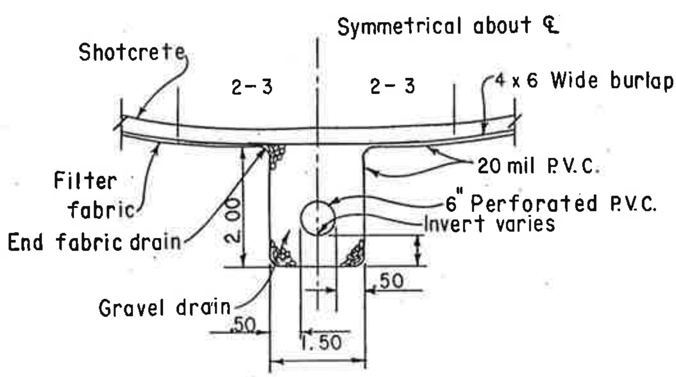
Mechanical stabilization includes overexcavating and refilling with suitable material or addition of fine grain soils like bentonite to pervious soils. Common chemicals that have been used successfully for years to stabilize soils include resins, petrochemicals, sodium silicate, lime and Portland cement. Recently, fly ash has been tested for soil stabilization and has potential for being a cost effective method.



DETAIL OF LINING
(Dimensions in feet)

HYDRAULIC PROPERTIES

Q	A	V	r	n	s	b	d	HB	HL
345	86.43	3.99	3.16	.017	.00045	8.00	5.44	8.20	6.50



DETAIL OF DRAIN

Figure 18. TOWAOC Canal - Shotcrete Canal Section.

Fly ash is a fine dust particulate material collected from flue gases of coal burning power plants. Since it is largely a waste product, its use for stabilization is a good method of disposal. Although the chemical composition of fly ash varies, the calcium oxide (CaO) constituent is most likely to affect soil stabilization. The effectiveness of fly ash can also be increased by combination with small amounts of Portland cement, hydrated lime or calcium sulfate. Different mixtures of fly ash are required for different soils. Tests are reported in Reclamation's 1986 report "Tests for Soil-Fly Ash Mixture for Soil Stabilization and Canal Lining". Soil stabilization might be sufficient by itself as a canal liner or it might be used in conjunction with other methods of linings to increase their effectiveness.

CONCRETE OVER GEOSYNTHETIC

The combination of concrete with geosynthetics is being used to solve unique canal construction problems. In India, low density polyethylene (LDPE) film covered with brick tiles is being used successfully for canal linings. Like all hard covers, the brick protects the geosynthetic LDPE film from large animal's hoofs and from vandalism. Hand placing brick tiles, however, would be too expensive except where labor is very inexpensive. The combination of concrete with geosynthetics seems very important in placing lining in existing unlined canals that cannot be dewatered. One method tested in India is a grouted mattress lining where two layers of a specially woven synthetic fabric are positioned and filled with fine grain concrete. This sinks to the canal bed underwater as it is filled with concrete.

Another method used by Reclamation is a slipform method used without unwatering the canal prism on the Coachella Canal. In 1990 and 1991, Reclamation lined a 1-½-mile reach of the Coachella Canal with a 30-mil PVC membrane cover topped with 3-inch monolithic slipform concrete. The design flow is 1,600 cubic feet per second; however, maximum usage is usually 1,000 cubic feet per second. This section was constructed as a prototype to evaluate environmental impacts, verify construction techniques, and refine cost estimates for lining canals that cannot be unwatered because of a continuous water supply need. A hard surface was chosen rather than earth to facilitate cleaning of the canal, and animal escape curbs are to be slipformed in the concrete (see Figure 19). The concrete mixture included anti-washout additives, and chemicals are to be added to the water during placement to counteract any adverse pH. Turbidity and effects on fish and wildlife are being studied on an ongoing basis.

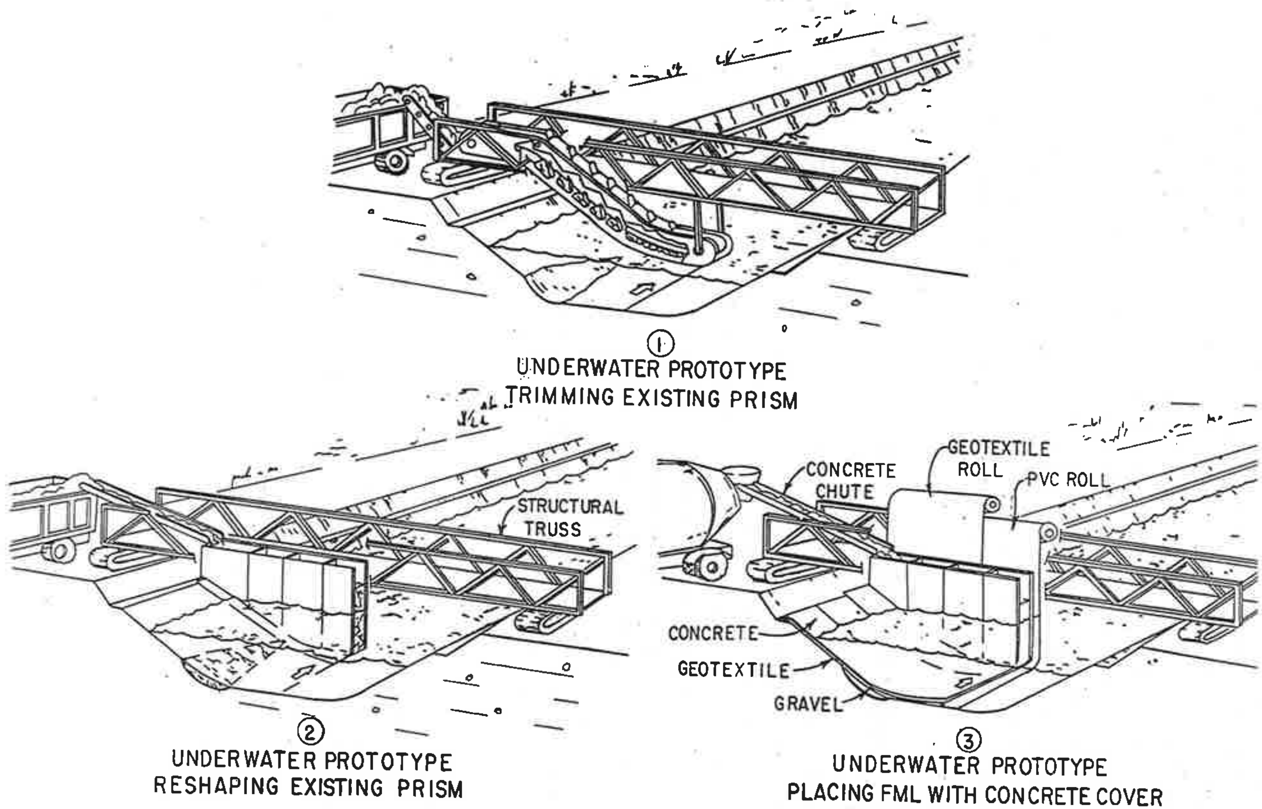


Figure 19. Conceptual Drawing of Underwater Lining.

The lining was placed in the early spring when flow demands and canal velocities were low. The concrete will provide a hard surface to protect the PVC, and open longitudinal joints are spaced 1.5 feet apart to provide relief points for the hydrostatic pressure between the concrete and PVC lining.

Some of the advantages of underwater lining of operating canals are as follows:

1. Should provide maximum seepage control.
2. No interruption of canal operations except for the brief time required to pass a turnout.
3. The new prism will provide a larger canal prism than a relocated canal and thereby provide an operational storage pool at least as large as the one presently available.
4. The need for acquiring additional or new right-of-way is not a factor to be considered.
5. The hard surface concrete lining can easily be cleaned by dredge or the side slopes scraped to remove hydrilla, moss, and silt deposition.
6. The lining will withstand relatively rapid water surface fluctuations, thereby providing desirable operating flexibility.
7. This alternative should provide a cost savings over a relocated canal as it eliminates the need for a large excavation and canal bank construction effort and should shorten construction time. Overall construction traffic in the area should also be reduced.
8. The completed research and environmental studies incorporated into the designs and specifications showed no adverse impacts from the construction. The canal should be safer for deer and large mammals and above all, will save water.

REPAIR AND REHABILITATION

Various types of lining material have been developed that are almost exclusively used for repair and rehabilitation. These are generally specialized materials for specialized applications.

Many older canals were lined with concrete, and over time the concrete has deteriorated. When it becomes ineffective to seal cracks or replace individual panels that are damaged, the concrete can be covered with different materials to rehabilitate the canal. While the old concrete is not as watertight as desirable, it provides a hard surface sub-base to support a watertight lining material. One of Reclamation's earliest experiences with this type of lining was in 1964 when 750 feet of the Contra Costa Canal was overlain with 1/32-inch butyl rubber lining. Because of shrinkage and ozone cracking, this lasted only a couple years. Recent research has shown that thick (100-mil) high density polyethylene, hypalon (chlorosulfonated polyethylene), asphalt with plastic sprays, or reinforced bitumen could be considered for this application. However, the material chosen must be able to withstand ultraviolet sunlight rays, weathering, and large animal traffic.

One recent example of a rehabilitation process for an existing concrete lined canal was the rehabilitation of the Putah South Canal of the Solano Irrigation District in Vacaville, California. The designs for this job were prepared by Summers Engineering, Inc., of Hanford, California. In November 1989, 2 inches of shotcrete lining with 2 pounds per cubic yard of fibermesh fibers was placed over a 40-mil textured high density polyethylene, the polyethylene was attached to the existing concrete lining. Approximately 5,000 feet of canal were rehabilitated.

Many of the same materials used to overlay concrete can be used as exposed linings to rehabilitate unlined earth canals. In 1987, the Kennewick Irrigation District in Kennewick, Washington, installed reinforced bitumen lining material over earth as an alternative to PVC lining covered with earth and gravel. Earlier installations of PVC had weeds rooting in the cover material that will eventually have to be removed with the possibility of the cover being reduced or the PVC damaged. The reinforced bitumen lining provided a watertight lining that will hinder weed growth. While the reinforced bitumen is initially more expensive than the PVC installation, some of the cost is offset by less earthwork during installation and hopefully less maintenance cost in the future.

UPPER DESCHUTES RIVER BASIN - CANAL LIVING DEMONSTRATION PROJECT

In March of 1991, Reclamation, in cooperation with the Oregon Water Resources Department, developed the Upper Deschutes River Basin - Canal Lining Demonstration Project. This is an approximately $3.2 million study to test the effectiveness of various types of materials for canal lining.

Fourteen suppliers submitted their products to be tested as canal linings. The types of materials submitted as proposed canal linings were as follows:

1. Polypropylene fiber shotcrete mix (2 suppliers)
2. Urethane spray foam
3. Pozzolon (fly ash)
4. Unreinforced shotcrete
5. Steel fiber shotcrete mix
6. Structural grout-filled mattress
7. Bituminous lining material
8. High density polyethylene
9. Very low density polyethylene
10. Reinforced hypalon lining with geotextile backing
11. Polyethylene with shotcrete cover
12. Polyethylene liner with geotextile cushion
13. Nonwoven polypropylene geotextile with polyethylene film and shotcrete cover

Each material was used to line a 500 to 1000 foot test section of canal, and approximately 2 miles of canals were lined. Flows in the test section ranged from 90 cfs to 1,100 cfs.

A report will be published in 1994 that will discuss the cost of lining, constructability, and the short term performance of each lining. Follow up reports are planned every 2 to 3 years to update the performance data on those various lining materials.

CONCLUSION

Unreinforced concrete, thick compacted earth, and PVC with a sand and gravel cover all provide acceptable and cost effective seepage control. Many new materials are also being introduced to the market that look promising as canal liners. In determining the type of canal liner to be used for a specific application some of the factors that need to be considered are as follows:

- economics
- project requirements
- temperature ranges
- hydraulic constraints
- right-of-way constraints
- degree of water tightness required

- foundation considerations
- groundwater and drainage
- availability of material (for compacted earth lining or cover for PVC lining) and associated haul distances
- operation and maintenance concerns
- environmental concerns
- concerns of local entities

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Bureau of Reclamation (1991). Upper Deschutes River Basin Water Conservation Project Canal Lining Demonstration Project, Description and Cost Estimate.

SESSION REPORT:
OVERSEAS EXPERIENCE WITH CANAL LINING

Dr. Muhammad Abid Bodla
IWASRI, Lahore, Pakistan.

Three papers containing canal lining experience from China, Egypt and U.S.A. were contributed under the theme of this technical session. These papers presented by the authors Lin Huashan, Dr. F.El Shibini and Thomas Mitchell summarize state-of-the art technology, experience and results of recent research work from these different parts of the world. A summary concentrating on key points of the presentations and ensuing discussions is presented here.

China

Lin Huashan discusses experience with geomembrane and concrete linings in China. Combination of membranes and concrete particularly their joint usage is shown to reduce the seepage losses and frozen heave damage to large extent under the prevailing conditions and is therefore preferred. Polystyrene laminate is found effective in seepage control and its combination with "U" shaped concrete lining will prevail in future. Low pressure pipe lines will replace the open channels in areas where lift irrigation is needed. Experience entailing test results of 18 year old burried PVC membrane lining is also included.

Discussions following the presentation concluded:

1. Many factors affect life of plastic lining. A good maintenance programma can assist in extending life.

2. Cost comparisons of different lining materials is not easy since it depends on site specific factors e.g. materials, labour, climate etc.

3. China experience is that stone lining is less effective in controlling seepage than concrete.

4. Small canal lining machine joining compound is asphalt but in humid areas no joining is used.

Egypt

Paper by Dr. F. El Shibini presents general overview of water resources potential in Egypt. Information on lining of El NASA canal is given along with description of seepage measurement by constant and falling head permeameters. Paper includes a general discussion of use of geotextiles, geomembranes and geocomposites for canal lining.

Discussion on the paper indicated:

1. Cost benefit analysis of canal lining depends on targeted objectives but is not easy to carry out. Economic analysis becomes complex as some benefits are intangible,

2. Egypt owns little information on economic life of plastic lining since it is only observed over last 1 or 2 years.

U.S.A.

Paper by Thomas E. Mitchell reflects upon a brief history of lining (1946-86) of USER operated canals. Types of lining include expose and berried membranes and earth lining.

Discussion on the paper surmised:

1. In U.S.A., labor is expensive, therefore PVC bonding becomes expensive. Overlap of PVC sheets by 3 ft. with sand and gravel on top is as good as if not better than chemical bonding. But polythene has to be bonded. Experience in Pakistan using overlap shows problems of weed growth, and rodent burrowing.

2. Assessing effectiveness of lining by measuring seepage rates before and after has problems of accuracy in measurement, hence specific testing of the lining material over time, if often, is more effective to determine longer term performance.

3. Polyethylene lining in the USA has not been as durable as PVC, also for underwater lining the polyethylene has a floatation problem.

4. In USA, relieving hydrostatic pressure beneath canal is effectively done with a flap valve (figure 12 & 13 of the paper).

5. Sedimentation problem less in lined canals because the design velocity can be higher. Where siltation is a problem, it can either be run through the system or install settling basins at the head of the canals.

General Discussion

On cost effectiveness and economics of lining, four factors were considered important:

1. Comparison of cost of water per unit volume before/after to establish savings.
2. Water extraction costs if canal not lined.
3. Water cost per unit of productive land.
4. Increased agricultural productivity per unit of land per unit of water.

TECHNICAL SESSION:
PAKISTAN EXPERIENCE WITH CANAL LINING

LINING OF IRRIGATION CHANNELS "THE PUNJAB EXPERIENCE"

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ABSTRACT

Pakistan has a basically Agricultural Economy which depends on Irrigation specially in the Semi-Arid Punjab. Explosive growth of Population has increased the demand of Irrigation Water. Water is a dwindling resource and present situation warrants intensive irrigation and water saving efforts. The Government of Punjab is trying to save water losses and achieve distribution equity through various actions including Lining of Channels. Lining applications include "Improvement of Hydraulic performance, minimizing percolation, control of waterlogging, Bank and Prism stability and lowering maintenance costs". Lining of Channels has been used as improvement method for Hydraulic Performance and reducing seepage in Punjab. Hard Surface Linings have mostly been used in Punjab and till recently Brick/Tile Lining has been the choice type, but is now yielding place to concrete on account of deterioration of Brick/Tile quality. Out of a total of 930 miles of Lined Channels, the concrete lining covers over 400 miles. The cost of brick and concrete linings compare favourably with each other. Lined Channels are designed with Manning's equation and in view of the existing field conditions the 'N' values of .017-.018 for brick/tile and .015 for concrete, with side slopes of 0.5:1 to 1.5:1 are adopted for various channel depths. The construction process is in line with general global practices. For concrete, a typical formwork has been developed to improve concrete lining quality allowing medium workability, good compaction and finishing. This formwork produces better panels, density, surface levels, line and grades. Availability of materials is better for concrete, both in terms of quality and availability. Quality control is easier for concrete in overall perspective. The life of linings depends on the use of good materials and proper construction. The lined reaches have shown improved water distribution and reduction in waterlogging. It has been observed that the maintenance cost of a lined channel is lower than that of an earthen channel. Lining of channels is economically viable and the Punjab experience in channel lining has been interesting and useful.

INTRODUCTION

Pakistan's economy essentially has an agricultural based and Irrigation is the main sustainer of agriculture, specially so in the Punjab with semi-arid climate. Due to large variation in temperatures, evaporation loss is substantially more than the annual precipitation. This coupled with un-even rainfall, makes the crop production almost impossible without irrigation water.

Explosive growth of population has increased the pressure on land and demand for irrigation water for enhancement of food and fibre production.

Water is a dwindling resource now, and increase in agricultural produce is only possible through intensive and extensive irrigation and better water management both in canals and on the farms.

Emphasis is therefore shifting to measures for saving of water from within the existing resource and system by reducing the controllable losses from the irrigation channels and farms, which are estimated at 20-25 percent and 40-50 percent from channels and farms respectively.

The Government of Punjab has been trying to reduce such water losses by improving water management on farms and canals out of its own resource and with the assistance of Federal Government and other financiers like USAID and IDA etc.

Through better management on the farms and with rehabilitation and lining of irrigation channels under different projects like the Command Water Management Project, the Irrigation Systems Management/Rehabilitation Project and Annual Development Programmes, the Punjab Government has improved the hydraulic performance of many channels of equitable supply distribution.

LINING OF CHANNELS IN PUNJAB

Lining of irrigation channels, normally has the following basic applications:

1. Improvement of Hydraulic performance.
2. Minimizing percolation.
3. Improvement of command.
4. Control of waterlogging.
5. Stability of Sections and Banks.
6. Reduction in maintenance cost.

In Punjab, lining of channels has been used as a tool for improvement of hydraulic performance and conveyance capacity of irrigation channels and also as a seepage reducing device.

The types of canal lining used the world over can be listed as below:

Hard Surface Linings

1. Reinforced cement concrete.
2. Plain cement concrete.
3. Shotcrete.
4. Prefabricated cement concrete units.
5. Bricks & tiles.
6. Asphaltic concrete.
7. Stone.
8. Soil cement and
9. Compacted/stabilized Earth.

Flexible Membranes

1. Asphaltic membrane.
2. Polyvinyl Chloride.
3. Synthetic rubber butyl membrane.
4. EPDM rubberized Membrane.
5. Resinous membrane.
6. Fiberglass.
7. Pre-fabricated asphaltic membrane.
8. Polyethylene and
9. Bentonite layer.

Most of the linings installed in older irrigation channels were reinforced. During recent years, reinforcement has been omitted wherever possible to reduce construction cost and because it did not materially improve effectiveness or durability.

Unreinforced linings are to some extent prone to damages by hydrostatic or other pressures under the lining than reinforced linings, but not to the degree that the difference in cost might be offset. Where unexpected hydrostatic pressures are encountered, unreinforced lining ruptures more readily than the reinforced type, thus relieving the pressure and localizing the damage. The main function of reinforcement is to minimize the tendency and severity of cracking, and their widening. This can be achieved even in unreinforced linings if transverse joints are provided at optimum spacing.

The reinforced concrete lining can however be justified under unusual conditions, such as high back pressure, unstable subgrade and in reaches where failure would endanger life and property outside the canal.

For recent projects in Punjab, mainly two types out of above referred types of lining have been used, i.e. brick/tiles lining and plain cement concrete lining. However in Command Water Management Project, a small length of about 1500 ft. in the tail reach of Jalleki Minor was provided with an EPDM Rubberized membrane below the concrete layer to cut off seepage on experimental concept. This membrane successfully cut-off all seepage and was unaffected physically, after one year of installation as indicated by the test results for a piece of membrane obtained from the site.

Till recently, brick/tile lining has been the choice type in Punjab, but with the deterioration in the quality of brick products and exodus of good brick layers to other countries, the plain cement concrete lining has gained favour and its use is increasing because it is more durable, less porous (almost impermeable), can be worked to a smoother finish, quicker to place and somewhat more responsive to moderate quality control. The concrete linings are also less prone to silt deposits and growth of Algae, or Fungii. The seepage/percolation losses can be reduced to a bare 1.13×10^{-6} cusec per sft. area against the value of 3×10^{-6} cusec per sft. or even more in the case of bricks on account of their increased porosity, resulting due to lack of control over manufacturing process. It has been experienced on works in Second Irrigation Systems Rehabilitation Project that the cost of concrete and brick linings, is almost the same per square foot of the lining area for the cross sections shown in Figure 1.

In addition to the old lined canals, over 900 miles of distributaries and minor channels have been lined as detailed below:

1.	Command Water Management Project	300 miles
2.	Irrigation Systems Rehabilitation (Project I & II)	380 miles
3.	Other Projects and ADP	250 miles
	Total:	930 miles

Out of above, the length lined with concrete comes to over 400 miles. The channels lined are mostly below 30 cusecs, but some channels with a total length of approximately 70 miles with discharge of over 50 cusecs have also been lined, mainly with concrete. The remaining length received brick on edge lining as shown in Figure 1. The primary aim in most of the cases was improvement of the hydraulic performance and conveyance capacity of channels to provide better deliveries to the tail outlets, but this also achieved, although in part, the aim of water saving too, while for other channels, especially in saline areas, the primary function was to reduce the seepage quantity.

As already mentioned in an earlier paragraph, the costs of brick and concrete linings compare favourable with each other. The cost of concrete and brick lining constructed according to cross sections shown in Figure 1 are compared in the following table.

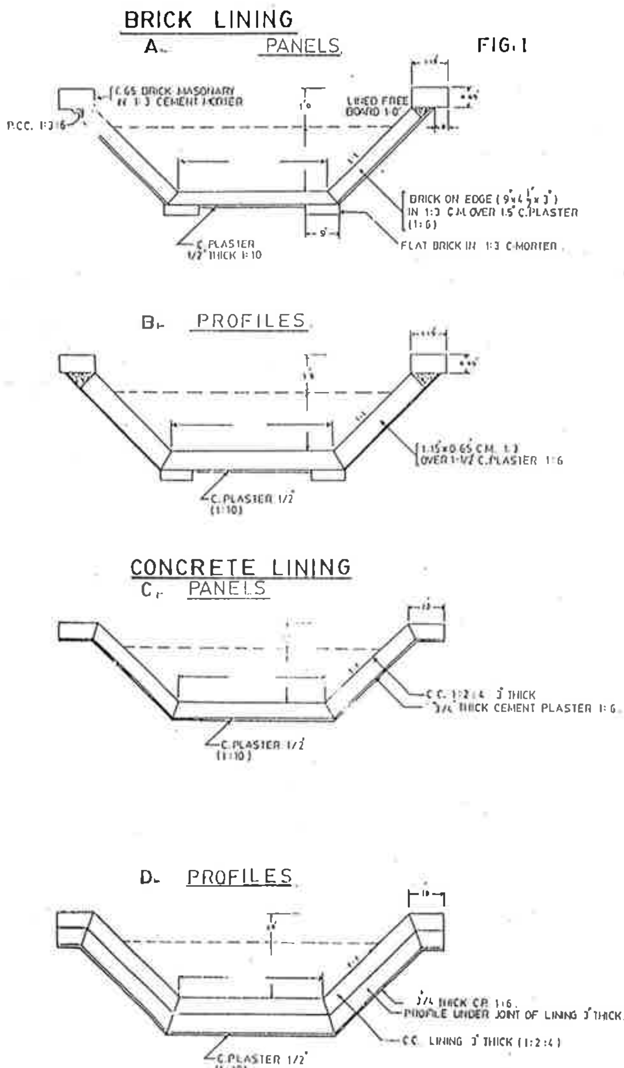

Figure 1.

Table 1. Comparison of brick and concrete lining cost.

S.No.	Name of Project	Average cost/Sft (In Rs.).		Remarks
		P.C.C.	BRICK	
1.	ISRP - 1 (1983-1988)	-	14.09	Total length 45 miles.
2.	ISRP - II (Under execution).	18.48	19.55	Total length 335 miles.
3.	Command Water Management Project. (1984-1989)	16.36	-	No significant length lined with brick. Total length 300 miles.

The cost of concrete lining in Command Water Management Project is lower because of its earlier execution. The average cost in IInd. ISRP is slightly higher because the lining of over 90 percent length has been executed during the last two financial years and therefore this cost can be considered as the base cost for the period July 1991 to June 1993.

DESIGN FOR LINING

The design of an irrigation channel involves the fixation of discharge and slope, determination of prism parameters, preparation of L-Section and redesign of outlets. The full supply levels in the lined portion of channel are fixed on the basis of availability and desired command of different outlets and modularity of tails. If need be, the head regulators of the channels are also redesigned. While fixing the water surface slope, the availability of control points viz falls is also reviewed for achieving the design slope which generates self cleaning or nearly the same velocities. This is not always possible in Punjab, specially in the southern areas where the land slopes are relatively flat and increase in slope is not feasible.

CHANNEL SECTION

The section parameters for lined portion are worked out with the usual Manning's Equation

$$V = \frac{1.486}{n} \times (R)^{\frac{2}{3}} \times (S)^{\frac{1}{2}}$$

where v, n, R & S have the usual meanings.

The velocity is also verified on the basis of "Simplified Hydraulic Design Criteria", a computer programme developed in ISR Project Design Cell which is in fact is an improved version of Lacey's equations incorporating the tractive forces and sediment transportation consideration. Under given conditions an effort is made to obviate deposition. With the value of v obtained above, the area, width and depth are calculated. The B:D ratio is selected to provide maximum velocity with the available slope, of course in consideration of the bed, full supply and land levels.

According to Manning's formula:

$$V \propto \frac{1}{n}$$

or larger the value of 'n', lower the velocity and vice versa. Thus, other parameters, remaining constant, for a change of 0.001 in rugosity, a change in slope by 7% can be attained. An earthen channel with a discharge capacity above 10,000 cusecs has the rugosity coefficient equal to 0.022 or 0.025, so that in a lined canal with the coefficient equal to 0.18, about 28 to 40% increase in slope and corresponding velocity can be achieved. It has been noticed that even with high order of velocities, a type of fungus appears on the bricks close to the water surface. This fungus formation entraps fine silt and clay and is considered to be one of the causes for the increase in the rugosity coefficient.

The values of 'n' generally adopted by various designers from different authorities vary largely depending on conditions in each case.

Mahboob, S.I. (1943) in his paper No.260 presented to Pakistan Engineering Congress Session on "Lining of channels" states:

> The Haveli Main Line was designed with a coefficient of 0.016 Lacey's formula, equivalent to 0.0146 in Manning's formula. When the channel was first opened Manning's 'n' worked out to be 0.014. Subsequently, however, the coefficient rose and it now varies between 0.018 and 0.020. There are two possible causes of this:

a) The presence of sand blown in or brought in from the head.

b) The presence of caddis worm in larger numbers.

It can be definitely stated whether this worm has a particular affinity for brick work. In any case, it would be advisable in future design to use a higher coefficient for brick linings say 0.018 and to provide an adequate free board.

As our workmanship in these days of untrained and unskilled labour has worsened, an expected low order of rugosity coefficient can never be attained. It is therefore always advisable to adopt a conservative value in line with Mahboob (1943) and learning from the experiences of Balloki Sulemanki Link, Haveli Canal and other old canals in the country. It is preferable to adopt an 'n' value of 0.018 to achieve the desired hydraulic performance. However in small channels with low discharges of less than 50 cusecs, the encroachment of free board is relatively not so serious and a somewhat lower value of 0.017 can be adopted to discourage the silting tendency in the earlier period of operation, without jeopardizing the conveyance capacity and hydraulic performance appreciably. Therefore the value of Manning's 'n' for designing lined channels of small discharge is taken as 0.017.

SIDE SLOPES FOR CHANNEL SECTION

As the lining are quite expensive, the section used should be most economical, which will have the least perimeter for the given area. The semicircle has the smallest perimeter but its construction and maintenance are quite difficult. From the construction and maintenance point of view, the optimum value of side slope is 1.5:1 while milder slopes are desirable. Since milder the slope, easier the construction, but larger the cost, it is usual to provide steeper slopes for small channels. In Punjab, the sides slopes for brick lining are kept as below:

1) For water depths less than 2 feet = 0.5:1

2) For water depths more than 2 feet = 1:1

3) For water depths less than 6 feet = 1.5:1

For concrete lined sections, minimum side slope are 1:1 in view of construction problems. However for depths more than 4 feet, the side slope has to be flattened to 1.5:1.

Based on above, the channel section parameters are fixed. Typical sections for brick and concrete lined channels appear in Figure 2.

Adequate freeboard has to be provided for lining to prevent overtopping during sudden rises in water levels. Provision of free board depends on the size of the canal, condition of flow, curvature of alignment, entry of rain water into the channel, increase in flow resulting from faulty regulation, variation in friction coefficient, accumulation of silt and operation methods. The normal free board for hard surface linings ranges from one foot for small channels to over 2 ft. for larger ones. In Punjab the freeboard for lining varies from 1.0 to 2.0 ft. while the height of canal bank above the top of lining varies from 6 inches to 1 ft.

CONSTRUCTION OF LINING

The construction of lining involves the following steps in working sequence:

1) Provision of an alternate supply channel termed as diversion.
2) Preparing the subgrade.
3) Cutting and shaping up the channel prism.
4) The construction of profiles.
5) Laying base plaster.
6) Curing of the base plaster.
7) Laying the lining layer.
8) Curing the lining.

The most difficult steps in the above sequence are preparing earthen sub grade to prescribed compaction percentage and laying of concrete on slopes.

The construction planning and problems faced are in fact site specific actions. Following paragraphs contain the general practice followed in Punjab.

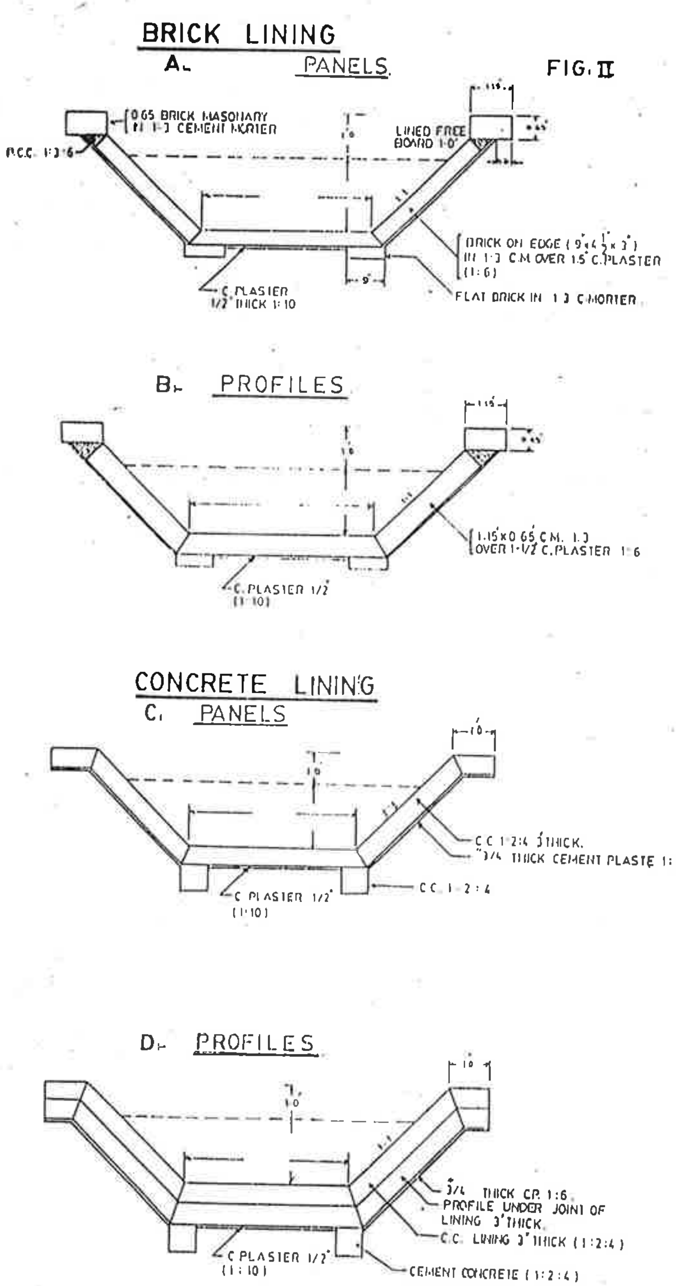
BRICK LINING
A. PANELS
FIG. II
LINED FREE BOARD 1'-0"
FLAT BRICK IN 1:3 C.MORTER
B. PROFILES
C.PLASTER 1/2"
(1:10)
CONCRETE LINING
C. PANELS
C.C. 1:2:4
C PLASTER 1/2"
(1:10)
D. PROFILES
3/4 THICK CP. 1:6
PROFILE UNDER JOINT OF LINING 3" THICK
C.C. LINING 3" THICK (1:2:4)
C PLASTER 1/2"
(1:10)
CEMENT CONCRETE (1:2:4)

Figure 2.

Provision of Diversion

The diversion channel is provided where the channel being perennial can not be closed or magnitude of lining is more than which could be handled in one annual closure. Diversion channel has the same discharge capacity as the main channel. The diversion channel can be either placed away from main channel or cut in one of the banks depending upon the local conditions. The diversion channel placed close to the original prism, has the advantage of being constructed in small sections allowing the use of existing outlets, while the lining work proceeds in reaches between outlets, but it has the disadvantage of causing seepage into the channel prism which hampers the lining progress and also effects the quality of lining work.

The diversion placed at a distance from the main channel, eliminates the problems of seepage in to the original prism, but at the same time, has the disadvantage of more cost and the necessity of provision of temporary outlets, as the diversion has to be a continuous channel. The temporary outlets are a source of malpractice and complaints. The diversion channel is therefore placed so as to allow the use of same outlets and also shifted from the main prism to the extent of eliminating or minimizing seepage.

A better alternative is to let the original prism run as it is and construct a new lined prism along side in the channel/existing patrol bank. This alternative also has some plus and minus points. The advantage is that the operation of the original channel continuous unhindered while the lining work remains in progress and also temporary outlets are not needed, but this alternative is only possible in patrol banks which are properly compacted or have to be compacted before excavating the channel prism. Since the new channel is placed close to the original running prism, the seepage problem appears in varying intensities and is site specific. This alternative also requires re-construction of all the outlets in the lined reach.

The selection of one of the above alternatives basically depends on the site conditions prevailing at the time of start of construction.

Preparation of Subgrade

After completion of the diversion channel, the original channel section is filled-up in properly compacted layers, to prepare a base pad for excavation of channel prism, of course after cleaning the original prism. After the compaction in the pad is ensured, the channel section is excavated and side slopes are again tested for compaction percentage. This process sometimes requires repetition of compactive effort, although such repetitions are site specific and vary from channel to channel. The above operation provides the base pad for excavation of the channel section.

Shaping up of Channel Prism

After preparation of sub grade, the channel section is cut in the base pad and shaped up to proper parameters, line and grade.

LAYING PROFILES

After preparation of sub grade and shaping up of the channel prism, profiles are constructed to demarcate the lining panels, because in the absence of lining machinery, the work is to be done manually in panels of ten feet length for concrete, and 20-25 ft. for brick work. Since the profiles are control sections, these are prepared with the help of steel templates of proper shape.

LAYING THE BASE PLASTER

After the profiles are in place, the base layer of plaster is placed both on sides and the bed. Plaster surface is finished with wooden float and scarred to provide proper bond to the subsequent lining layer.

Brick Lining

Laying of brick lining is simple. The bricks are laid on edge in a thin 1:3 cement sand mortar layer for proper bonding. All the joints are properly filled and struck flush with the brick surface to achieve maximum smoothness of surface to bring the value of 'n' as close to the adopted value as possible.

Concrete Lining

The main problem in laying the concrete layer on slope is the control of the slump and workability. The low slump concrete, although it maintains its thickness on the slope, becomes unworkable and is very hard to finish, while increase in slump results in flowing of concrete which also can not be finished to proper thickness. It has been observed that if laid without forms, the concrete with a slump of one inch to one and a half inch can be worked to reasonable finish but poses problems in compaction of the concrete layer. However if forms are used, a slump of 2 to 3 inches provides adequately dense and properly finished concrete. The compaction is effected by employing form vibrators. The forms produced better panels, in density, surface, laying, line and grade. A sketch of typical forms used on some channels in 2nd. ISR Project appears as Figure 3.

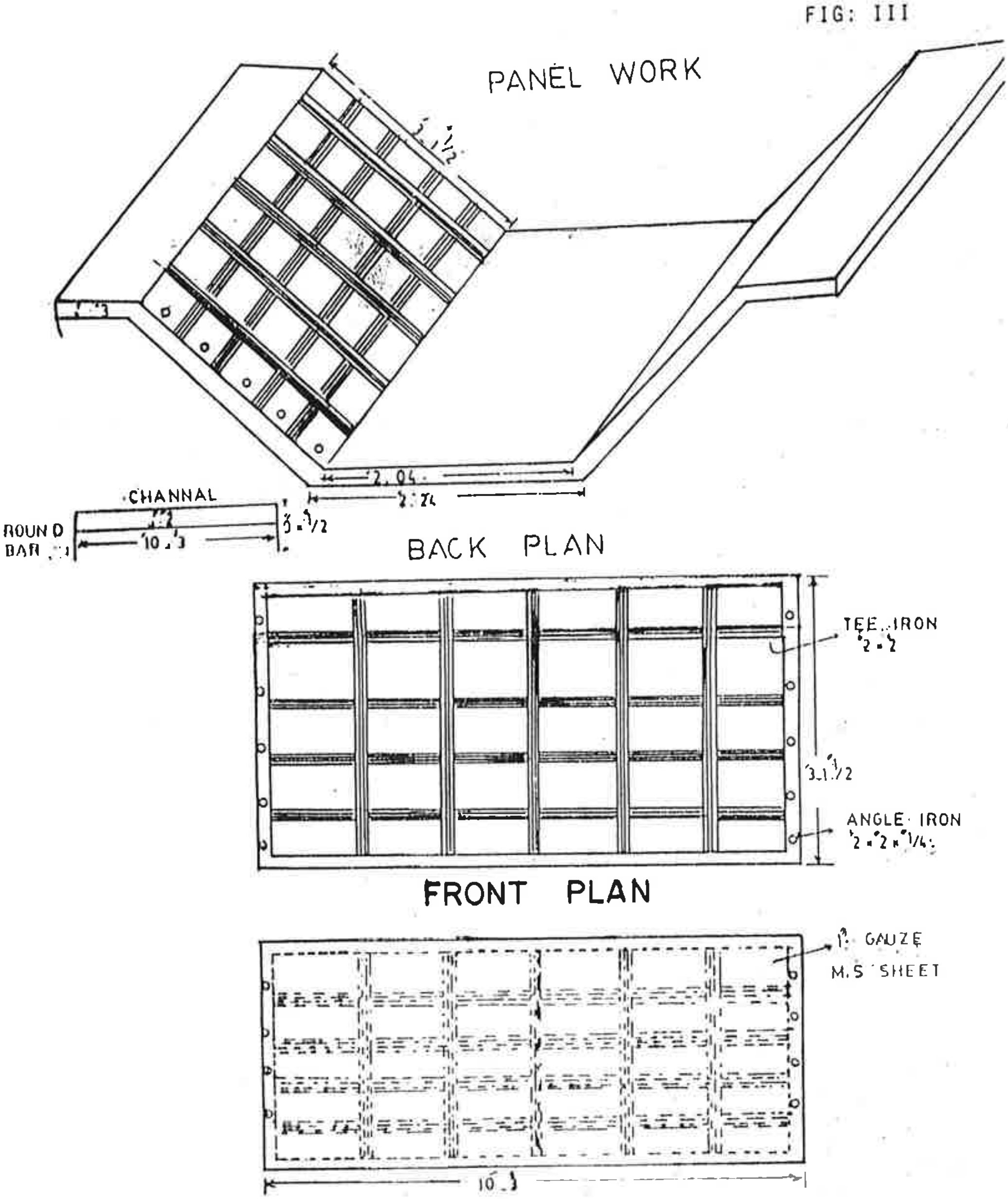
FIG: III
PANEL WORK
CHANNAL
ROUND BAR
BACK PLAN
TEE IRON
ANGLE IRON
FRONT PLAN
GAUZE
M.S SHEET

Figure 3.

CURING

Curing is very important as it is the key to strength of concrete and mortar and a difficult item of construction to execute. Since the work is to be kept continuously moist for ensuring proper hydration of cement and achieving proper strength, proper curing becomes more problematic. It requires adequate and dedicated curing staff to work round the clock to ensure proper curing. This is achieved by the use of Burlap, Sprinklers, or Curing Drain constructed on the top edge of the lining. After three days the newly lined section is filled with water to ensure constant supply of curing water.

AVAILABILITY OF MATERIALS

The all basic materials for both types of lining (Brick and Concrete) are available in the market, but the quality of bricks and bricktiles is generally unacceptable. Due to heavy demand, the kiln owners do not agree to selection at the kiln stacks and work site selection as to be relied upon which always poses hard to control multiple problems and the quality of brick work suffers. There is no such problems in concrete materials.

However the crushstone coarse aggregate manufactured by crusher units in the province, lacks proper gradation, and therefore mixing of various size fractions is necessitated to obtain a properly graded coarse aggregate. Generally the coarse aggregate with maximum size of three quarter inch mesh crushstone has been used for lining work except in specific locations which required different maximum sizes. There is no problem in obtaining cement of both portland and sulfate resisting types. In areas where the sand does not contain the coarser particles (No.4-16), the missing sizes are obtained from the crusher sievings usually termed as "Pan", but this requires due care, as the pan fraction from very hard stone (sometimes brittle) crushing by jaw crusher contains flaky pieces and needles which can not be used for concrete as it causes serious impairment to the strength of concrete instead of adding to it. The rotary crushers however produce well shaped cubical particles which have no problems associated with them. The other alternative for obtaining as well graded sand is to import from Haro River deposits, but this sand becomes very costly due to carriage over long distances.

QUALITY CONTROL

Quality control in general depends on the workman and supervisor, "A lousy supervisor gets a lousy job", so goes the saying but a lot also depends on the efficiency of workman who lays brick or concrete. Under the present day conditions, brick lining requires more extensive supervision, as the quality of every brick that is laid has to be ensured, while in the case of concrete, the mixer is the most important supervision unit, although the placement and finishing processes also require some attention. In over all perspective, the quality control of concrete lining is slightly more assuring and easier to achieve.

LIFE OF LININGS

The period for which a lining would remain physically useful, depends on several variables like exposure to weather, extent of variation in temperature, saline soils and water, quality of materials and construction, and the type of physical loading. However the useful physical life of 1:2:4 P.C.C. lining is considered to be around 40 to 50 years and a 20-25 years useful life is expected out of brick lining.

However the deterioration of brick quality has rendered the above expectation, more a guess than a rational estimate i.e. the life of brick lining now depends on brick quality and is widely variable from work to work and location to location. The increased porosity of the bricks renders the brick lining unsuitable as seepage reduction/control measure. However brick linings constructed about 8-10 years from now are still in good shape.

Concrete linings on the other hand are more reliable and durable and suited for seepage reduction and are capable of reducing seepage to even less than 1×10^{-6} cs/ft^2. However concrete lining under lain by a suitable membrane are really effective and completely cut off the seepage reducing the loss to zero. The opening up of channel banks on the back of concrete lining has in several cases shown no seepage at all.

As mentioned earlier, the lining of channels done in Punjab has been oriented mainly towards improving the hydraulic performance and conveyance capacity of the channels, rather than seepage reduction, although seepage has been reduced along all lined channels as a by product in varying degrees. No efforts have yet been made towards estimation of the water so saved, but the improved water supply on the tail outlets indicates substantial savings which can be estimated at about 70 percent of the loss through earthen channels.

In lined reaches sub soil water levels along the lined channels have substantially dropped.

ENVIRONMENTAL EFFECTS

The environmental effects of lining an irrigation channel are well known. However it can be said in brief that linings reduce seepage and mitigate the effects of waterlogging and under helpful conditions are instrumental in reclaiming the wet lands/swampy area strips along the channels, and in turn results in eliminating the ill effects of such marshy areas.

CONSTRUCTION PROBLEMS

The construction problems are mainly the deteriorating quality of construction materials and non-availability of trained construction workers and staff. Other problems of faced in construction are mostly site specific and can be easily solved if the construction management is judiciously handled.

PROBLEMS OF OPERATION AND MAINTENANCE

The problems that are faced in operation and maintenance are related to either the design and construction effects or some natural phenomena. Some of these are introduced briefly in the following paragraphs:

a) As already indicated earlier, the most important factor in designing a lined section is the adoption of an optimum value for Manning's. If the value of 'n' is taken on the lower side and actual value attained on commissioning is higher, velocities lower than the envisaged are experienced with the result that the design discharge requires larger depths, thus raising the water surface level and causing encroachment on the free board. This phenomenon is very much pronounced in larger channels, but may not appear to be serious for small channels. The experience on canals lined in previous decades, reveals some serious problems that were faced on these channels. Haveli Canal and Balloki Sulemanki Link are two very glaring examples in the Punjab, where the linings had to be raised by almost 2 feet to maintain a proper free board.

b) In reaches where the lining is rougher than envisaged or where a larger section has been provided, berming and silting are the two problems that are commonly experienced. The only solution in such cases is to remove the effects regularly and periodically to keep the channel clean.

c) **Weed:** In the channels where berming has occurred or on the other hand water is clear, growth of weeds is encouraged. The types of weeds are different in the two cases. In the case of berming, removal of berms is the best solution, but in the case of clean water the weeds have to be removed manually, mechanically, chemically or biologically at regular intervals.

d) **Damage of Lining:** The principal causes of damages of lining are physical loads in addition to those envisaged in design, subsidence of subgrade and sudden drawdown. The last situation may not be experienced in shallow channels or the channels which are in filling. The damages are basically cracking, settlement, or chemical deterioration due to action of salts which can be to some extent mitigated by the use of sulfate resisting cement for construction.

e) **Maintenance Activities:** The maintenance of lined channels is simple and less costly if it is done regularly according to a proper programme. The maintenance activities include the up keep of earthen banks, linings and cleanliness of the channel prism. The first and last can be accomplished by the maintenance gangs and if need be, by supplementing them with causal staff additions. The up-keep of lining has to be done carefully with proper roster, in case, berming and weed problems are encountered. In case of subgrade settlement, where the lining is damaged, it has to be replaced after restoration of the settled subgrade. By and large lined channels require less effort and expenditure on their up keep.

f) **Annual Expenditure:** At the moment, the expenditure on lined channels is not accounted for separately, but it would be worth while to prepare a yardstick for maintenance of lined channels and to keep the account of expenditure under separate sub-head of account.

g) **Acceptable Maintenance Levels:** Obviously the acceptable levels for maintenance in channels aim at running the channel successfully to its AFS and distributing the supply equitably along the whole channel right up to its tail. This will need removal of those short comings which could effect the hydraulic performance of the channel, on priority.

h) **Trade-Off Between Initial Cost and Subsequent Maintenance:** The trade-off between initial cost and subsequent maintenance becomes a secondary issue, because channels are not lined with the aim to reduce the maintenance expenditure. Basic aim for provision of lining is either to cut-off seepage or improve the hydraulic performance and conveyance capacity of the channel. However maintenance cost of a lined channel if maintained to a proper programme is definitely lower than that for a earthen channel.

ECONOMIC VIABILITY OF LINING

Considering the real value of water for economic growth of the country, the lining of channels is prima-facie, a viable proposition. The equity of distribution achieved by improving the hydraulic performance and conveyance capacity of the channel results in substantial increase in production and socio-economic uplift of the people. Water is a very valuable commodity and economic impact of water savings through seepage reduction, and consequent increase in agricultural production off-set the lining costs. Generally the lining projects have reasonable EIRR.

ROLE OF APPLIED RESEARCH

The principal questions to be answered by applied research for decision making support regarding "lining for seepage reduction" are:

1. Availability of different lining materials for reducing seepage.

2. Selection of best type that would ensure maximum reduction in seepage.

3. Cost of various types.

4. Identification of the best type that gives an optimum trade-off between costs of construction and benefits.

5. Effect of seepage reduction on groundwater table and related problems.

6. Maintainability of various types of linings and identification of the best type.

CONCLUSION

The Punjab experience regarding lining of irrigation channels have in overall perspective been interesting and useful. Punjab has benefitted from canal lining and intends to continue with lining of irrigation channels on need and fund availability basis.

LINING OF IRRIGATION CHANNELS IN SINDH PROVINCE

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ABSTRACT

The Irrigation Channels in the Province of Sindh (Pakistan) are mostly unlined i.e. earthen channels. Heavy seepage losses take place while delivering the Irrigation water from the headworks to the field. Thus looking to this the Irrigation and Power Department, Government of Sindh physically launched the Command Water Management Project during the year 1986-87 for lining of small earthen channels. Two systems of Rohri Canal offtaking from Sukkur Barrage were taken up for this Project. These systems are Naulakhi and Sehra systems. The channels upto 30 cusecs discharge were lined and the channels or those reaches of channels having discharge of more than 30 cusecs were rehabilitated. The cost of lining per mile of the channel having a wetted perimeter of about 12 feet was worked out to about Rs.1.6 Million. Channels in a length of about 140 miles were lined which saved the water estimated to about 51 cusecs. This paper describes the benefits of lining which are considered to be multidimensional. The system improvement benefits include saving in the seepage and other losses of the channel, equitable and assured supplies of Irrigation Water and improvement in the flow condition of channel due to proper section, gradient and smooth surface etc. The agricultural and economical benefits include extra area brought under cultivation due to saving of water, increase in the crop yield due to assured and timely application of water, improvement of the economical condition of the farmers, increase in the revenue recoveries of the Government and significant reduction in the maintenance cost of the channels etc. All these benefits have made the lining of Irrigation channels economically viable and it is concluded that the Government of Sindh should go for more projects of lining of channels. The demand of food and fibre is ever increasing in Pakistan on account of tremendous population growth. To meet with this increasing demand of food and fibre more and more areas have to be brought under cultivation with all possible efforts to increase the yield. To achieve these targets more quantity of water and it's assured supplies would be required for which lining of the irrigation channels will play a great role.

BACKGROUND

The Irrigation System of Sindh Province of (Pakistan) comprises of main canals, branch canals, distributaries, minors and water cources. This network of canals is fed by three barrages along River Indus i.e. Gudu Barrage, Sukkur Barrage, and Kotri Barrage. All the canals off-taking from Sukkur Barrage are perennial canals and those off-taking from Gudu and Kotri Barrages are non-perennial and operate only during Kharif season with nominal share of water during Rabi season. The entire network of channels along all the three barrages comprised of earthen channels except Akram Wah Ex-Kotri Barrage which was originally constructed as Lined Canal.

This network of Irrigation Sytem in Sindh Province utilized about 45 MAF annually for application of Irrigation Water at the field. It is considered that about 10 to 15% of this water is lost in channels during conveyance of the same to the fields from head to the tail of the channels.

All the canals off-taking from Sukkur Barrage headworks are unlined. Entire system i.e. main canals, branch canals, distributaries and minors were all unlined i.e. earthen channels. These unlined channels are in operation since 1932. It was realised during the course of operation of these channels that the water table was gradually rising and the main reason for that was considered to be percolation of water from the Irrigation channels.

Due to this situation it was decided to start lining of channels which was the only solution to check percolation of water into the soil and save the valuable Irrigation water from being lost.

The Command Water Management Project was thus launched during the year 1984-85. The areas selected were Naulakhi and Sehra Branch systems of Rohri Canal off-taking from Sukkur Barrage and the channels having discharge upto 30 cusecs were proposed to be lined besides keeping proper berm and strengthening of banks as per specifications. The channels of these systems having discharge more than 30 cusecs were proposed to be rehabilitated in the reaches where the discharge was exceeding 30 cusecs. This policy was adopted in view of the financial constraints.

The schemes were prepared by the Irrigation and Power Department of the Sindh Province and works were actually started during the year 1986-87. Lining of about 140 miles of channels along these systems were thus completed upto June 1992. The work was executed under the loan from International Funding Agencies (IFA) and NESPAK worked as consultants for designing, project planning and execution. The Irrigation & Power Department of Sindh was the executing agency. The Command Water Management Project also had agriculture component for lining of water cources and preparation of model farms. This component of the project was executed by the Agriculture Department of Sindh Province with NESPAK as consultants.

Cement concrete lining of channels was carried out under the project besides rehabilitation of the channels in the head reach. The concrete lining work included

1:10 ratio of cement plaster ½" thick over properly compacted earthen section. 3" cement concrete 1:2:4 layer was laid over the cement plaster.

Working methodology for lining of channels was that in the begining a temporary diversion was constructed in a length of about 2000 ft. in the berm of the channels if available or a separate bank was constructed on either side of the channels (Figure 1 and 2) and the water was allowed to flow in the diversion channel to feed the command area lands regularly without any break.

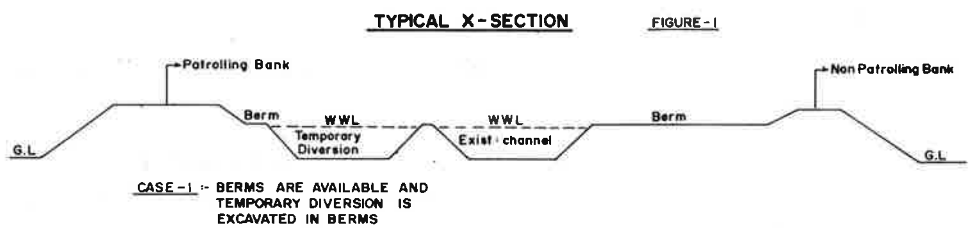

Figure 1. **Typical X-section.**

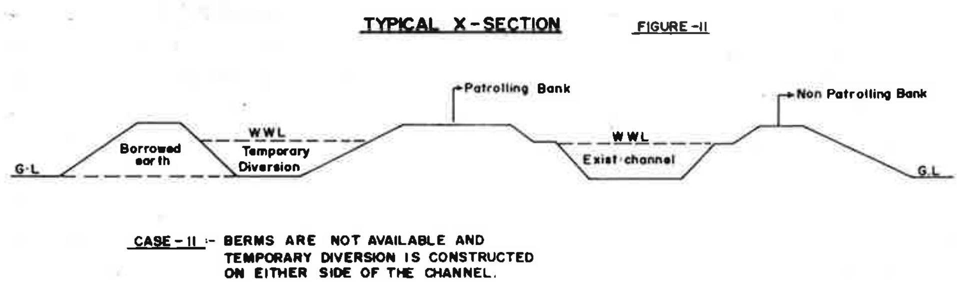

Figure 2. **Typical X-section.**

The existing channel was completely filled with borrowed earth and was fully compacted with the help of small petrol engine rollers to the extent of more than 90%. After that the design section was excavated and the bed and slopes were again compacted by proper watering and ramming. A layer of cement plaster ½" thick in a ratio 1:10 was provided over this properly compacted earthen section and then the cement concrete of 1:2:4 ratio 3 inches thick was laid over the cement plaster layer in alternate pannels of 10 ft. each, having a joint at every 50 ft. interval which was filled with bitumen, sand and saw dust.

The primary purpose of lining of the channels was to stop the percolation of sweet Irrigation Water from the channel's bed and utilize the same "saving" for increasing the intensity and the agricultural production.

After lining it was noticed that water became available in the tails of the minor where there was acute shortage since many years before the lining work. This gave a clear indication that the water is saved consequent to lining of the channels.

Before the lining work, breaches usually occurred in these channels during Kharif season but after lining of the channels, no such report has yet been received.

Also the basic purpose of this project was to increase agriculture production through improved water management alongwith efficient supply of agriculture services and increasing cropping intensity per acre.

ESTIMATE OF COSTS OF CONSTRUCTING LINING

The average cost per mile of lining of the channel was about Rs.1.6 million. The cost includes construction of temporary diversion, cement plastering the channel section, cement concreting 1:2:4, earth work for strengthening the banks, compaction of earth works such as excavation in Irrigation Channels, borrow pit excavations leads of earth etc. This cost also includes necessary workcharge establishment for watching of temporary diversion, nicking layout and supervision.

Remodelling of outlets which was a separate part but very essential and relevant to lining for equitable distribution of water, was also done. The average cost was Rs.0.035 million for remodelling of each outlet.

WATER SAVING ASSUMED

It was assumed at the inception of project that Irrigation Water will be saved to an extent of about 10 to 15 percent which would comprise of percolation, evaporation and spillage. Water saving was also worked out on the standard conception of percolation at the rate of 6 cusecs per million s.ft. of wetted perimeter as under:-

Total length of all minors	=	140 miles
Total discharge in all minors	=	608 cusecs
Number of minors	=	43
Average discharge/minor	=	14.1 cusecs
Channel having section:		
B	=	5.3 ft.
D	=	2.5 ft.
Side slope	=	1:1
S	=	1 in 5000
Wetted perimeter	=	12.3 S.ft.
Wetted perimeter of all minors	=	12.30x140x5000
	=	86,10,000 S.ft.
Water saving	=	6 cs:/million Sft
	=	8.61x6
	=	51.66 Cs:
	=	Say 8.5%

This saving of water can be utilized and 51.66x345 = 17822 acres of extra land can be increased in the culturable command of these channels proposed to be lined.

ESTIMATE OF ACTUAL WATER SAVING

After the lining work was completed on the channels, these were run on the designed gauge at head and necessary data was collected. From the Table-1 for outlet discharges and also from the Table-2 for cultivation figures, this can be seen that seepage lossess and other lossess have been reduced and saving is achieved from 7% to 10%.

Increase in cultivation in the command of lined channels is to the extent of about 8 to 9 percent. This gives clear indication about the saving of water on account of minimizing of water lossess along the lined channels.

OTHER BENEFITS OF LINING

Lining of channels has also improved hydrology of the channels resulting into minimizing the lossess and increasing the efficiency of the channel. This has also helped in the equitable distribution of water as due to proper gradient of the channels the tail end outlets get their due share of water as soon as the channel starts functioning which continues undisturbed. Before the lining of the channels breaches and leaks occurred usually in Abkalani season (Kharif Season). Due to these breaches, heavy lossess had occurred to the Government in shape of expenditure for recouping the breachs or leaks. Standing crops, roads, houses etc. were also damaged which resulted in the shape of heavy economic lossess to the farmers and land owners and also to the other public. After lining work, no report of breach or leak has been received along these lined channels.

Table 1. Statement Showing Comparative Cultivation Figures along some of the Lined Channels during the Years 1985-86 and 1992-93.

S.No.	Name of Channel	Actual Cultivation (Acres)		Actual Increase (Acres)	Percentage Increase
		1985-86 Before Lining	1992-93 After Lining		
1.	Dalipota Minor	12,995	14,070	1075	8.27
2.	Khan Wahan Minor	10,701	11,575	847	8.16
3.	Dewan Minor	8,046	8,774	728	9.04
4.	Lundo Minor	1,807	1,943	136	7.52
5.	Larik Minor	5,741	6,221	480	8.36
6.	Sial Distry	11,356	12,355	999	8.79
7.	Gul Minor	9,019	9,649	630	6.98
8.	Salehpur Minor	2,980	3,280	300	10.06
9.	Manjuth Minor	1,047	1,146	99	9.45
10.	Let Minor	10,199	11,041	842	8.25

Table 2. Outlet Discharge of let Minor in Head Middle and Tail Reach Portion Before and After Lining Work.

S.No.	No. of Outlet	R.D.	Design Discharge Cs:	Actual Discharage After Lining Cs:	Percentage Increase	Average %age Increase
1.	2-R	3,116	0.65	0.70	7.69	
2.	3-R	5,184	1.44	1.55	7.63	
3.	4-R	5,284	1.11	1.2	8.10	
4.	3-L	25,763	1.25	1.35	8.00	
5.	4-L	28,701	1.30	1.40	7.69	
6.	5-L	31,200	1.20	1.30	8.33	
7.	12-L	56,865	0.95	1.05	10.52	
8.	13-L (Tail)	58,900	1.95	2.15	10.52	9.55

EFFECTS OF LINING ON THE FARMERS

Equitable distribution of water and its continuous and assured supplies have on one hand increased the intensity of cultivation and on the other hand increased the crop yields per acre on account of proper and timely application of water to the crops. This has resulted into great economical benefits to the farmers. These benefits will improve the general economical condition of the farmers. In future it would also be possible for the farmers to invest more in the field, go for mechanization give proper inputs & increase the yields further more which will help a lot in achieving the required target of food and fibre which is ever increasing due to tremendous population growth.

PROBLEMS OF CONSTRUCTION

The main problem during lining work was the continuity of supply to the farmers through temporary diversion which was constructed on one side of the channels. The supply was not closed and water was allowed to run continuously through the diversion. As the water had to be supplied to the outlets on both sides of the channels for which gaps were to be left and at these points diversion was again aligned to meet with original channel for feeding water to the outlets on the other side. This process takes time and it was very difficult to supply the designed discharge to the outlets during construction. However, equitable discharge was given to all the outlets.

PROBLEMS OF OPERATION

No major problem was observed during operation of lined channels. A few minor problems which are mentioned as under were however noticed:

i) To save time and expenditure, open brick channel was not constructed and circular pipes were laid from lined channel to the outlet head to supply equitable discharge to all the lands even on the tail of minors but during course of time some pipes got chocked by the bushes etc. which resulted in the reduction of discharge in some of the outlets.

ii) Irrigation channels are the main source of water for the villagers for their cattle. The buffaloes sometime damage the lining.

iii) Joints are left at every 50 ft. interval which were filled with bitumen, sand and saw dust. Shrub has been noticed in the joints which attracts deposition of different materials carried by the flowing water.

iv) A thin silt layer ranging from 0.1 ft. to 0.3 ft. was observed in certain channels.

MAINTENANCE ACTIVITIES IN LINED CHANNELS

No major maintenance activity is carried out along the lined channels. Minor maintenance like removal of shrubs sprinkling of banks etc. is carried out as a routine. The only major damage was caused during heavy rains of 1992 which required major maintenance work of reconstruction of damaged lining. In fact due to lining of channels the maintenance activity is considerably reduced. The major maintenance work of silt clearance is totally eliminated.

PRINCIPAL CAUSES OF DAMAGES

No damage has occurred to the lined section due to technical design application or due to under specifications of the work except the heavy rains during the year

1992 which occurred due to back runners. Minor damages have also been caused by the bufalloes in the channel. Due to traffic comprising of tractor trollies, bullock carts and jeeps etc. the soil of bank/berm which holds the lining is removed. Consequently due to reduction in the strength of soil the cracks have occurred in the slopes at very few places.

PHYSICAL CONDITION OF LINING

Physical condition of lining in all the channels on Naulakhi and Sehra system is generally good, except the portion damaged due to heavy rains during the year 1992.

DESIGN OF LINED CHANNELS

1. The design was based on Mannings equation:

$$V = \frac{1.486\ S^{\frac{1}{2}}\ R^{\frac{2}{3}}}{n}$$

   The Manning's 'n' value was assumed as 0.016 for 1:2:4 concrete having steel trowel finish but practically it is not possible by labour, which require reconsideration in assuming the value of "n".

2. Larger section of channels in length have been designed but actually these sections should be shorter. Due to larger section, the water can not maintain its velocity on which it is designed hence thin layer of silt gets deposited on bed of the channels.

BEST MEANS OF ENSURING HIGH STANDARDS OF CONSTRUCTION

The best way of lining of the channels is by mechanical means, which is already introduced in the developed countries.

This will reduce the cost of scheme as well as minimize the time period for its completion. By using machinery, a channel having discharge of 10 to 15 cusecs can be completed within about 30 days. The quality of work of lined channel constructed by labour is not of the standard as that of machine work. Filling of joints should be carried out with the material which are water tight and do not give away as on its removal there is silt deposition and subsequently growth of shrubs. The inspection path side of the lined channels should preferably be converted into metalled road so as to keep the bank soil intact and save it from any damage caused due to the movement of traffic.

LIFE TIME OVER WHICH LINING WILL PROVIDE A USEFUL REDUCTION IN SEEPAGE

After lining of the small channels of 30 cusecs in Naulakhi and Sehra Branch systems it was observed that the seepage has reduced.

If the lined channels will be maintained properly and the damage will be repaired on the right time, then the seepage can be reduced to the extent of about 10%. The experience of Naulakhi and Sehra systems shows that the useful life of lining can be expected to be more than 10 years.

ACCEPTABLE LEVELS OF MAINTENANCE

The lined channel should be maintained properly. If any damage is occurred it should be repaired at the right time. It should also be observed that no crack etc. should occur in the lined section but if it occurs due to some reason, it must be filled in with cement sand mortar by mechanical means. It should also be seen that earthen bank should always be in contact with the concrete lining. No hollow gaps should be allowed to form between concrete and soil. In case this occurs, the same may be recouped as early as possible. Patrolling and non-patrolling banks should be properly maintained. This maintenance standard can be achieved from 1.5% of the project cost allocation per annum for the maintenance purpose.

ECONOMIC VIABILITY OF LINING

Economic viability of lining can be worked out considering two aspects. Firstly by Agriculture benefits i.e. extra cultivation on account of the saving of water by minimizing the losses and increase in the overall yield. Secondly by reduction in the maintenance cost. On the lining of Naulakhi and Sehra Branch Systems of Rohri Canal in Sindh Province. Both these aspects have been noticed very significantly. Saving of water was estimated to be about 51 cusecs. Thus from this saving of water of 51 cusecs about 5100 acres can be brought under cultivation during Kharif and about 10200 acres during Rabi. Thus annual increase in area would be more than about 15000 acres. This can result into net agriculture benefits based on Rs. 5000 per acre, to about Rs. 75 million. This much estimated benefit and increase in overall yield supplemented by revenue recoveries and huge saving in the maintenance cost has made lining of channels an economically viable project for the Government.

CONCLUSION

It has been discussed that lining of the channels result into multidimensional benefits. These benefits are of two types. First category of benefits is the improvement in the working of the channel which includes saving of water due to minimizing the seepage losses, assured and undisturbed Irrigation supplies and equitable distribution of water.

Second category of the benefits is Agro-economical which include increase in the agriculture area on account of water saved by minimizing the losses, increase in per acre yields of crops due to timely and assured Irrigation supplies, improvement of economical condition of the farmers, increase in the revenue recovery of the Government and significant reduction in the maintenance cost of the channels. All these benefits have rendered the lining of channels as an economically viable project. Thus it is finally concluded that Irrigation & Power Department, Government of Sindh, Pakistan should go for more and more channel lining projects.

REFERENCES

NESPAK's Reports about Command Water Management Project.
The Departmental record about Command Water Management Project.

NORTH WEST FRONTIER PROVINCE PAKISTAN EXPERIENCE IN CANAL LINING

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ABSTRACT

Prior to partition, the canal lining experience in the North West Frontier Province consisted of brick-and-mortar lining. In recent decades, considerable experience has been gained with concrete lining. Much more emphasis is now placed on soil compaction of the subgrade and using appropriate materials in the lining joints to reduce seepage. In addition design criteria have been improved such as flatter side slopes and more realistic value of the Manning roughness coefficient.

INTRODUCTION

Canal lining aims at providing a smooth impervious or semi impervious layer of suitable material over the canal cross section so as to reduce the hydraulic roughness and thus deliver increased discharge in a comparatively smaller canal section, by increasing the velocity. The technology of canal lining in the sub continent was introduced during the British Government for imparting stability to the canal section and traversing sandy reaches, rather than minimizing seepage losses in transit. The lining, mostly done with bricks in a double layer, included a layer of Surkhi lime mortar between the bricks which further reduced the seepage. In NWFP such type of lining was done on the Maira Branch of the Upper Swat Canal system. After independence and further advances in concrete technology, the brick lining was replaced by concrete lining which was found to be more durable and impervious. In the beginning, the concrete lining was only provided at places where the canal was passing through sandy areas and the side slopes were more vulnerable to frequent damages as a result of trespassing by cattle, humans, etc. As per normal practice, the original earthen section of the canal was usually restored by providing concrete lining rather than redesigning the canal section with the required design parameters. This resulted in a reduction in the full supply depth of water, which adversely affected the withdrawing capacity of outlets due to reduced working head. This necessitated proper design criteria for the lined section so as to attain a full supply depth which is required for proper functioning of the outlets. The channel section was normally designed using Manning's Equation, taking the coefficient of roughness as 0.015.

LINING PROCEDURE

The procedure followed for laying concrete lining in NWFP usually includes, firstly, proper preparation of the earthen sub base, done on both the side slopes and bed with required soil compaction. After verification of adequate compaction, through field test, the concrete profiles of 6"×9" size are laid with joint spacing as determined by the Engineer incharge. Lining of a specified thickness is then laid over the sub grade already prepared, providing construction joints over the profiles which are, later on, plugged with proper sealing material. The concrete lining, done in such a manner, normally gives satisfactory results with very few chances of failure as practiced on a number of canals in the province.

PROBLEMS OF LINING

Problems during construction usually includes excessive excavation and inadequate compaction of the sub base, which subsequently causes settlement and cracks; in the concrete lining. Once cracks appear in the concrete lining, the sub base becomes saturated of the concrete during any abrupt reduction in canal supplies.

The design roughness coefficient of 0.015 is usually never achieved in practice due to improper surface finish and sediment deposition. Thus, with a given cross sectional area, the canal discharge occupies comparatively more area, causing either overflow or inadequate freeboard.

Due to the limited canal closure period, the concrete lining work is required to be completed in a great hurry which adversely affects the quality of work. Diversion arrangement can not be made as additional land width is generally not available along the canals, unlike canals in the Punjab where the land width is sufficient for this purpose. Thus, due to time constraints, the execution of work is mostly arranged in shifts which naturally leaves enough chances for imperfect work during nights. As observed, the lining work done on steeper side slopes (i.e. half to one) is more vulnerable to damages and is usually unstable as compared with lining work done on flatter slopes.

The strategy in the method of construction followed by contractors also plays a vital role in the proper execution of work. As noticed the contractors normally lay the lining for the side slopes first, followed by lining of the bed, thus creating a joint between the bed and the side slopes which subsequently proves to be a weak section causing trouble.

With such construction difficulties, the NWFP, Irrigation Engineers have gained considerable experience and have been making efforts to modify and improve the construction techniques as well as the design criteria for lining so as to eliminate the chances of any failure at a later stage. To overcome the problem of inadequate compaction as described above, a new strategy for improving the side slopes has been devised which includes formation of a subgrade by using a 1-20 mix comprising of one cement and twenty nullah run material which provides increased stability and consequently a more durable concrete lining. The 1-20 mix, after laying, is given a smooth surface by applying a cement plaster of I:3 cement sand mortar ½" thick followed by concrete lining of the required thickness. The surface is worked until a smooth finish is provided. The coefficient of roughness is usually adopted as 0.017 for design, which has given more satisfactory results. As a result major lining work done on the Warsak Lift and Gravity canals, and on new minors served by the Lower Swat Canal system under Mardan SCARP, have given satisfactory results. To reduce seepage, the lining joints are filled with a proper material comprising of bitumen, saw dust and sand which has worked satisfactorily. Other materials, tried by the Mardan SCARP Consultants like Poly Sulphide did not work properly and had to be replaced by the aforementioned materials. Construction joints are provided by laying alternate panels ten feet apart over the already constructed subgrade profile, while expansion joint is provided at 50 feet intervals.

Besides the method of construction, the quality of concrete lining is mostly dependent upon the construction material, like sand, aggregate, cement, water etc: used by the contractors and the required mixing in the proper water-cement ratio.

Lining in waterlogged soils was also done under the Mardan SCARP while converting the water courses into minors. Since the soil foundation could not be compacted brick lining was adopted rather than concrete lining. The channel was designed as rectangular instead of trapezoidal as used for concrete lining. To carry out the lining work, the earthen section was prepared and deep pits close to the section to be lined were dug at approximate intervals of 25 feet for the collection of the seepage water which was continuously pumped to keep the bed in-between the pits from becoming saturated. Mix graded shingle was laid in the bed and compacted followed by placing a Polythene sheet on top. A concrete mix (I:2:4) 6 inches thick was laid on the top of the Polythene sheet and their after side walls 9 inches thick in bricks were constructed in (I:3) cement sand mortar. The inner side of the walls and bed was provided with ½ inch thick plaster of I:3 cement sand and a concrete coping (I:2:4) 3 inches thick was laid on top of the side walls. The backfill was started after 7 days. The above specifications worked very well and the channels so lined have been operating, successfully for the last

5-years with no maintenance so far. Interviews with different irrigators indicated that the cultivated land increased from one acre to 1.3 acres with the same discharge and length of time which means a discharge saving of 30% after lining.

CONCLUSION

The quality of lining work in the NWFP, during the last few years has considerably improved resulting sufficient reduction in loss of irrigation water due to seepage in transit.

The estimation of reduction in seepage losses has not been done but the shortages at the tail end have been minimized to a great extent as a result of lining.

REFERENCE

North West Frontier Province experience in canal lining.

BALOCHISTAN MINOR IRRIGATION AND AGRICULTURAL DEVELOPMENT PROJECT - APPROACH TO CHANNEL LINING

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ABSTRACT

The principal benefit on all schemes developed by Balochistan Minor Irrigation and Agricultural Development Project (BMIADP) is the increased availability of water for irrigation. This is achieved by improving the efficiency of the diversion structure and by reducing the operational and seepage losses in the conveyance system. The lining of the main canal and the construction of ancillary structures such as aqueducts, siphons and super passages normally represents the main component of the civil works.

ESTIMATES OF LOSSES

Detailed investigation on a number of small perennial schemes suggest seepage losses between 4 and 5% per 1,000 ft for small unlined, farmer constructed and maintained canals. Losses in engineered unlined channels are likely to be approximately half of these rates. For lined channels, measured seepage losses ranged from 0.5 to 0.9% per 1,000 ft.

Operational losses depend on the method of water distribution and the irrigation scheduled. The findings from an intensive monitoring programme of a typical small scheme with a large number of farmers suggest values in the order of 10%.

DESIGN FLOWS

The design flow is difficult to define because of the considerable variation in annual rainfall and hence surface runoff in Balochistan. An analysis of flow data on a number of BMIADP schemes recorded over the last 11 years suggest the following proportions for dry, average and wet years:

Dry Year	(1:10 to 1:20)	=	Dry year Flow (DYF)
Average year		=	1.5 to 2.5 x DYF
Wet Year	(1:10 to 1:20)	=	2.5 to 3.5 x DYF

The allowance for freeboard on small lined trapezoidal canals is 6 inches. On rectangular sections of canals a freeboard of 6 inches is used for capacities up to 10 cusecs and 9 inches when the flow rate is greater.

LINED CHANNELS

The rational for channel lining on BMIADP schemes is to reduce seepage and operational losses, control erosion and reduce maintenance. Both trapezoidal and rectangular sections have been used, though the latter are preferred. They are more durable and have a longer life expectancy.

TRAPEZOIDAL SECTION

Although there are examples of concrete lined trapezoidal canals over 30 years old, which are still in good condition. BMIADP experience suggests a far shorter life because of poor construction techniques. The main causes of failure can be attributed to poor earthworks and the lack of compaction, the thickness and quality of the concrete and the forming of the joints.

Figure 1 shows details of a typical in-situ concrete lined trapezoidal channel. Current practice is to use 4 inch thick un-reinforced concrete, class B on channels with a bed width up to 2 ft and 6 inches for wider channels. For these thicknesses the side slopes are entirely dependant on the support of the earth bank. Consequently the quality of the earthworks is of critical importance. On the small canals the recommended procedure is to form and compact a platform in the full width of the canal plus banks and then excavate the canal section. Canals constructed in cut are likely to be more stable than those on embankments or in partial cut.

RECTANGULAR SECTION

Details of a typical rectangular lined section are shown in Figure 2. The lining comprises an ansate un-reinforced concrete base and vertical stone or block masonry side walls with flush pointed joints. The recommended base thickness is 6 inches for bed widths up to 3 ft and 9 inches where it is greater. The side walls are sufficiently thick to withstand the water pressure without relying on the earth banks for stability. In the case of dressed stone masonry block walls up to 1.5 ft high the recommended width is 6 inches with 9 inches up to 2.5 ft.

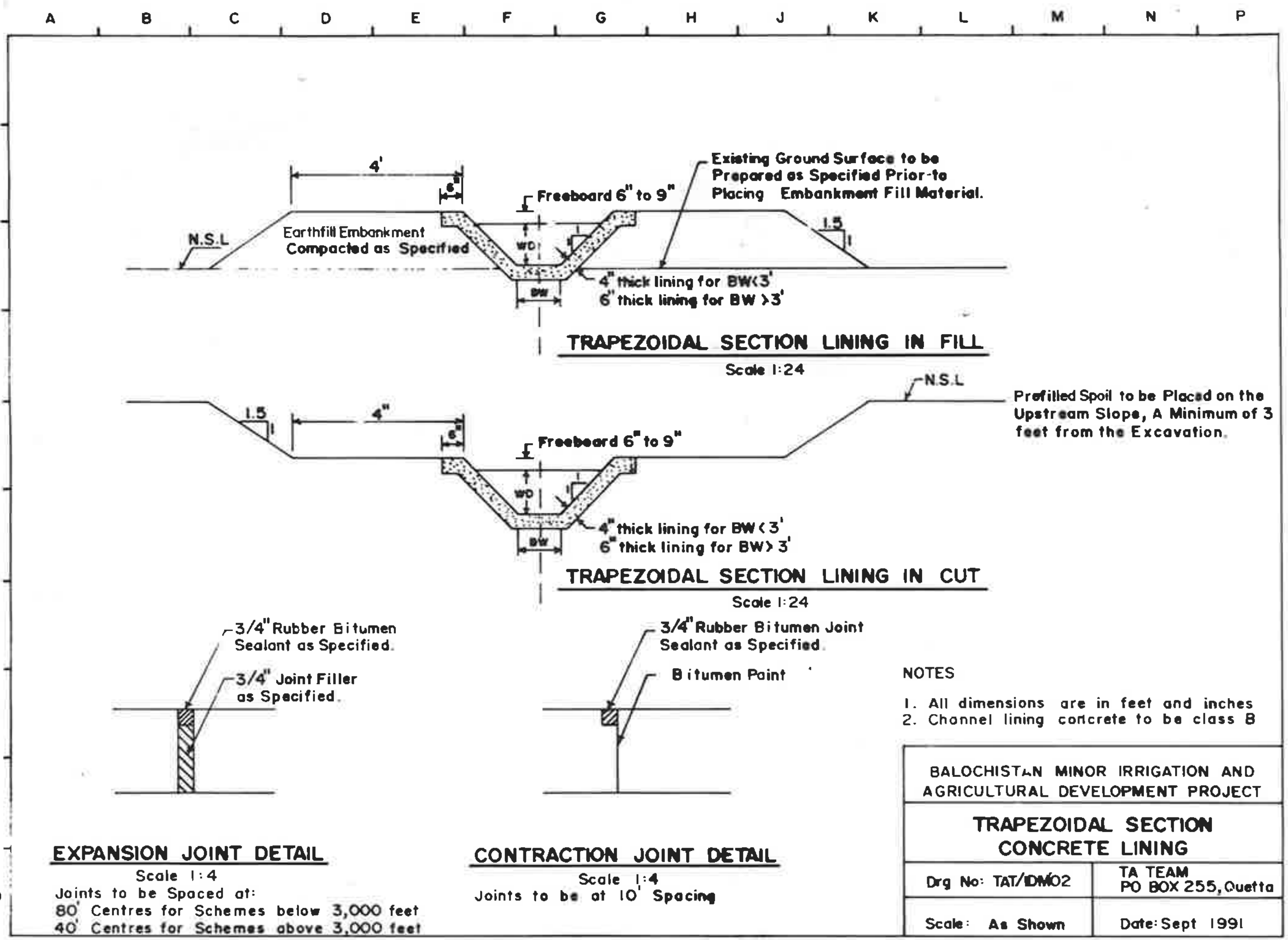

Figure 1. Trapezoidal Section Concrete Lining.

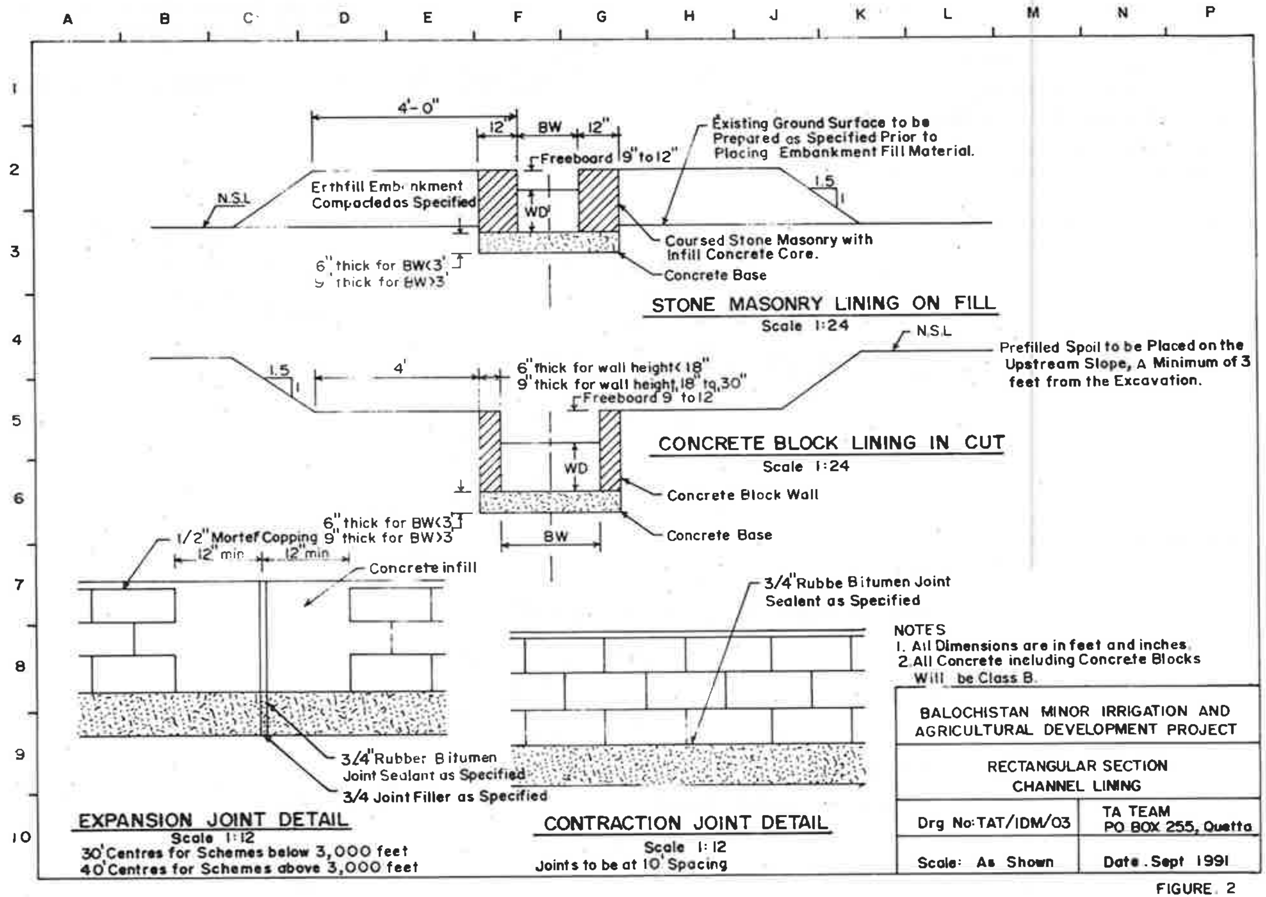

Figure 2. Rectangular Section Channel Lining.

The most economical depth to bed width ratio for rectangular sections with a capacity less than 10 cusecs is about 1:3. For greater flow rates the ratio is between 1:2 and 1:1.5.

COMPARATIVE COSTS

Based on the above design criteria the comparative cost estimate for trapezoidal and rectangular lined canal sections for various capacities and bed slopes is presented in the following table.

Comparative Cost Estimates for Lined Canal Sections.

DISCHARGE (CUSECS)	BED SLOPE (FT/FT)	TRAPEZOIDAL SECTION		RECTANGULAR SECTION	
		B/D RATIO	Rs./FT	B/D RATIO	Rs./FT
2	.004	1	87	3	197
2	.002	1	92	3	208
5	.004	1	103	3	230
5	.002	1	110	3	245
10	.002	1	129	2.5	285
10	.001	1	140	2.5	376
15	.002	1	167	2	425
15	.001	1	180	2	459
20	.002	1	178	1.5	458
20	.001	1	192	1.5	495

Notes:

1. Trapezoidal section side slopes 1:1
2. Base rates: concrete Rs: 50 per cu ft, stone masonry Rs 40 per cu ft
3. Allowance for earthworks Rs: 25 per ft for capacities less than 10 cusecs and Rs 50 for greater than 10 cusecs

From the above cost comparison it can be seen that rectangular stone masonry channel is some 2.2 times more expensive than trapezoidal concrete channel for the flows up to 10 cusecs most regularly encountered in minor irrigation schemes in Balochistan.

Nevertheless, adoption of this form of channel lining in the mountainous and remote areas of Balochistan is considered beneficial for the following reasons:

* rectangular channel does not rely on properly prepared and compacted earthworks for structural integrity - this is very important, as poor earthworks compaction is a major cause of failure of trapezoidal lining world wide;

* considerably greater durability - the concrete base slab is easy to construct and can be readily compacted; the metamorphosed limestone generally used for the masonry walls is very hard and resists abrasion exceedingly well;

* ease of construction - in Balochistan where consistent high quality concrete production is not a specialty of the contractors, but where good quality masons familiar with stonework can be found, this form of construction can be undertaken readily to good quality standards;

* rectangular sections require considerably less width for construction than trapezoidal - this is also important where the channel follows on contour across steep and often rocky hill sides or crosses through existing orchards, as is often the situation in Balochistan;

* ease of maintenance - all works on BMIADP schemes, including the channel lining obviously, are handed back to the beneficiaries for operation and maintenance which is solely their responsibility. Repair of damage to a stone masonry channel is usually within the capability of the community, after training, whereas good concrete making, placing and curing skills are not so readily available;

* use of locally available material - rectangular stone masonry channels make most use of the generally readily available local materials.

CONCLUSION

Summing up, in the specific and unique circumstances of Balochistan Minor Irrigation schemes, the use of the much more expensive rectangular stone masonry channels, where the economics of the scheme allow, are considered much more durable and sustainability is worth the additional cost.

This form of construction, however, is not at all cost effective or practical in the plain areas where raw materials are not available and where flows are much greater than around 10 cusecs and need not be considered.

REFERENCE

B.M.I.A.D. PROJECT.

SESSION REPORT:
PAKISTAN EXPERIENCE WITH CANAL LINING

Dr. Muhammad Abid Bodla
IWASRI, Lahore, Pakistan.

This session contained papers contributed by Mansoob Ali Zaidi, Shuja A. Junejo, Raqib Khan and Abdus Salam Khan, summarizing experiences derived from lining of irrigation channels in the four provinces of the country i.e., Punjab, Sindh, NWFP and Balochistan.

Punjab

Paper describes that canals in Punjab have conventionally been brick lined in years 1936, 1941, 1946, 1952 and 1966 but more recent trend has been towards concrete lining. Design is mainly based on Manning's equation and local criteria and slopes (bed and side) in Punjab are generally small.

Main discussions following the presentation were:

1. Remark by Mr. Mitchell (USBR) on side slopes in the US, 2.5: 1 for polyethylene, 1:1 and 1.5:1 for concrete;

2. Mr. Ghulam Mustafa Shah, Chief Engineer, Water (Central) WAPDA raised questions on types of joints applied to the linings and enquired rationale for applying mortar underneath the lining. The author Mansoob Ali Zaidi explained that joints normally consist of concrete base profiles, bitumen coating, PVC sheets and sealers. Further thin layer of mortar is applied to bond soil with concrete;

3. Mr. F.A. Zuberi, Director General IWASRI: Any problems caused by hydrostatic pressure in waterlogged areas with high water table?

   Mr. Zaidi: Chance of these problems is small, as canals are shallow and are in partial cut and partial fill. This problem can be expected in deep canals which are mostly in cut.

Sindh

Key points presented in the paper suggest that lining experience in Sindh is limited: First 1950, later 1980; and recent in 1986. Experience with brick lining is not good but concrete appears better. Good monitoring system is not available, hence evaluation of lining done on the basis of cultivation data. Waterlogging seems reduced, but effect not clear due to tubewells operation. Economic conditions are improved due to lining. Lining poses construction problems, mainly seepage through joints. Lining is reported to reduce maintenance costs and damages shown mainly due to traffic and animal trespassing.

Discussion mainly focussed on following questions and answers;

Q1. Dr. Irshad Ahmad, IRI, Punjab Irrigation Department: How are weeds removed? Does physical removal result in regrowth.

A1. Weeds are removed physically and problem of regrowth exists.

Q2. Mr. F.A. Zuberi, (D.G., IWASRI): Were observations taken on condition of lining during canal closure and were any problems of bulging or removal of slabs observed?

A2. No bulging or other problems were observed. Main damage is by traffic and buffalo trespassing.

NWFP

Paper contains brief history of lining before independence in 1947, after 1947 and in recent times. After 1947 lining was done without adhering to a careful design. Problems during construction work are stated. Construction materials and methods are discussed and construction in waterlogged conditions is explained. Maintenance issues are also discussed.

The main arguments following the presentation related to the issue of quality control in canal lining. The author commented that quality control has improved. Compaction initially done manually is now achieved through mechanical compaction. Also better mix of materials is applied and so far no damages have been observed.

Balochistan

Principal experience in the paper is based on minor irrigation schemes. Average loss of water from unlined source is reported 4 to 5% and from lined source 0.5 to 0.9%. Designs of trapezoidal and rectangular lined channel prisms are discussed. Paper includes a summarized cost comparison for various canal discharges and bed slopes. Merits of stone masonry, which is not viable in plains, are also mentioned.

General Discussion

Q. The objective of canal lining is often defined as improvement of the hydraulic efficiency. Waterlogging conditions often persist. Does lining actually reduce seepage?

A. All linings reduce seepage.

Remark by Prof. Skogerboe, Director IIMI, Pakistan: The data quoted for seepage rates by USBR (Mr. Mitchell) and for Punjab (Mr. Mansoob Ali Zaidi) are similar and are in agreement with my own data which indicates good quality control.

Q. Can we conclude from the discussion that with good quality control canal lining in Pakistan is successful? (Dr. K. Sanmuganathan, HR Wallingford, U.K.)

A. Yes, provided subgrade is properly prepared. Quality control by laboratory tests on compaction is very necessary (Mansoob Ali Zaidi).

GROUP DISCUSSIONS:
EXPERIENCE WITH CANAL LINING

GROUP I: OVERSEAS EXPERIENCE WITH CANAL LINING

Facilitator: **Muhammad Ehsan, NESPAK, Lahore, Pakistan**
Reporter: **Ata-ur-Rehman Tariq, CEWRE, Lahore, Pakistan**

The session was well attended and participants have shown a keen interest in the subject matter. The discussion focussed on four questions:

1. What were/are the primary reasons for lining of the canal?

2. Were the anticipated objectives of lining achieved, what is evidence to this and how the results were verified?

3. Were/are there any alternatives to save water other than lining the canal?

4. What were general causes of failure of canal lining projects, if any?

Q.1: The reasons to line the canal were different in different countries and also in different parts of the country. In North China, lining was done to save water from seepage due to water scarcity. In South China, it was to improve the hydraulic efficiency of canal as well as to prevent weed vegetation control. In Egypt the whole water supply system in 'new areas' are lined to save water from percolation and also for the stability of the channel prism. The reason for lining canals in USA includes seepage control for environmental considerations e.g. prevention of waterlogging in area adjoining the canals, minimizing saline groundwater return to river, seepage control for saving water (saved water to be used for urban water requirements) and to improve hydraulic performance/stability and/or weed control.

Q.2: The general experiments in China showed that seepage was reduced by 80%. The results were obtained before and after project comparisons, with and without project analysis for different projects. In Egypt no particular monitoring and evaluation was carried out. No water shortages in the project area were considered which reflects that system is performing as planned i.e. seepage losses are at their anticipated level. On the other hand, if water shortages were noted it was reflected as the lining has failed to provide the desired benefits. In USA lining was considered to be quite effective.

Q.3: There was no other alternative to save water/improve hydraulic performance/stability in new areas of Egypt. In old areas tubewell pumpage was an alternate to lining therefore minimum lining was carried out in these areas. In China, improved operation and maintenance programmes were alternate to lining of canals in south part of China as the main reason of lining in this area was hydraulic efficiency cum vegetation-weed control.

Q.4: The causes of failure of lining were varied at different places. For masonry and concrete lining a quick drawdown causes the concrete ponds to bulge out and collapse.

Forest lizard was also a problem in cold area. However, this was not a problem if the quality of concrete work was very good.

It was brought that failure problems results when short-cut is taken in the design, quality control, maintenance and operation stages of lined channels.

Other causes of failure were deferred maintenance of lined canals. These problems multiply and failure occurs before it was expected. If normal maintenance (e.g. repairing turn out concrete ponds and filling up/fixing up any cracks) was carried out then the life of lining was obtained as more than 40 years whereas no maintenance results in failure within 5 to 10 years.

General Remarks:

1) Combination lining (membrane + pcc/masonry/soil stabilization) performed best in China.

2) Most of lining work in USA includes concrete and no or minimum membrane was used. A point was raised as to why then use of membrane is strongly advocated in other countries.

3) Trespassing is kept at a minimum in USA.

4) A research project is underway in USA (Oregon) by USBR where 14 different lined sections (of different materials) are placed and are being

monitored to determine their effectiveness. The results (interim) will be available in early 1994.

GROUP II: PAKISTAN EXPERIENCE WITH CANAL LINING

Facilitator: **Hammond Murray Rust, IIMI, Colombo, Sri Lanka.**
Reporter: **Allah Bakhsh Sufi, IWASRI, Lahore, Pakistan.**

Potential Benefits Accruing from Canal Lining

Out of the several potential benefits cited during the group discussions, the few mainly emphasized are as under;

(a) Seepage Loss/Watertable Control: There was a general opinion that canal lining does save seepage losses, however, its degree of effectiveness depends upon type of lining material, proper design and O&M. Further investigations are needed to determine the seepage losses from different existing lined canals.

(b) Hydraulic Performance: Canal lining does have effect on improving hydraulic performance, such as; minimize canal slope required for its command, reduced cross-section saves land, reduced maintenance, bank stability and minimize evaporation losses.

(c) Equitable Water Supply and Sediment Distribution: Canal lining assures the equitable water and sediment distribution, along the channel length and consequently, the tail end users gets their appropriate shares, provided the design is based on proper pre-project data collection and investigation which is rather available to few agencies but not appropriately designed for.

Causes of Lining Failure

A number of factors have been responsible for lining failure, such as; inappropriate design, selection of material, high watertable effects, poor drainage provisions and poor maintenance and operation. After a long exchanged views, it was concluded that mainly the following are the causes that contribute much towards the failure of lining:

- Shortage of funds
- Improper Project Management
- Lack of pre and post project data collection and investigations

FACTORS TO SUCCESSFUL LINING

- Link with O&M at the outset.
- Proper monitoring and quick approach to use results identified.

LIFE OF LINING

Pakistani experts, narrated that better O&M can provide a functional life to the lined canals ranging from 30-50 years. However, the investigations in the context of seepage loss requires a proper monitoring to assess the life of lining in terms of seepage control.

TECHNICAL SESSION:
DESIGN AND SEEPAGE MEASUREMENTS

A COUNTRY PAPER ON CANAL LINING THE EGYPTIAN EXPERIENCE

Yehia Abdel Aziz,
Project Director, Irrigation Improvement Project, Ministry of Public Works and Water Resources, Cairo, Egypt.

ABSTRACT

Egypt's rapid population growth and greater per capita consumption has lead to a increase in demand for foodstuffs outstripping the growth in domestic production. Water is a key input in Egypt's agricultural production system. Virtually all of Egypt's water is from the Nile River capacity coming from outside of Egypt. Chances to increase Nile River Capacity is subject to international politics. Improving the efficiency (water savings) of Egypt's irrigation system offers the best solution to the production problem. Egypt is lining canals and mesqas (water courses), as well as installing low pressure irrigation pipelines to improve water delivery efficiency (water savings), reduce operation and maintenance costs (cost savings) and require less right of way (land savings).

INTRODUCTION

Egypt has a total land area of about one million square kilometers or 238 million feddans (1 fed. = 0.42 ha.). About 96% of the country is desert. The remaining 4%, concentrated mostly in the valley of the Nile and its delta, is agriculturally productive. Egypt is also densely populated (50.45 million, 1986 census), averaging 1300 persons per square kilometer.

The arable area of about 7.0 million feddans amounts to only 0.12 feddans per capita and is among the lowest levels of availability in the world. The land base for agriculture production consists of about 6.0 million feddans of "old" lands and about 1.0 million feddans of reclaimed "new" lands.

Rapid population growth combined with greater per capita consumption due to increasing living standards has lead to a growth in demand for foodstuffs outstripping the growth in domestic production. This results in increasing dependence of food imports. There is an urgent need to raise agricultural production in order to reverse this trend. Although there is some potential for further development of "new" lands, the main contribution to increased agricultural production must come from greater productivity on the "old" lands.

Rainfall is very rare, only about 20 millimeters at Cairo. Annual rainfall averages about 150 millimeters in a narrow band along northern coastal areas where an insignificant amount of rainfed agriculture is practiced. Upper Egypt is virtually rainless. The productivity of Egypt's limited land resource depends on irrigation.

Since the dawn of Egyptian civilization the River Nile has played a key role in our nation's development. In fact, in no other country in the world has a single waterway played so important a role in the social-economic development of a nation as has the River Nile. The River Nile is the main source of surface water, accounting for more than 95% of Egypt's water resources. The ground water reservoirs underlaying the Nile valley and delta are also dependent on the Nile water.

Virtually all the water available for irrigation comes from outside of Egypt, passing through Lake Nasser near the southern border of Egypt. Lake Nasser is the reservoir formed by the construction of the High Aswan Dam. The average annual inflow at Aswan is about 84 milliard m^3 (1 milliard = 1000 million). The Nile Waters Agreement between Egypt and Sudan allocates 55.5 milliard m^3 to Egypt and 18.5 milliard m^3 to Sudan, with assumed reservoir losses of 10 milliard m^3 per year. The 55.5 milliard m^3 of Nile water available to Egypt, a very limited resource, is already almost nearly exploited. The only chances to increase Nile River water are outside of Egypt and subject to international politics.

Water is a key constraint input in Egypt's agricultural production system. Improving the water use efficiency of the "old lands" is the best solution to Egypt's dilemma. That of providing for the greater demand of agricultural products due to the rapidly growing population. Substantial increases in agricultural production can be achieved by making more efficient water use through improvement and better management of the irrigation systems. Improvements and modernization of the irrigation water delivery system will save water by reducing management and seepage losses.

The majority of the existing irrigation systems in Egypt were constructed in their present form in the first half of this century. The systems were not designed to provide the degree of control needed for the efficient distribution of water which is required by present circumstances. Water delivery in Egypt's "old lands" is based mainly on the operation of several extensive canal systems. These systems are served by principal canals with offtakes from the Nile upstream from the river's seven major barrages.

Each principal canal, with its sub-principal canals, feeds a number of command areas. There are also some individual command areas which are fed directly from the Nile. Typically, water is distributed within each command area by a main canal and a number of branch and sub-branch canals. These canals in turn supply water to mesqas which are small channels generally serving from about 30 to more than 150 feddans of cropped land. Most farmers take water from these private mesqas, although many extract directly from the canals (direct outlets). The private mesqas belong to the water users, who are responsible for their operation and maintenance under the current Irrigation and Drainage Act.

Most canal systems operate by gravity, but some command areas are fed by pumping from principal canals or directly from the Nile. A key feature of the traditional system in the old lands is that water is supplied to farmers about ½ meter below ground level. This requires farmers to lift water from the mesqas to their lands using animal powered sakias and diesel powered pumps. This system, adopted with the introduction of perennial irrigation in the 19th century, was intended to discourage excessive water use by farmers.

A majority of Egypt's canals are excavated into the alluvium clay soils of the Nile Delta. Seepage is generally not a problem in the delta canals. Slope protection and/or stability is a greater problem, especially through villages and near structures. The cross section of many of the canals has been enlarged due to repeated cleaning. Canal seepage losses is a greater problem in the irrigated areas with sandier soils along the upper reaches of the Nile valley. Canal seepage is a major concern in reclamation projects in desert soils.

Seepage from the mesqas is a problem in sandier soils. The physical condition of the mesqas is the greatest problem. Most are over sized due to repeated cleaning and pumping directly from the mesqas rather than from a pump sump. Mesqas bank degradation is a common problem, especially through villages. The hydraulic capacity is many times the size needed. Many mesqas have a top width in excess of 4 meters. Grass, weeds, and trees growing in the mesqas is also a serious problem.

CANAL LINING IN EGYPT

Canal lining is a impervious or semi-pervious coating that is placed on the surface of the canal. The primary purpose is to reduce canal seepage, reducing water losses and water logging of adjacent agricultural lands. Another purpose is canal bank or side slope stabilization to prevent erosion, slope slippage, etc. Other benefits include:

smooth linings, such as concrete, lower friction loss.

concrete linings prevent vegetative growth that restricts flow (friction loss) and is costly to remove (decreased maintenance cost). Repeated cleaning of earthen canals damages the canal side slopes and banks.

- the lower friction losses reduces the cross-section size resulting in decreased earthwork, smaller structures, less surface evaporation and land savings.

- higher water velocities can be used with concrete linings without causing erosion.

Types of lining being used in Egypt includes: machine placed concrete, blown on concrete (gunite or shotcrete), hand placed concrete, precast concrete sections, stone pitching, stone pitching with an impervious membrane and rock filled gabion mattresses. Irrigation pipelines are also being used.

In Egypt's irrigation system improvements, main and branch canals are being switched from a rotation flow, where the canal is out of service from ½ to ⅔ of the time, to continuous flow. Under continuous flow the required capacity is only about ½ of the present capacity. Because of the reduced flow rate under continuous flow and the improved hydraulics of a concrete lining, the required cross-section is much smaller. This requires partial filling of existing canals before lining. The original excavated material has long since been hauled away and used. It is illegal to remove soil from the fields. Backfill for canals in the delta area is not closely available. Another restraint to lining existing canals is providing water service while canals are being lined.

TYPES OF LINING USED IN EGYPT

Concrete Lining

Concrete lining in one of the more effective linings used in Egypt. Types of concrete linings used include: machine placed concrete, blown on or "gunite" concrete, hand placed concrete and precast concrete sections. Concrete lining is used extensively in horizontal expansion projects, new or reclamation projects bringing irrigation to formerly desert lands. These lands are normally very sandy and canal conveyance losses can be very high. The proper channel cross section is easily constructed and water service is not a problem. In the "old lands" canal lining has been largely limited to branch canals in sandier soils.

Rock Pitching

The primary purpose of rock pitching is slope protection and/or stabilization. The rock is manually placed on the canal slope. It is keyed in the canal bottom and has as narrow ledge at the top. The normal thickness of the rock pitching is half a meter. The surface is mortared together. Rock pitching is an effective and economical method to protect and stabilize canal side slopes and banks. We have successfully used precast blocks in place of rocks or stones. It has a neat appearance. It is used extensively on the canals serving the "old lands" in Egypt, especially through villages and on the areas immediately upstream and downstream of canal structures.

Rock Pitching with an Impervious Membrane

An impervious membrane can be placed underneath the rock pitching and across the bottom. This makes an effective canal lining, preventing seepage losses. The rock pitching on the slopes is a very effective protective covering for the membrane lining.

Rock Filled Gabion Mattress

This is a special form of gabion with a larger plan area/thickness ratio than the typical box or basket gabion. The rock filled mattress provides a flexible channel lining. Some settlement or movement can take place without damage to the lining. Base preparation is less critical than for rigid lining. If the purpose is to provide erosion or stability protection, a pervious filter is placed under the rock filled mattress. The filter may be a sand-gravel filter or a geotextile. The filter allows water movement through the mattress but prevents soil movement as would be the case if there is external hydrostatic pressure from a high water table. This application was used on the El Nasar canal in Egypt with very good success. Two previous attempts to stabilize the bank slopes were unsuccessful. Concrete lining was tried, but failed due to external hydrostatic pressure from a high water table. A concrete piling barrier to cut off the water flow and stabilize the slope was also unsuccessful.

An impervious membrane lining can be placed under the rock filled mattress to prevent seepage losses. This makes a very effective canal lining. The rock filled mattress is an effective protective covering on the canal slopes.

Precast J-Section Concrete Lining

We have a pilot Irrigation Improvement Project (IIP) in Egypt. One of the main activities is the improvement of our mesqas. The mesqas are smaller channels owned by the water users that deliver irrigation water to the water users. These mesqas serve command areas from about 30 to 150 feddans in size. They are similar to the Pakistan water courses. Traditionally the mesqas delivered water below ground level. This required water users to lift the water to the marwas that carry it to the fields. In the IIP, these mesqas are termed "low level mesqas". The practice of each farmer lifting water from the mesqas is termed "multiple point lifting", i.e. farmers using their own pumps.

Our improved mesqas deliver water to the marwas by gravity "high level mesqas". A single pumping plant is located at the head of the mesqas "single point lifting". We use two basic mesqas improvement alternatives, an above ground level concrete lined mesqas or a low pressure pipeline mesqas.

The concrete lined mesqas are lined by using unique precast sections in the shape of a "J", with the tail missing. Two of these J-sections are placed together forming a "U" shaped lined section, with nearly vertical sides and a rounded bottom. This method of lining is referred to as J-section lining. Each precast section is about 65 centimeters high, with a 40 centimeter base and 20 centimeters wide. Maximum flow depth is about 50 centimeters. Additional capacity is obtained by placing a block between the two "J" section, widening the channel.

The J-sections are cast in the contractors casting yard. A casting machine is used with a fairly dry concrete mix. The casting machine compacts the concrete by vibrating or tamping. After the sections are compacted they are ejected from the machine and left to begin curing on the casting floor. After the initial set of the concrete, the sections are stacked up and cured under moist conditions.

To install the J-section lining the old below ground level mesqas is filled in and compacted, building a pad on which the J-section mesqas is constructed. The individual sections are mortared together. A ½ meter wide earth berm is constructed on each side of the lined mesqas. The final "U" shaped channel with vertical sides requires a narrower right-of-way width than a trapezoidal shaped channel.

Low Pressure Irrigation Pipelines

Although low irrigation pipelines are not technically channel lining, they serve the same purpose. They are being used extensively as an alternative to the J-section lining for improved mesqas discussed above. The pipeline mesqas operates similar to the J-section lined mesqas. The difference is that the water is delivered in a buried pipeline to the marwas through an alfalfa valve. Other than that, it operates essentially the same as the lined mesqas. Because the pipeline is buried, most of the land used by the old mesqas can be cropped.

SUMMARY AND CONCLUSIONS

Several kinds of canal lining is used successfully in Egypt. Lining of the "old lands" delivery canals to prevent seepage losses is limited. Lining for slope protection is used extensively, as this is the major problem. Lining to prevent seepage losses is used extensively on the "new lands", or horizontal expansion projects.

Egypt is planning a very extensive irrigation improvement program of the "old lands" as a follow up to the pilot IIP. Changing the present "low level, multiple point lifting" mesqas to "high level, single point lifting" mesqas is the major activity. These improve mesqas will be either concrete lined or low pressure pipeline. Another major improvement is the change from a rotation delivery schedule to continuous delivery to the mesqas.

The mesqas are owned by water users or farmers, which are being organized into Water Users Associations (WUAs). The WUAs are responsible for the operation and maintenance of their mesqas, this includes arranging the water delivery to all water users. A mesqas cost recovery program is being implemented to recover the mesqas improvement costs. These funds will be used for additional improvement.

In addition to reducing seepage losses, the improved mesqas system insures that all water users get their share of water. Under the present uncontrolled management of the mesqas and the rotation delivery system, the head reach farmers on the mesqas tend to over irrigate using water that should go to the tail reach farmers. Under the improve system all water users get a full supply. The single point lifting has reduced the pumping cost for all the water users. Farmer acceptance of these improvements has been very good. Egypt is looking forward to an extensive mesqas lining programme.

RECENT EXPERIENCE OF LINING ON SMALL CHANNELS IN PUNJAB PROVINCE WITH PARTICULAR REFERENCE TO IRRIGATION SYSTEMS REHABILITATION PROJECT

Muhammad Ehsan[1], Nasar Iqbal Dodhy[2] and Muhammad Sarwar Sial[3]

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ABSTRACT

Irrigation systems in plain lands of Pakistan are generally unlined. Recently, on three projects cofinanced by international agencies, a considerable number of small channels have been lined with various objectives. Lining has been done with concrete, stone masonry or brick masonry giving channels rectangular or trapezoidal cross section. This paper focuses on the experiences gained in Punjab province on Irrigation Systems Rehabilitation Project on which the authors have been engaged and reported that the lined parts of channels are giving satisfactory hydraulic performance contributing towards assured supplies to farmers that was not available to them in the past. The paper also records lining data and design considerations that have been adopted for the other two projects namely 'Command Water Management Project' and 'Khushab SCARP Project' as comparable information for interest and correlation if desired by the reader. They also point out that so far linings on these projects have been insufficiently monitored and evaluated and apparently more work is needed that should be done on unified basis.

INTRODUCTION

Most of the irrigation system in the sub-continent was established by the British. It was designed unlined. It brought life to the fields of Indus plain. However, a few years after the commencement it resulted in rise of water table particularly in low lying areas. Gradually, the twin problem of waterlogging and salinity has been turning the fertile lands in to barren areas.

The rise in water table was mainly due to seepage from channels. Green et al. (1967) holds the same opinion, as referred by Glenn O. Schwab in his report "Surface Drainage of Irrigated Land in Pakistan", prepared recently in 1986.

The other reasons are flat topography and man-made obstructions in natural surface drainage such as roads, railways, irrigation channels, flood bunds and other private and public installations.

The problem of water logging would have not arisen, had a balanced sub-surface drainage system been introduced at the time of construction of irrigation system. Later when the seriousness of the problem was recognized in sixties, two-fold approach was considered to control the menace:

- establishing drainage network to drain out the water from subsoil, thereby lowering water table to required level (5 ft is evaluated to be minimum level) which could not be constructed until 1960s.

- Lining of irrigation channels in order to stop seepage through channel prisms.

Additional drainage network constructed in 1960s was not adequate to defeat the problem. However, it brought some relief to the irrigation systems. M.I. Shaheed, SE, Irrigation Department, in 1985 recommended more tributary drains in Punjab (Glenn O. Schwab, 1986). For the canal systems having waterlogging problems, he suggested that the length of drains should be equal to or even greater than the length of canals. However, he noted that canal to drain length ratio in 10 sample canal systems in Punjab was 3.6:1 which was far less than needed.

Until 1980s lining was done on individual channels in selected reaches. High construction costs prevented carrying out lining of the channels enmasses on system/sub-system basis even in critical waterlogged areas.

With financial help from international donor agencies, recently three projects have been undertaken where, lining of channels has been used to achieve various objectives of the projects as follows:

a. Irrigation Systems Rehabilitation Project

Purpose of Lining: Improve hydraulic performance by increasing velocities without reduction in irrigation command in tail reaches of channels where existing velocities were 1 ft/sec or less. These low velocities caused deposition of sediment resulting in reduced supplies and increase in requirement and cost of maintenance. Lining was aimed to provide assured supplies to users in the tail reaches at less maintenance requirements and reduced recurrent cost of maintenance as well.

b. Command Water Management Project

Purpose of Lining: Seepage control and improved water control.

c. Khushab Salinity Control Project

Purpose of Lining: Save seepage water going into saline ground.

This paper reviews the design and channel selection criteria adopted for lining on Second Irrigation Systems Rehabilitation Project and recalls available information on the other two for comparison. It considers the detailed experience and lessons learnt on Irrigation Systems Rehabilitation Project which may be found helpful for similar projects in future. It recommends in its conclusions for monitoring of these works on a uniform basis and thereby widen scope of learnings.

IRRIGATION SYSTEMS REHABILITATION PROJECT (ISRP)

General

Irrigation System of Pakistan had gradually deteriorated and become less reliable for assured supply and equitable distribution, particularly in tail reaches. The situation had arisen due to continued accumulation of maintenance because of paucity of funds and inability of the irrigation department to operate and regulate the channel supplies while remaining within operating limits in the past. With assistance from the World Bank and USAID a rehabilitation project was framed. During its first phase, badly deteriorated channels and drains were rehabilitated, generally by strengthening banks, clearing silt, cutting berms and carrying out repairs to damaged hydraulic structures and protection works. Experience of Phase I also taught that some channels or systems/sub-systems suffered from chronic hydraulic problems, particularly at the tails. While earthwork dominated the Phase I activity a few channels were lined at tails to improve their hydraulic performance. In such channels, the existing velocities were 1 ft/sec or less and were increased by lining with available slope and without losing irrigation command. The performance of these channels was appreciated by the engineers associated with the project and the Bank Missions. The list of these channels is given as Annexure 1.

After the critical works and channels/drains had been rehabilitated during Phase I of the Project, it was decided that rehabilitation of channels in Phase II should be carried out on system/sub-system basis. It was accepted that besides accumulated maintenance there could be hydraulic problem existing in the channel which must be addressed while rehabilitating it. Therefore, a procedure was adopted for determining as to whether or not a system/sub-system or channel had a hydraulic problem. Broadly, a channel or a reach might be considered as problematic if it suffered from one or more of the following;

a) It could safely take the discharge it intended to pass.

b) It had a chronic tail shortage problem.

c) It had history of periodic silt clearance, overgrown berms or breaches, and

d) the outlets had a persistent and general complaint of short discharges.

In case a channel had a hydraulic problem, it was to be removed through appropriate solution. Based on experience in Phase I, it was found that the lining of the tails could provide a solution to achieve assured supply and equitable distribution and to address the problem(s) indicated above.

First phase of the Project was implemented between 1982 and 1988 in which cost of the civil works was Rs. (PAK) 1097 million. The Second Irrigation Systems Rehabilitation Project was initiated in 1989 and is scheduled for completion in December 1993. The cost of the Second Phase of the Project is estimated at US$ 220 million in which cost of civil works is approximately US$ 175 millions. The project proposes rehabilitation of 13429 Km of irrigation channels and 1296 Km length of drains which would benefit approximately 4.1 million hectares of irrigated lands of which 0.825 million hectares would also be afforded improved surface drainage.

The Project is being implemented by Provincial Irrigation Departments (PIDs) assisted by consultants NESPAK. Co-financiers to Government of Pakistan are World Bank, USAID and Government of Netherlands.

The project is located in all the four provinces of Pakistan. This paper discusses only lining carried out in the Punjab Province where it was used as a solution to hydraulic problem(s) defined above. The particulars of the Project works to be carried out in the Punjab province are as follows;

S.No.	Items	IDA	USAID	Total
1.	No. of Schemes	464	45	509
2.	Cost of Schemes (Rs.M)	1214.66	147.61	1362.27
3.	Length of channels to be rehabilitated(km)	7123.00	60.60	7183.60
4.	% Length of channels to be rehabilitated	19.41	0.17	19.57
5.	Length of drains to be rehabilitated (km)	139.00	522.00	661.00
6.	% Length of drains to be rehabilitated	2.20	8.26	10.46
7.	CCA to be benefitted (M. Hac.)	2.23	0.02	2.25
8.	% CCA to be benefitted	26.67	0.24	26.91
9.	CA to be benefitted (M. Hac.)	0.15	0.36	0.51
10.	% CA to be benefitted	6.33	15.19	21.52

Annexure 2 gives the list of channels in Punjab Province where lining has been completed as of September 30, 1993. Channels where lining has not been completed or is outstanding in September, 1993 are not included in this list. Accumulated length of channels lined as of September 30, 1993, is approximately 221 Km.

Selection Criteria for Lining

During implementation of first phase of the project, lining was provided to a number of channels such as Lagar, Gohour Daur, Sultan Pakhra distributaries in Faisalabad zone and Bahawalnagar distributary in Bahawalpur zone of Punjab Province etc, mainly to improve hydraulic performance. These channels were notorious for tail shortages. Complete list of the channels which were lined during Phase I in Punjab Province is given as Annexure 1. These channels were lined mostly in tail reaches because of recurrent silt deposition problem resulting in inequitable distribution of irrigation water. Inspections and interviews with farmers afterwards confirmed that marked improvement in their hydraulic performances had occurred. Tails were being served adequately. Some of the channels were lined in the reaches located in populous areas such as Samundri Distributary and Tandlianwala Distributary. This was done in order to render these reaches less prone to trespass and to avoid rapid deterioration.

Selection of channel reaches for lining in Phase II was based on evaluation of hydraulic data which indicated tail shortages and/or history of periodic silt clearance. In channel reaches where silt deposition posed a chronic problem and it was not possible to increase gradient due to command constraints, lining was provided to improve hydraulic performance by;

- reducing roughness,
- improving alignment and providing regular section, and
- preventing trespassing.

Type of Lining

Following factors were taken into consideration when selecting type of lining:

- Availability of construction material.
- Ease of construction.
- Availability of workmanship, giving consideration to remote areas.

Brick masonry was commonly used in Punjab followed by concrete lining. Typical sections used are shown in Figures 1 to 3.

Design Standards of Lining

Channel Geometry:	Trapezoidal sections with 1:1 side slope when Full Supply Depth (FSD) was more than 2 ft. Side slope were made 0.5:1 for FSD less than 2 ft. Rectangular section was used where discharge was less than 3 cfs.	
Thickness:	Brick Masonry	- 4.5 inches nominal
	Plain Concrete	- 3 inches
Value of Manning's 'n':	<u>Lining type</u>	<u>Mannings 'n'</u>
	Brick Masonry	0.017
	Concrete	0.015
Free board:	1.0 ft in lined section and 0.5 ft in earthen section giving total at 1.5 ft.	

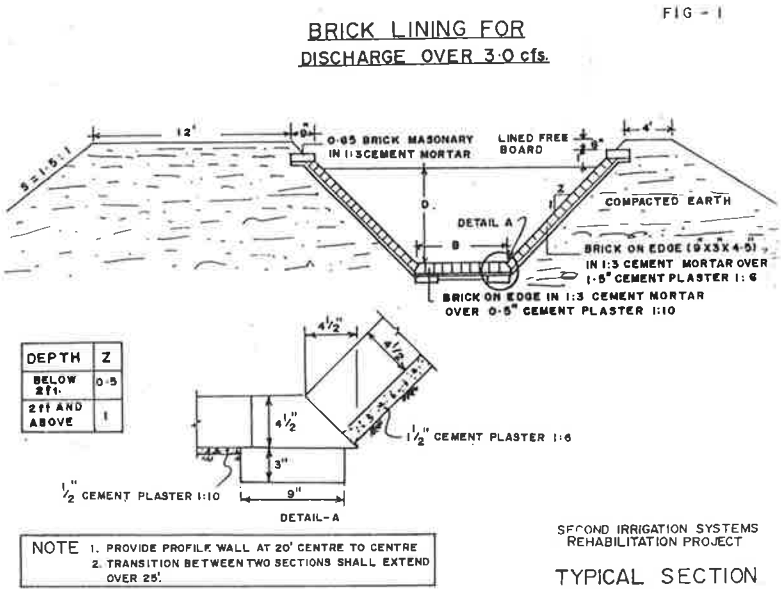


Figure 1. Brick lining for discharge over 3.0 cfs.

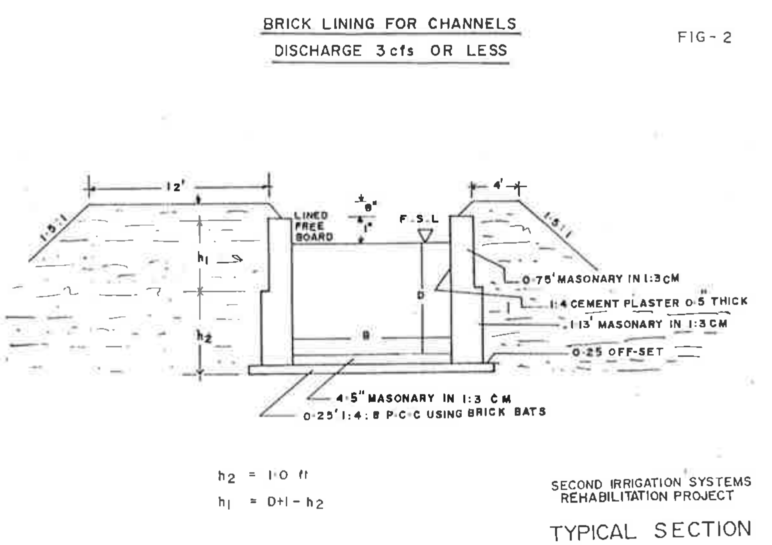
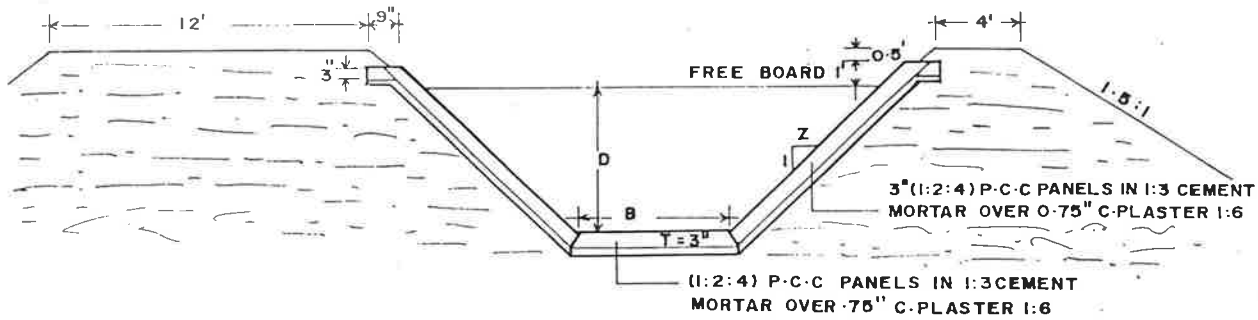


Figure 2. Brick lining for channels discharge 3 cfs or less.



DEPTH	Z
BELOW 2ft	0·5
2' AND ABOVE	1

JOINT SEALANT: MIXTURE OF SAWDUST, BITUMEN & SAND.

NOTE:

1. PROVIDE PROFILE WALL AT 10' CENTRE TO CENTRE WITH CONSTRUCTION JOINT AT PROFILE.
2. TRANSITION BETWEEN TWO SECTIONS SHALL EXTEND OVER 25'.
3. EXPANSION JOINTS AT 50' CENTRE TO CENTRE

SECOND IRRIGATION SYSTEMS REHABILITATION PROJECT

TYPICAL SECTION

Figure 3. Concrete Lining.

Cost of Lining

Cost of lining per foot varied considerably. Unit cost depended upon location of works, type of materials used, the size of the channel and period made available for implementation. For example, the lining works to be carried out during short closure periods needed more logistic requirement and control while otherwise these required diversion works. An estimate of cost based on sample of works under implementation in 1993 indicate that lining with brick masonry (4.5") and plain concrete (3") were in the order of Rs.22 and Rs.18 per square foot respectively.

Monitoring and Evaluation

Monitoring of the performance of the lining has not been provided in the scope of the Project. Only evaluation of the rehabilitation impact by ACOP, WAPDA or PERI (Punjab Economic Research Institute) is underway on selected channels which may be either lined or unlined. Only impressions and views of the field engineers were gathered who reported that when water reaches the start of the lined sections, the supplies are reaching the tail users and silt deposition has generally reduced. In brief the lined tails were demonstrating improved hydraulic performance.

COMMAND WATER MANAGEMENT PROJECT (CWMP)

This pilot project, among other things, aimed to improve irrigation supplies on CCA of 206,000 hectares has been completed recently in December, 1992. It employed integrated system improvement approach and the components comprised canal rehabilitation and remodelling, drainage and on-farm water management. The project was implemented by provincial irrigation departments with consulting services provided by a joint team from National Development Consultants (NDC) and National Engineering Services of Pakistan (NESPAK).

CWMP provided lining for certain sections of smaller distributaries and minors to reduce seepage losses to save water and improve water control.

The project comprised seven sub-projects, 4 in Punjab and 1 each in three other provinces. Approximate 483.90 km length of channels was lined in this project. The information about major channels lined until 1990 is reproduced in Annexure 3 (Mashhadi and M. Akbar, 1990). Annexure 4 indicates listing (ACOP) of additional channels lined under CWMP.

In general PCC (1:2:4) was used to line the channels. A number of channels were lined with brick masonry. RCC pipe lining was experimented on minor-1 of Lasbela canal and buried membrane (butyle) lining on Thathi Uttar minor of Thokar Niaz Beg for a length of 1000 ft in head reach. Figure 4 and 5 show typical sections used for lining under CWMP.

The design standards adopted for the lining are stated as follows:

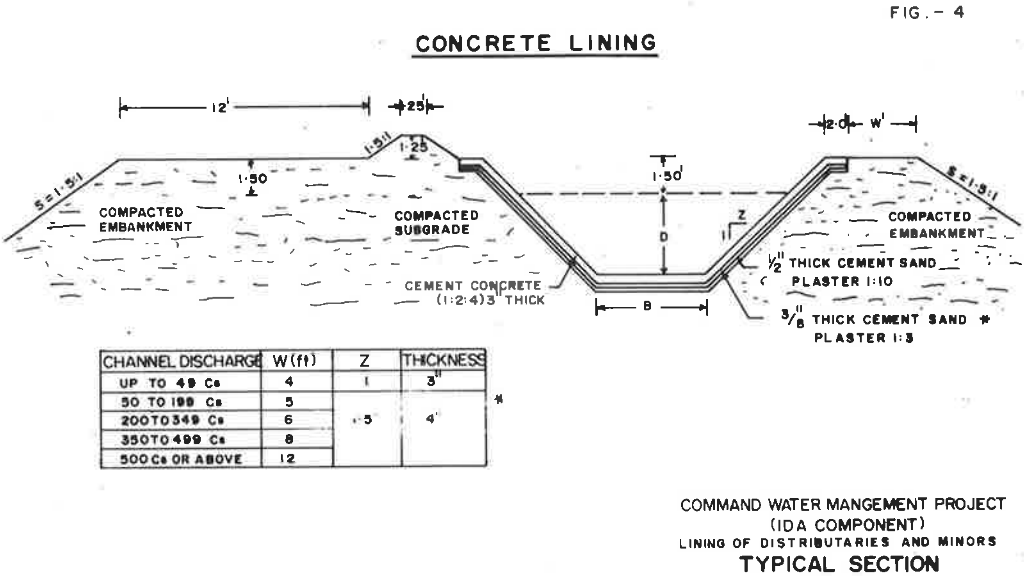
Section Geometry:	Generally trapezoidal section was adopted with side slopes of 1:1 for discharge less than 50 cfs and 1.5:1 for discharge more than 50 cfs. In some cases rectangular section was used. Circular reinforced section was adopted for one channel only.
Value of Manning's 'n':	Manning's 'n' values of 0.016, 0.018 and 0.017 were used for PCC, PCC with coarser sand, and RCC pipe lining respectively. Value of Manning's 'n' for brick masonry with cement plaster finish has been assumed as 0.015.
Thickness :	Lining thickness adopted was 3 inches for smaller channels and 4 inches for larger channels such as 6R Hakra and Warsak lift canal. Rectangular sections were designed as retaining walls.
Free board:	1.5 ft

Monitoring and Evaluation

No monitoring and evaluation has been carried out to assess effectiveness of lining as a means to control or reduce seepage and improvement in hydraulic performance.

KHUSHAB SALINITY CONTROL AND RECLAMATION PROJECT (KHUSHAB SCARP)

The project has been prepared to benefit CCA of 38234 hectares. The project was initiated in 1989 and is under progress for completion in 1995 (revised date of completion). The project aims at eliminating waterlogging and salinity, and improving irrigation supplies by providing combination of surface and sub-surface drainage and lining of irrigation channels in the project area.



CHANNEL DISCHARGE	W(ft)	Z	THICKNESS
UP TO 49 Cs	4	1	3"
50 TO 199 Cs	5	·5	4"
200 TO 349 Cs	6		
350 TO 499 Cs	8		
500 Cs OR ABOVE	12		

*

Figure 4. Concrete lining.

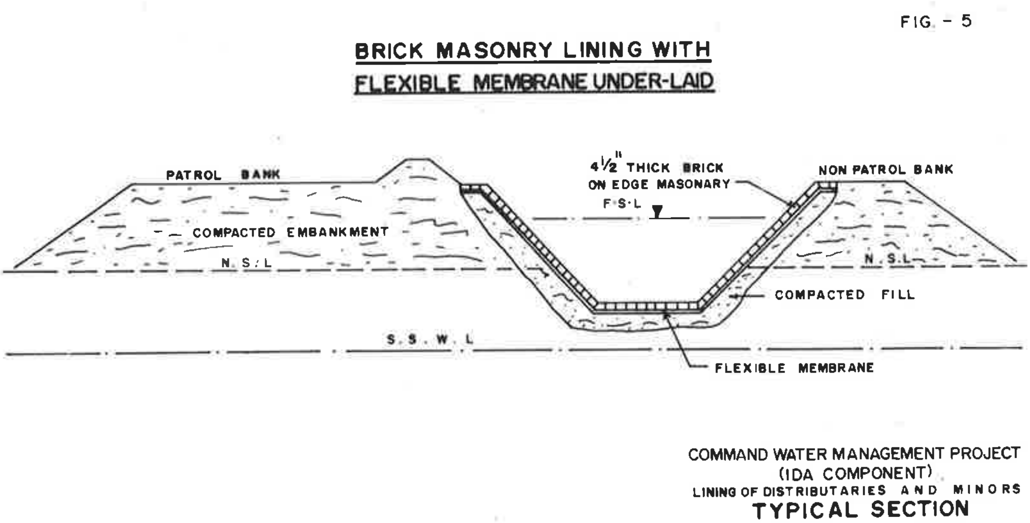


Figure 5. Brick masonry lining with flexible membrane underlaid.

Lining is being provided to save water which otherwise is lost by seepage from canal reaches in saline lands.

Initial target of the project was to line 86.3 Km of channels which is expected to be revised to 103.9 Km.

By the end of June, 1993 about 52 Km of lining had been carried out. Only PCC is being used for lining channels under this project. List of the channels lined or proposed to be lined under this project is provided as Annexure 4.

The design standards adopted for the lining are as follows:

Section Geometry:	Trapezoidal section with side slopes of 1:1 for discharge less than 50 cfs and 1.5:1 for greater discharge.
Value of Manning's 'n':	0.014
Thickness :	2.5 inch
Free Board:	1.0 ft

Figure 6 shows typical cross-section of a lined channel in Khushab SCARP.

Monitoring and Evaluation

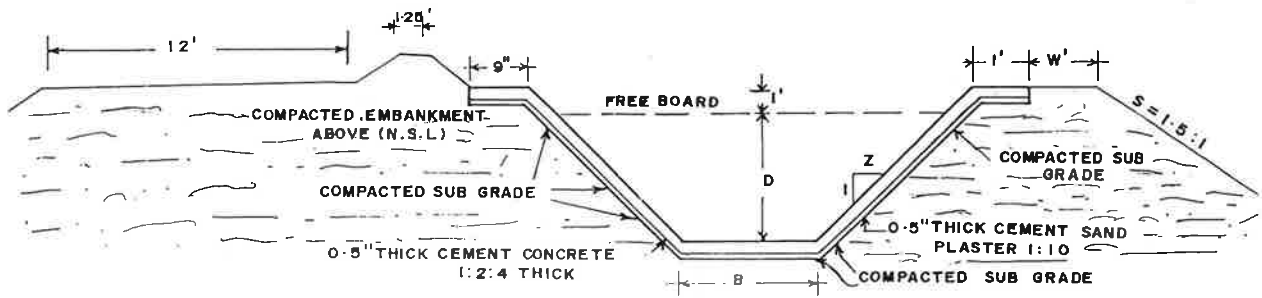
Monitoring has been included in the Project to evaluate impact of lining on seepage control and conveyance efficiencies including silt carrying capacities. Agency responsible for this assignment is PID, Punjab and it is likely to be initiated in January, 1994.

LINING CARRIED OUT UNDER OTHER PROJECTS

In Punjab large channels such as Haveli Canal, Thal Main Line Upper, Thal Main Line Lower, Mohajir Branch, Sidhnai Mailsi Canal and B.S I Link Canal are lined canals. It is known that PID Punjab under their O&M programs has also done some lining of the channels but it is not significant. The lining was generally done on channels which had serious seepage losses due to porous strata.

FIG · 6

CONCRETE LINING
SHOWING VARIOUS DETAILS



KHUSHAB SCARP
CANAL REHABILITATION AND LINING COMPONENT

TYPICAL SECTION

Figure 6 Concrete Lining Showing Various Details.

Unfortunately, complete design information and any details regarding actual performance after construction could not be obtained. Hopefully it will become available for Punjab after PID, Punjab has installed database under consideration at present.

EXPERIENCE GAINED AND LESSONS LEARNT ON IRRIGATION SYSTEMS REHABILITATION PROJECT WITH RESPECT TO LINING OF SMALL CHANNELS

1. The channels proposed to be lined were designed to achieve a velocity equal or more than the "regime velocity". A value of 1.3 feet/second for "regime velocity" has been recommended by PRC/CHECCHI for tail reaches of small channels in their Hydraulic Design Guidelines for "Small Lined Channels in Pakistan". It was envisaged that if the velocity in the lined reach was equal or more than the recommended velocity, there would be no deposition of silt, and that assured irrigation supply would be available to the water users in the tail reaches. Experience indicated that providing the outlets in the head reach do not draw off more than their authorized supplies and maintenance is carried out regularly, this design consideration was sufficient.

2. Lining in Irrigation Systems Rehabilitation Project Phase-I was initially designed with Manning's 'n' for brick masonry assumed to be 0.014 or 0.015. Measurements made in a few channels later on indicated that the measured values for cleaner surface of lining was in the order of 0.017. Others showed higher values where sediment deposition was also observed. Following table gives the data observed on a number of channels lined between 1984 and 1986 during Phase-I of the Project. A value of 0.017 for Manning's 'n' for brick masonry lining has been used in Irrigation Systems Rehabilitation Project Phase-II.

3. Lining would reduce but will not eliminate siltation in practice. If operation of the channel is not to be regulated for most of time and less than authorized water reached starting point of the lining, the sediment did deposit in the channel bed.

4. For the channel reaches where discharge was 3 cfs or less, rectangular section was adopted for its greater efficiency for silt transport and to obtain wider bed widths, as at least 1 ft wide bed is required for maintenance. Visual inspections showed that this section was performing satisfactory.

'n' VALUE DETERMINATION MAY, 1991

Channel Name	RD	Channel Parameters							N	Remarks
		Q (Cfs)	A (Sq.ft)	V (fps)	W (ft)	P (ft)	R (ft)	l/s		
Mungi Disty*	111+500	4.44	4.42	1.00	5.50	6.35	0.70	4878	0.017	Brick Lining
Mungi Disty*	120+500	3.08	3.23	0.95	3.75	4.75	0.68	2597	0.024	Brick Lining (0.6' sediment deposit on bed)
Machiana Disty*	32+500	5.05	4.67	1.08	3.75	5.64	0.83	5405	0.017	Brick Lining
Murad Minor*	4+500	5.21	6.00	0.87	5.00	6.68	0.90	3636	0.026	Brick Lining (0.2' sediment deposit on bed)
Lagar Disty**	-	-	-	-	-	-	-	-	0.017	Brick Lining
Gour Dour Disty**	-	-	-	-	-	-	-	-	0.017	Brick Lining

* Data observed by ACOP.
** Data observed jointly with NESPAK.

5. Section with side slope of 0.5:1 is suitable and economical for brick lining in comparison to side slope of 1:1 provided that angle of repose of subgrade material is adequate to support itself.

6. It was experienced that concrete placement for lining on side slope steeper than 1:1 was difficult. For concrete lining side slopes of 1:1 were used.

7. Brick lining has generally been preferred over concrete because it is easy to construct and repair and for the same thickness is economical. However, quality of bricks available in market is variable and substandard. This consideration led to adopting 4.5" thickness for lining with brick masonry. Durability considerations demand that quality of bricks must be attended.

8. Use of cattle ghats in the reaches of discharge less than 30 cfs was observed to obstruct flow severely. It also caused damage to adjoining lined banks.

CONCLUSIONS

1. Recent experience and information regarding design, materials of construction, quality of construction and durability are scattered with individuals and field offices. It would be desirable to compile the information from each project and

inventory be prepared for reference. Or else the experience will be gradually diffused in the mind of individuals and would be lost.

2. It also appeared that monitoring of the performance on scientific grounds of the works had not been given its deserved attention. It is considered appropriate that an exercise to evaluate all the completed works be carried out to determine most suitable and durable type of lining and sections to be used in different areas and/or regions.

3. Prevailing inability to enforce regulations has caused serious problems for irrigation channels. Users tend to observe less respect for the channels. Generally influential people in the upper reaches draw more water by tempering outlets or making cuts. Lining on such channels will not redress tail shortage. Additionally where the channel takes considerably less water than authorized, velocity would reduce and silt deposition will occur. Serious efforts are needed to cultivate good habits in the users.

4. As yet, no monitoring and evaluation have been carried out in respect of the channels lined under ISR Project or any other project in Pakistan for determining/establishing;

   - reduction in operation and maintenance cost,
   - variation in Manning's 'n' with aging, and
   - reduction in seepage.

   It is recommended that a sample of channels lined under various projects should be selected, experiments designed and research and studies carried out to evaluate above factors.

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INFORMATION ON CHANNELS
LINED UDNER
IRRIGATION SYSTEMS REHABILITATION PROJECT PHASE-I
PUNJAB PROVINCE

Name of the Channel	Name of the Parent Channel	Reach (ft)	Lined Length	Type of Lining Brick Masonry/ Concrete etc.	Remarks
1	2	3	4	5	6
Ghour Dour Disty	Upper Gugera Branch	48800-67919	19119	Brick Masonry	Full Lining
Lagar Didty	Upper Gugera Branch	44000-62218	18218	Brick Masonry	Full Lining
Tarkhani Disty	Lower Gugera Branch	132000-153033	21033	Brick Masonry	Full Lining
Minor No. 1 of Tarkhani Disty	Tarkhani Disty	20400-26760	6360	Brick Masonry	Lining on sides only
Mungi Disty	Lower Gugera Branch	108300-121278	12978	Brick Masonry	Full Lining
Khatwan Disty	Lower Gugera Branch	23100-32600	9500	Brick Masonry	Lining on sides only
Debora Disty	Rakh Branch	42700-49100	6400	Brick Masonry	Full Lining
Sammundri Disty	Burala Branch	20000-27000	7000	Brick Masonry	Lining on sides only in populous area in Samundri Town
Tandlianwala Disty	Burala Branch	60500-66000	5500	Brick Masonry	Lining on sides only
Chiniot Disty	Jhang Branch Upper	151462-161153	9691	Brick Masonry	Full Lining
Sultan Pakhra Disty	Bhowana Branch	172000-180466	8466	Brick Masonry	Full Lining
Jhang Minor	Sultan Pakhra Disty	00000-28963	28963	Brick Masonry	Full Lining
Ghaggi Minor	Sultan Pakhra Disty	0000-2685	2685	Brick Masonry	Full Lining
Assian Minor	Chokera Disty	06900-24300	17400	Brick Masonry	Lining on sides only
Chokera Disty	Southern Branch	84450-90000	5550	Brick Masonry	Lining on sides only
Machiana Disty	Upper Jhelum Canal	30000-41150	11150	Brick Masonry	Lining on sides only
Bhachar Disty	Gujrat Branch	47100-64500	17400	Brick Masonry	Full Lining
Amingarh Disty	Sadiq Branch	28500-35747	7247	Brick Masonry	Full Lining
Melay Disty	Southern Feeder	20000-26670	6670	Brick Masonry	Lining on sides only
Jholepur Disty	Southern Feeder	35000-46350	11350	Brick Masonry	Lining on sides only
Uppi Minor	Jholepur	0000-6648	6648	Brick Masonry	Lining on sides only
Shahpur Disty	Shujabad Branch	50600-55100	4500	Brick Masonry	Lining on sides only
6-R Disty	LBDC	4350-11984	7634	Brick Masonry	Lining on sides only
Maisli Disty	SMB Link	29695-36300	6605	Brick Masonry	Lining on sides only
Bahawalnagar Disty	Fordwah Branch	11800-21900	10100	Brick Masonry	Full Lining
5-R Yousaf Disty	Rahimyar Khan branch	30600-36750	6150	Brick Masonry	Full Lining
Bahawal Disty	Forwah Branch	64500-68012	3512	Brick Masonry	Lining on sides only
Jamlera Disty	Khadir Branch	57912-64660	6748	Brick Masonry	Lining on sides only
4L T.D. Disty	Tail Disty	29000-33760	4760	Brick Masonry	Full Lining
1L/3L Minor	3L Disty	26000-31000	5000	Brick Masonry	Lining on sides only
1R/3L Disty	3L Disty	92000-99750	7750	Brick Masonry	Full Lining

Annexure - 2
Sheet 1 - 2

DETAILS OF LINING OF CHANNELS * IN PUNJAB PROVINCE SECOND IRRIGATION SYSTEMS REHABILITATION PROJECT

Name of the Channel	Name of the Parent Channel	Discharge at Head (cfs)	Reach	Discharge at Start of Lined Reach (cfs)	Type of Lining Brick Masonry/ Concrete etc.	Geometry (Trapezoidal/ Rectangular)	Bed Width (ft.)	Bed Slope (ft/000 ft)	Side Slope H:V	Thickness of Lining (inches)	Full Supply Depth (ft.)	Value of n	Free ** Board (ft.)
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Nankana Minor	Shark Pur Disty	54.00	54500-64105	6.00	Brick Masonry	Trapezoidal	4.39	0.42	1:1	4.5	1.65	0.017	1.50
Minor No. 2 of Pauliani	Lowa Gugera Branch	10.16	00060-18000	10.16	Concrete	Trapezoidal	1.99	0.30	1:1	3.0	1.70	0.015	1.50
Kaluana Disty	Lowa Gugera Branch	19.80	04000-16310	17.60	Concrete	Trapezoidal	2.57	0.40	1:1	3.0	1.90	0.015	1.50
Sarwali Minor	Tarkhani Disty	31.50	00000-33600	28.00	Brick Masonry	Trapezoidal	6.92	0.34	1/2:1	4.5	1.85	0.017	1.50
Minor No. 7	Killianwala Disty	12.82	00000-13715	12.82	Brick Masonry	Trapezoidal	3.53	0.31	1/2:1	4.5	1.80	0.017	1.50
Minor No. 8	Killianwala Disty	5.42	00000-08600	5.42	Brick Masonry	Trapezoidal	2.98	0.30	1/2:1	4.5	1.20	0.017	1.50
Kanjwani Disty	Killianwala Disty	31.00	30100-47724	8.00	Brick Masonry	Trapezoidal	3.73	0.36	1/2:1	4.5	1.25	0.017	1.50
Summundri Disty	Burala Branch	47.61	47333-62288	22.50	Concrete	Trapezoidal	4.23	0.35	1:1	3.0	1.80	0.015	1.50
Gharak Disty	Burala Branch	10.00	00000-06896	4.00	Brick Masonry	Trapezoidal	1.70	0.45	1:1	4.5	1.20	0.017	1.50
Azmat Shah Disty	Burala Branch	9.70	00000-07263	9.75	Brick Masonry	Trapezoidal	3.02	0.50	1:1	4.5	1.30	0.017	1.50
Kot Ahmed Yar Minor	Chiniot Disty	42.20	00033-47710	14.25	Concrete	Trapezoidal	3.75	0.27	1:1	3.0	1.60	0.015	1.50
Kot Wasawa Minor	Chiniot Disty	15.53	00019-28452	10.17	Concrete	Trapezoidal	3.03	0.25	1:1	3.0	1.50	0.015	1.50
Khai Disty	Jhang Branch Upper	43.00	57690-76456	10.00	Brick Masonry	Trapezoidal	2.55	0.42	1:1	4.5	1.40	0.017	1.50
Narwala Minor	Nasrana Disty	15.70	11000-15804	10.00	Brick Masonry	Trapezoidal	3.70	0.30	1:1	4.5	1.65	0.017	1.50
Burewala Minor	Mochiwala Branch	5.60	00000-06076	5.60	Brick Masonry	Trapezoidal	2.70	0.42	1/2:1	4.5	1.20	0.017	1.50
Mustan Pur Minor	Mochiwala Branch	4.30	00000-09435	4.30	Brick Masonry	Rectangular	2.77	0.40	1/2:1	4.5	1.20	0.017	1.50
Pindori Minor	Khewra Disty	13.00	01600-14720		Brick Masonry	Rectangular	2.80	0.40	1/2:1	4.5	1.20	0.017	1.50
Khenora Minor	Khewra Disty	20.00	24255-30778	8.50	Brick Masonry	Trapezoidal	3.30	-	1/2:1	4.5	1.40	0.017	1.50
			30778-38316	2.75	Brick Masonry	Rectangular	1.92	-	-	4.5	1.30	0.017	1.50
Khewra Disty	Jhang Branch Lower	390.00	091820-116210	57.00	Brick Masonry	Rectangular	22.00	0.33	1:1	4.5	2.25	0.017	1.50
Dhamaki Disty	Mailsi Canal	16.19	10318-19022	10.19	Brick Masonry	Trapezoidal	6.27	0.22	1:1	4.5	1.50	0.017	1.50
			19022-22677	9.35	Brick Masonry	Trapezoidal	3.80	0.26	1:1	4.5	1.40	0.017	1.50
			22677-24822	6.30	Brick Masonry	Trapezoidal	3.26	0.26	1/2:1	4.5	1.30	0.017	1.50
Umer Minor	Mailsi Disty	8.26	00000-04000	8.26	Brick Masonry	Trapezoidal	3.47	0.31	1/2:1	4.5	1.40	0.017	1.50
			04000-09650	7.16	Brick Masonry	Trapezoidal	3.30	0.31	1/2:1	4.5	1.30	0.017	1.50
5L Pakpattan Disty	Pakpattan Canal	227.00	100900-115172	34.00	Brick Masonry	Trapezoidal	7.17	0.20	1:1	4.5	2.20	0.017	1.50
			115172-118620	30.00	Brick Masonry	Trapezoidal	6.83	0.20	1:1	4.5	2.10	0.017	1.50
			118620-128000	12.30	Brick Masonry	Trapezoidal	2.73	0.28	1/2:1	4.5	1.80	0.017	1.50
			128000-129700	8.00	Brick Masonry	Trapezoidal	2.73	0.28	1/2:1	4.5	1.60	0.017	1.50
			129700-130928	3.75	Brick Masonry	Trapezoidal	1.89	0.28	1/2:1	4.5	1.30	0.017	1.50
1L/5L Minor	5L Disty	6.15	00000-06434	6.15	Brick Masonry	Trapezoidal	2.20	0.34	1/2:1	4.5	1.50	0.017	1.50
2L/5L Minor	5L Disty	8.27	00000-04325	8.27	Brick Masonry	Trapezoidal	2.23	0.35	1/2:1	4.5	1.50	0.017	1.50
			04325-06323	4.88	Brick Masonry	Trapezoidal	1.71	0.35	1/2:1	-	1.50	0.017	1.50
3L/5L Minor	5L Disty	9.59	00000-05750	9.59	Brick Masonry	Trapezoidal	2.45	0.40	1/2:1	4.5	1.50	0.017	1.50
			05750-08880	5.17	Brick Masonry	Trapezoidal	1.70	0.40	1/2:1	4.5	1.50	0.017	1.50
3R/11L Minor	11L Disty	14.10	00000-08480	14.10	Brick Masonry	Trapezoidal	4.88	0.26	1/2:1	4.5	1.65	0.017	1.50
			08480-14966	9.40	Brick Masonry	Trapezoidal	3.09	0.26	1/2:1	4.5	1.60	0.017	1.50
3L/Zakhira Minor	Bahawal Pur Disty	6.00	00000-03000	6.00	Brick Masonry	Trapezoidal	2.60	0.20	1/2:1	4.5	0.50	0.017	1.50
1L/3L/D.B.	3L/D.B. Disty	8.00	00000-11750	8.00	Brick Masonry	Trapezoidal	3.35	0.35	1/2:1	4.5	1.40	0.017	1.50
1L/4L/D.B Minor	4L/D.B	26.00	14851-23500	11.00	Brick Masonry	Trapezoidal	-	0.40	1/2:1	4.5	1.88	0.017	1.50
2L/AP.BR. Disty	A.P. Branch	11.00	2000-5000	11.00	Brick Masonry	Trapezoidal	5.50	0.27	1/2:1	4.5	1.70	0.017	1.50
5L/AP.BR.	A.P. Branch	47.00	31700-38750	12.00	Brick Masonry	Trapezoidal	4.54	0.28	1/2:1	4.5	1.40	0.017	1.50
Banduki Disty	Minchin Branch	37.00	24250-29650	7.30	Brick Masonry	Trapezoidal	3.30	0.23	1/2:1	4.5	1.73	0.017	1.50

* For which rehabilitation works completed as of September 30, 1993

** 1 foot in lined portion and 0.5 foot in earthen section.

Annexure - 2
Sheet 2 - 2

DETAILS OF LINING
OF CHANNELS * IN PUNJAB PROVINCE
SECOND IRRIGATION SYSTEMS REHABILITATION PROJECT

Name of the Channel	Name of the Parent Channel	Discharge at Head (cfs)	Reach	Discharge at Start of Lined Reach (cfs)	Type of Lining Brick Masonry/ Concrete etc.	Geometry (Trapezoidal/ Rectangular)	Bed Width (ft.)	Bed Slope (ft/000 ft)	Side Slope H:V	Thickness of Lining (inches)	Full Supply Depth (ft.)	Value of n	Free ** Board (ft.)
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Mau-Mubarik	Rahim Yar Khan	35.00	24111-27800	6.00	Brick Masonry	Trapezoidal	3.30	0.30	1/2:1	4.5	1.20	0.017	1.50
Sarkar Sub Minor	Machka Minor	21.00	00000-14350	21.00	Brick Masonry	Trapezoidal	3.51	0.16	1/2:1	4.5	2.50	0.017	1.50
Gudu Sub Minor	Machka Minor	9.00	00000-12600	9.00	Brick Masonry	Trapezoidal	1.63	0.25	1/2:1	4.5	1.90	0.017	1.50
Waliwah Minor	Ganesh Disty	22.00	17334-27075	7.00	Brick Masonry	Trapezoidal	2.27	0.27	1/2:1	4.5	1.70	0.017	1.50
Jagat Pur Minor	Ganesh Disty	15.30	00000-13807	15.30	Brick Masonry	Trapezoidal	4.86	0.21	1/2:1	4.5	1.90	0.017	1.50
5R/15L Minor	15L Minor	6.20	00000-06504	6.20	Brick Masonry	Trapezoidal	2.00	0.61	1/2:1	4.5	1.35	0.017	1.50
6R/15L Minor	15L Minor	5.80	00000-05992	5.80	Brick Masonry	Trapezoidal	2.59	0.34	1/2:1	4.5	1.30	0.017	1.50
2L/15L Minor	15L Minor	16.00	11900-18586	4.38	Brick Masonry	Trapezoidal	2.06	0.79	1/2:1	4.5	1.00	0.017	1.50
Julke Minor	Buchar Kahna Disty	9.43	00000-05086	9.43	Brick Masonry	Trapezoidal	3.05	0.35	1:1	4.5	1.40	0.017	1.50
			05086-08500	6.63	Brick Masonry	Trapezoidal	2.97	0.35	1/2:1	4.5	1.30	0.017	1.50
Baddoki Minor	Buchar Kahna Disty	24.33	13000-18490	16.69	Brick Masonry	Trapezoidal	4.24	0.31	1:1	4.5	1.70	0.017	1.50
			18490-29518	13.36	Brick Masonry	Trapezoidal	3.51	0.34	1:1	4.5	1.60	0.017	1.50
			29518-34730	5.15	Brick Masonry	Trapezoidal	1.82	0.34	1/2:1	4.5	1.50	0.017	1.50
Shalimar Disty	BRBD Link	30.00	00000-12000	30.00	Brick Masonry	Trapezoidal	6.58	0.22	1:1	4.5	2.10	0.017	1.50
			12000-16000	23.00	Brick Masonry	Trapezoidal	5.80	0.23	1:1	4.5	1.90	0.017	1.50
			16000-21000	18.00	Brick Masonry	Trapezoidal	4.75	0.24	1:1	4.5	1.80	0.017	1.50
			21000-24000	13.00	Brick Masonry	Trapezoidal	3.50	0.25	1:1	4.5	1.70	0.017	1.50
			24000-30000	8.20	Brick Masonry	Trapezoidal	2.12	0.29	1:1	4.5	1.60	0.017	1.50
Boali Minor	Muridkey Disty	16.34	00000-06000	16.34	Brick Masonry	Trapezoidal	4.56	0.30	1/2:1	4.5	1.80	0.017	1.50
			06000-08200	12.17	Brick Masonry	Trapezoidal	3.48	0.35	1/2:1	4.5	1.70	0.017	1.50
			08200-15130	6.80	Brick Masonry	Trapezoidal	2.20	0.42	1/2:1	4.5	1.50	0.017	1.50
Kuthiala Minor	Muridkey Disty	32.00	00000-08500	32.00	Brick Masonry	Trapezoidal	7.92	0.26	1/2:1	4.5	2.00	0.017	1.50
			22500-28500	9.40	Brick Masonry	Trapezoidal	2.70	0.33	1:1	4.5	1.50	0.017	1.50
			28500-31000	3.81	Brick Masonry	Trapezoidal	2.13	0.35	0:1	9.0	1.50	0.017	1.50
Shamke Minor	Muridkey Disty	14.00	10000-15550	6.77	Brick Masonry	Trapezoidal	2.63	0.34	1/2:1	4.5	1.43	0.017	1.50
Ahmad Wala Minor	Sikhanwala Disty	28.00	21000-24000	11.70	Brick Masonry	Trapezoidal	3.37	0.35	1/2:1	4.5	1.70	0.017	1.50
			24000-30960	9.60	Brick Masonry	Trapezoidal	3.06	0.35	1/2:1	4.5	1.60	0.017	1.50
Shimar Minor	Adhi Kot Distributary	67.00	56400-75900	13.00	Brick Masonry	Trapezoidal	3.59	0.23	1:1	4.5	2.05	0.017	1.50
Shahwala Minor	Adhi Kot Distributary	64.00	45000-59577	25.00	Brick Masonry	Trapezoidal	5.98	0.23	1:1	4.5	2.30	0.017	1.50
Bitta Sub Minor	Shahwala Minor	8.00	0000-8000	8.00	Brick Masonry	Trapezoidal	2.85	0.25	1/2:1	4.5	2.00	0.017	1.50
Chillianwala Disty	Gujrat Branch	104.50	097000-105308	3.00	Brick Masonry	Trapezoidal	2.48	0.42	0:1	9.0	1.35	0.017	1.50
Aala Minor	Chillianwala Disty	5.00	0000-9500	5.00	Brick Masonry	Trapezoidal	2.74	0.40	1/2:1	9.0	1.45	0.017	1.50
Maujianwala Minor	Chiallianwala Disty	31.50	33000-41600	3.00	Brick Masonry	Trapezoidal	2.40	0.35	0:1	9.0	1.45	0.017	1.50
Minar Sub Minor	Maujiwanwala Minor	5.00	05623-11490	2.50	Brick Masonry	Trapezoidal	1.76	0.41	0:1	9.0	1.60	0.017	1.50
Nihal Singhwala Minor	Chiallianwala Disty	14.50	28000-30450	2.00	Brick Masonry	Trapezoidal	2.01	0.42	0:1	9.0	1.25	0.017	1.50
Rukkan Minor	Bhallowal Distributary	52.00	45000-64352	10.00	Brick Masonry	Trapezoidal	3.12	0.28	1/2:1	4.5	2.05	0.017	1.50
Sanda Sub Minor	Rukkan Minor	5.00	0000-6200	5.00	Brick Masonry	Trapezoidal	2.10	0.40	1/2:1	4.5	1.65	0.017	1.50
Miana Gondal Minor	Bhallowal Distributary	12.50	00000-14280	12.50	Brick Masonry	Trapezoidal	4.38	0.35	1/2:1	4.5	1.85	0.017	1.50

* For which rehabilitation works completed as of September 30, 1993

** 1 foot in lined portion and 0.5 foot in earthen section.

Annexure - 3
Sheet 1 of 5

COMMAND WATER MANAGEMENT PROJECT (IDA COMPONENT)
HYDRAULIC DATA OF MAJOR LINED CHANNELS

PUNJAB PROVINCE

Name of the Channel	Reach	Discharge (cfs)	Type of Lining Brick Masonry/ Concrete etc.	Bed Width (ft.)	Side Slope H:V	Full Supply Depth (ft.)	Value of n	Remarks
1	2	3	4	5	6	7	8	9
Shah Kot Distributary	117315-131800	33.00	C.C	4.80	1:1	2.40	0.016	
	131800-142435	18.00	C.C	3.40	1:1	1.80	0.016	
	142435-153515	4.00	Brick Masonry	2.20	-	1.20	0.016	
Niaz Beg Distributary	133500-150129	92.00	C.C	9.10	1/2:1	3.20	0.016	
	150129-156081	81.00	C.C	8.40	1/2:1	3.10	0.016	
	156081-166736	60.00	C.C	6.20	1/2:1	2.90	0.016	
	166736-169750	42.00	C.C	5.20	1:1	2.80	0.016	
	169750-173000	40.00	C.C	4.90	1:1	2.80	0.016	
	173000-175612	36.00	C.C	4.70	1:1	2.70	0.016	
	175612-180000	19.00	C.C	3.20	1:1	2.00	0.016	
	180000-183635	18.00	C.C	3.20	1:1	1.90	0.016	
	183635-185240	11.25	C.C	2.90	1:1	1.60	0.016	
1L/3R Pakpattan Minor	000000-020600	28.00	C.C	4.80	1:1	2.40	0.016	
	20600-30968	19.18	C.C	4.00	1:1	2.10	0.016	
	30968-40550	9.16	C.C	3.10	1:1	1.50	0.016	
6-R Hakra Distributary	00000-13750	482.00	C.C	28.50	1/2:1	5.00	0.016	
	13750-32000	437.00	C.C	28.50	1/2:1	4.60	0.016	
	32000-37550	409.00	C.C	28.50	1/2:1	4.60	0.016	
	128000-135150	14.70	C.C	3.90	1:1	1.70	0.016	
	135150-138800	9.50	C.C	2.80	1:1	1.60	0.016	
	138800-148360	5.70	C.C	1.90	1:1	1.40	0.016	
2L/6R Hakra Minor	00000-21270	30.00	C.C	5.00	1:1	2.30	0.016	
	21270-24200	17.00	Brick Masonry	3.90	1:1	1.70	0.016	
	24200-30000	14.50	Brick Masonry	3.70	1:1	1.60	0.016	
	30000-32000	10.00	Brick Masonry	2.70	1:1	1.50	0.016	
	32000-34790	6.50	Brick Masonry	1.80	1:1	1.40	0.016	

Source: Paper by Mashhadi & Akbar (1990), Proceedings of Engineering Congress

COMMAND WATER MANAGEMENT PROJECT (IDA COMPONENT)
HYDRAULIC DATA OF MAJOR LINED CHANNELS

SINDH PROVINCE

Name of the Channel	Reach	Discharge (cfs)	Type of Lining Brick/Concrete etc.	Bed Width (ft.)	Side Slope H:V	Full Supply Depth (ft.)	Value of n	Remarks
1	2	3	4	5	7	8	9	10
Khanwahan Minor	11500-15000	36.7	Concrete	5.10	1:1	2.80	0.018	
	15000-19200	30.59	Concrete	4.80	1:1	2.60	0.018	
	19200-24430	25.42	Concrete	4.30	1:1	2.40	0.018	
	24430-30500	19.64	Concrete	3.80	1:1	2.20	0.018	
	30500-33595	15.02	Concrete	3.40	1:1	2.00	0.018	
	33595-37240	10.40	Concrete	2.60	1:1	1.80	0.018	
	37240-42000	8.20	Concrete	2.50	1:1	1.60	0.018	
	42000-43285	5.67	Concrete	2.20	1:1	1.40	0.018	
	43285-46435	3.52	Concrete	1.50	1:1	1.20	0.018	
	46435-49950	1.21	Concrete	1.50	1:1	1.00	0.018	
New Keti Minor	00000-03866	12.58	Concrete	3.30	1:1	1.80	0.018	
	03866-09186	9.17	Concrete	3.00	1:1	1.60	0.018	
	09186-11766	6.66	Concrete	2.70	1:1	1.40	0.018	
	11766-15186	3.03	Concrete	1.40	1:1	1.20	0.018	
Sial Minor	00000-00460	21.36	Concrete	1.10	1:1	3.36	0.018	
	00460-04000	17.85	Concrete	1.00	1:1	3.10	0.018	
	04000-05000	13.92	Concrete	1.00	1:1	2.80	0.018	
	05000-05200	11.66	Concrete	1.00	1:1	2.60	0.018	
	05200-09150	4.51	Concrete	0.50	1:1	2.30	0.018	
Mohio Minor	00000-08000	18.00	Concrete	4.00	1:1	2.00	0.018	
	08000-16500	17.00	Concrete	3.00	1:1	1.80	0.018	
	16500-22900	17.00	Concrete	2.50	1:1	1.50	0.018	
Dewan Minor	00000-09500	30.00	Concrete	5.00	1.5:1	2.50	0.018	
	09500-19500	18.25	Concrete	3.75	1.5:1	2.00	0.018	
	19500-27650	13.00	Concrete	2.50	1.5:1	1.80	0.018	
	27650-28200	12.50	Concrete	2.00	1.5:1	1.50	0.018	
Keti Old Minor	00000-00500	17.90	Concrete	1.50	1:1	2.75	0.018	
	00500-06000	10.36	Concrete	1.50	1:1	2.10	0.018	
	06000-09650	3.90	Concrete	1.00	1:1	1.53	0.018	
Detha Minor	00000-10400	33.02	Concrete	2.00	1:1	3.55	0.018	
	10400-22000	21.08	Concrete	1.50	1:1	3.10	0.018	
	22000-27000	7.88	Concrete	1.50	1:1	2.00	0.018	
	27000-32350	2.70	Concrete	1.50	1:1	1.20	0.018	

Source: Paper by Meshhadi & Akbar (1990), Proceedings of Engineering Congress

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Sheet 3 of 5

COMMAND WATER MANAGEMENT PROJECT (IDA COMPONENT)
HYDRAULIC DATA OF MAJOR LINED CHANNELS

SINDH PROVINCE

Name of the Channel	Reach	Discharge (cfs)	Type of Lining Brick/Concrete etc.	Bed Width (ft.)	Side Slope H:V	Full Supply Depth (ft.)	Value of n	Remarks
1	2	3	4	5	7	8	9	10
Larik Minor	00000-04200	32.58	Concrete	2.50	1:1	3.40	0.018	
	04200-08633	24.92	Concrete	2.50	1:1	3.00	0.018	
	08633-16950	18.80	Concrete	1.75	1:1	2.80	0.018	
	16950-22900	12.09	Concrete	1.50	1:1	2.40	0.018	
	22900-27024	5.59	Concrete	1.00	1:1	1.85	0.018	
Let Minor	28000-31250	32.75	Concrete	5.70	1:1	2.50	0.018	
	31250-33510	25.51	Concrete	5.20	1:1	2.30	0.018	
	33510-38133	21.05	Concrete	5.00	1:1	2.10	0.018	
	38133-42857	16.21	Concrete	4.50	1:1	1.90	0.018	
	42857-48149	10.15	Concrete	3.30	1:1	1.70	0.018	
	48149-51245	5.44	Concrete	2.00	1:1	1.50	0.018	
	51245-56365	3.51	Concrete	1.60	1:1	1.30	0.018	
	56365-58900	1.97	Concrete	1.20	1:1	1.10	0.018	
Darbello Minor	35050-37850	35.61	Concrete	5.40	1:1	2.80	0.018	
	37850-40100	29.31	Concrete	5.10	1:1	2.60	0.018	
	40100-44200	24.77	Concrete	4.90	1:1	2.40	0.018	
	44200-51100	20.48	Concrete	4.70	1:1	2.20	0.018	
	51100-54200	16.90	Concrete	4.20	1:1	2.00	0.018	
	54200-57300	11.55	Concrete	3.70	1:1	1.80	0.018	
	57300-59600	6.93	Concrete	2.60	1:1	1.60	0.018	
	59600-61000	3.50	Concrete	1.50	1:1	1.40	0.018	
	61000-66000	1.19	Concrete	1.50	1:1	1.20	0.018	
Abji Minor	00000-03000	36.92	Concrete	4.40	1:1	3.00	0.018	
	03000-07088	34.94	Concrete	6.50	1:1	2.40	0.018	
	07088-17000	30.92	Concrete	6.30	1:1	2.30	0.018	
	17000-25300	26.28	Concrete	6.00	1:1	2.10	0.018	
	25300-28000	21.09	Concrete	5.70	1:1	1.90	0.018	
	28000-29953	21.09	Concrete	5.70	1:1	1.90	0.018	
	29953-36578	15.83	Concrete	5.10	1:1	1.70	0.018	
	36578-37800	10.74	Concrete	4.30	1:1	1.50	0.018	
	37800-41200	6.58	Concrete	3.10	1:1	1.30	0.018	
	41200-44600	2.18	Concrete	1.10	1:1	1.10	0.018	

Source: Paper by Mashhadi & Akbar (1990), Proceedings of Engineering Congress

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COMMAND WATER MANAGEMENT PROJECT (IDA COMPONENT)
HYDRAULIC DATA OF MAJOR LINED CHANNELS

NWF PROVINCE

Name of the Channel	Reach	Discharge (cfs)	Type of Lining Brick/Concrete etc.	Bed Width (ft.)	Side Slope H:V	Full Supply Depth (ft.)	Value of n	Remarks
1	2	3	4	5	7	8	9	10
Warsak Lift Canal	39200-54900	172.00	C.C	8.60	1/2:1	4.30	0.016	
	54900-63000	158.00	C.C	8.10	1/2:1	4.20	0.016	
	63000-65000	148.00	C.C	7.90	1/2:1	4.10	0.016	
	65000-67000	136.00	C.C	7.50	1/2:1	4.00	0.016	
	67000-70300	130.00	C.C	7.50	1/2:1	3.90	0.016	
	101100-112300	95.00	C.C	6.50	1/2:1	3.40	0.016	
	112300-114200	87.00	C.C	6.30	1/2:1	3.30	0.016	
	114200-122000	63.00	C.C	6.10	1/2:1	2.80	0.016	

Source: Paper by Mashhadi & Akbar (1990), Proceedings of Engineering Congress.

COMMAND WATER MANAGEMENT PROJECT (IDA COMPONENT)
HYDRAULIC DATA OF MAJOR LINED CHANNELS

BALOCHISTAN PROVINCE

Name of the Channel	Reach	Discharge (cfs)	Type of Lining Brick/Concrete etc.	Bed Width (ft.)	Side Slope H:V	Full Supply Depth (ft.)	Value of n	Remarks
1	2	3	4	5	7	8	9	10
Minor No. 1	00000-00150	14.00	Pipe	1.00	-	-	0.018	
	00150-00800	6.51	Pipe	-	-	-	0.017	
	00800-02100	4.22	Pipe	-	-	-	0.017	
	02100-04900	1.68	Pipe	-	-	-	0.017	
	04900-07600	1.68	Pipe	-	-	-	0.017	
Minor No. 3	00000-00300	14.00	C.C	1.00	1/2:1	1.20	0.018	
	00300-03000	11.14	C.C	1.00	1/2:1	1.10	0.018	
	03000-05500	8.19	C.C	1.00	1/2:1	0.90	0.018	
	05500-09800	4.96	C.C	0.50	1/2:1	0.90	0.018	
Minor No. 4	00000-00125	39.00	C.C	2.00	1/2:1	1.92	0.018	
	00125-02500	39.00	C.C	2.00	1/2:1	1.55	0.018	
	02500-05300	35.57	C.C	2.00	1/2:1	1.50	0.018	
	05300-07800	29.35	C.C	2.00	1/2:1	1.40	0.018	
	07800-10750	24.35	C.C	2.00	1/2:1	1.30	0.018	
	10750-12100	22.32	C.C	2.00	1/2:1	1.45	0.018	
	12100-13050	19.67	C.C	2.00	1/2:1	1.25	0.018	
	13050-17300	15.35	C.C	2.00	1/2:1	1.45	0.018	
	17300-19800	12.62	C.C	1.50	1/2:1	1.25	0.018	
	19800-20300	11.43	C.C	1.50	1/2:1	1.15	0.018	
	20300-21250	9.61	C.C	1.50	1/2:1	"	0.018	

Source: Paper by Mashhadi & Akbar (1990), Proceedings of Engineering Congress.

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Sheet 1 of 1

COMMAND WATER MANAGEMENT PROJECT
INFORMATION ABOUT SOME MORE LINED CHANNELS

Name of the Channel	Reach (ft)/ Length Lined (Miles)	Discharge (cfs)	Type of Lining Brick Masonry/ Concrete etc.	Bed Width (ft.)	Bed Slope (ft/000 ft)	Side Slope H:V	Full Supply Depth (ft.)	Value of n	Remarks
1	2	3	4	5	6	7	8	9	10
PUNJAB									
Padwan	0.98	15.00	Brick Masonry	NA	NA	NA	NA	NA	
Pacca Dalla	2.01	6.00	PCC	NA	NA	NA	NA	NA	
Kamogill	3.20	17.00	PCC	NA	NA	NA	NA	NA	
Jamke	2.14	16.00	PCC	NA	NA	NA	NA	NA	
1R/3R Minor Pakpattan	5.42	25.00	PCC	NA	NA	NA	NA	NA	
2L/3R Minor	1.54	5.00	PCC	NA	NA	NA	NA	NA	
3L/3R Minor Pakpattan	1.48	6.00	PCC	NA	NA	NA	NA	NA	
1R/4R Minor Pakpattah	2.57	6.00	PCC	NA	NA	NA	NA	NA	
5-R Disty Pakpattan	2.40	8.00	PCC	NA	NA	NA	NA	NA	
1L/5R Minor Pakpattan	2.12	13.00	PCC	NA	NA	NA	NA	NA	
2L/5R Minor Pakpattan	4.30	9.00	PCC	NA	NA	NA	NA	NA	
1R/6R Minor Pakpattan	5.18	19.00	PCC	NA	NA	NA	NA	NA	
1L/6R Minor Pakpattan	2.93	6.00	PCC	NA	NA	NA	NA	NA	
2L/6R Minor Pakpattan	4.02	10.00	PCC	NA	NA	NA	NA	NA	
1R/6R Minor, 6R Hakra	4.56	26.00	PCC	NA	NA	NA	NA	NA	
2R/6R Minor, 6R Hakra	1.17	5.00	Brick Masonry	NA	NA	NA	NA	NA	
1L/6R Minor, 6R Hakra	3.61	24.00	PCC	NA	NA	NA	NA	NA	
1R/6R Sub Minor, 6R Hakra	3.61	32.00	PCC	NA	NA	NA	NA	NA	
1L/1L/6L Sub Minor, 6R Hakra	5.67	21.00	PCC	NA	NA	NA	NA	NA	
SINDH									
Naulakhi Branch	0-75800	377.00	PCC	NA	NA	NA	NA	NA	
Khushik Minor	0-12900	12.00	PCC	NA	NA	NA	NA	NA	
Jatoi Minor	0-46375	26.00	PCC	NA	NA	NA	NA	NA	
Mahesar Minor	0-2652	8.00	Brick Masonry	NA	NA	NA	NA	NA	
Sehra Branch	0-63000	383.14	PCC	NA	NA	NA	NA	NA	
Sa'ehpur Minor	0-11600	15.00	PCC	NA	NA	NA	NA	NA	
Manjith Minor	0-12000	9.00	PCC	NA	NA	NA	NA	NA	
Darbello Minor	35050-66000	35.61	PCC	NA	NA	NA	NA	NA	
Old Keti Minor	0-9050	17.90	PCC	NA	NA	NA	NA	NA	
Thatt Minor	0-14965	10.00	PCC	NA	NA	NA	NA	NA	
Puran Minor	0-13800	8.57	PCC	NA	NA	NA	NA	NA	
BALOCHISTAN									
Minor No. 2	17300-19800		PCC	NA	NA	NA	NA	NA	
Minor No. 5	1.78	14.00	PCC	NA	NA	NA	NA	NA	

Source: ACOP

LINING DETAILS
KHUSHAB SCARP PROJECT
CANAL REHABILITATION AND REMODELLING COMPONENT

Name of the Channel	Name of the Parent Channel	Discharge at Head (cfs)	Reach	Discharg at Start of Lined Reach (cfs)	Type of Lining Brick/Concrete etc.	Geometry (Trapezoidal/ Rectangular)	Bed Width (ft.)	Bed Slope (ft./1000 ft.)	Side Slope H:V	Thickness of Lining (inches)	Full Supply Depth (ft.)	Value of n	Free Board (ft.)	Year of Completion	Remarks
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Bolah Distributary	Mahajir Branch	504	00000-01210	84	Concrete	Trapezoidal	9.750	0.30	1.5:1	2.5	3.40	0.014	1.00	1992	
			01210-08100	32	Concrete	Trapezoidal	8.300	-	1.5:1	2.5	3.20	0.014	1.00		
			08100-08000	-	Concrete	Trapezoidal	8.125	-	1.5:1	2.5	2.85	0.014	1.00		
			08000-08150	-	Concrete	Trapezoidal	8.500	-	1.5:1	2.5	2.25	0.014	1.00		
			08150-08750	-	Concrete	Trapezoidal	8.125	-	1.5:1	2.5	2.88	0.014	1.00		
			08750-13500	-	Concrete	Trapezoidal	9.500	-	1.5:1	2.5	2.25	0.014	1.00		
			13500-20250	25	Concrete	Trapezoidal	8.000	-	1.5:1	2.5	2.30	0.014	1.00		
			20250-26000	15	Concrete	Trapezoidal	3.380	-	1.5:1	2.5	2.88	0.014	1.00		
			26000-33903	8	Concrete	Trapezoidal	1.500	0.36	1.5:1	2.5	2.55	0.014	1.00		
1-R Minor of Bolah Disty	Bolah Distributary	84	00000-06000	15	Concrete	Trapezoidal	4.000	0.30	1.5:1	2.5	2.50	0.014	1.00	1992	
			06000-10000	12	Concrete	Trapezoidal	3.000	-	1.5:1	2.5	2.45	0.014	1.00		
			10000-15875	5	Concrete	Trapezoidal	1.180	-	1.5:1	2.5	2.25	0.014	1.00		
1-L Minor of Bolah disty	Bolah Distributary	63	00000-15200	27	Concrete	Trapezoidal	4.300	0.30	1.5:1	2.5	3.00	0.014	1.00	1992	
			15200-20000	19	Concrete	Trapezoidal	3.000	-	1.5:1	2.5	3.10	0.014	1.00		
			20000-27200	17	Concrete	Trapezoidal	3.600	-	1.5:1	2.5	2.80	0.014	1.00		
			27200-34175	8	Concrete	Trapezoidal	2.000	0.59	1.5:1	2.5	2.20	0.014	1.00		
Shiwala Minor	Dhak Distributary	206	00000-04500	80	Concrete	Trapezoidal	9.500	0.17	1.5:1	2.5	3.75	0.014	1.00	1993	In Progress
			04500-08300	38	Concrete	Trapezoidal	5.250	-	1:1	2.5	3.40	0.014	1.00		
			09300-14000	37	Concrete	Trapezoidal	4.500	-	1:1	2.5	3.35	0.014	1.00		
			14000-22700	27	Concrete	Trapezoidal	4.500	-	1:1	2.5	3.10	0.014	1.00		
			22700-27500	15	Concrete	Trapezoidal	3.250	-	1:1	2.5	2.75	0.014	1.00		
			27500-32200	8	Concrete	Trapezoidal	2.000	0.24	1:1	2.5	2.20	0.014	1.00		
Ghagh Minor	Shiwala Minor	80	00000-12000	37	Concrete	Trapezoidal	8.250	0.24	1:1	2.5	3.10	0.014	1.00	1993	In Progress
			12000-18500	16	Concrete	Trapezoidal	3.500	-	1:1	2.5	2.70	0.014	1.00		
			18500-26450	7	Concrete	Trapezoidal	2.000	0.50	1:1	2.5	2.20	0.014	1.00		
Sandral Minor	Ghagh Minor	30	00000-08000	13	Concrete	Trapezoidal	2.170	0.30	1:1	2.5	2.80	0.014	1.00	1993	In Progress
			08000-14900	7	Concrete	Trapezoidal	1.660	-	1:1	2.5	2.30	0.014	1.00		
			14900-25020	4	Concrete	Trapezoidal	1.000	0.45	1:1	2.5	2.20	0.014	1.00		
Rajar Minor	Dhak Distributary	43	00000-04850	28	Concrete	Trapezoidal	3.050	0.19	1:1	2.5	5.00	0.014	1.00	1993	In Progress
			04850-08520	23	Concrete	Trapezoidal	4.750	-	1:1	2.5	2.80	0.014	1.00		
			08520-13500	20	Concrete	Trapezoidal	4.250	-	1:1	2.5	2.80	0.014	1.00		
			13500-19000	145	Concrete	Trapezoidal	3.000	-	1.5:1	2.5	2.80	0.014	1.00		
			19000-24220	11	Concrete	Trapezoidal	2.250	-	1:1	2.5	2.70	0.014	1.00		
			24220-31000	8	Concrete	Trapezoidal	2.000	-	1:1	2.5	2.50	0.014	1.00		
			31000-32250	3	Concrete	Trapezoidal	1.000	0.28	1:1	2.5	2.20	0.014	1.00		
Khushab Distributary	Nure wala Distributary	345	05487-16000	38	Concrete	Trapezoidal	4.000	0.18	1:1	2.5	3.60	0.014	1.00	1994-95	Work not yet started
			16000-26500	29	Concrete	Trapezoidal	3.650	-	1:1	2.5	3.50	0.014	1.00		
			26500-38500	18	Concrete	Trapezoidal	3.000	-	1:1	2.5	3.00	0.014	1.00		
			38500-44815	11	Concrete	Trapezoidal	1.500	0.32	1:1	2.5	2.50	0.014	1.00		
1-R Minor of Khushab Disty	Khushab Disty	191	00000-16000	48	Concrete	Trapezoidal	8.580	0.20	1:1	2.5	3.50	0.014	1.00	1994-95	Work not yet started
			16000-23000	38	Concrete	Trapezoidal	7.250	-	1:1	2.5	3.25	0.014	1.00		
			23000-30000	27	Concrete	Trapezoidal	7.750	-	1:1	2.5	2.75	0.014	1.00		
			30000-34792	27	Concrete	Trapezoidal	8.000	-	1:1	2.5	2.25	0.014	1.00		
			34792-41200	18	Concrete	Trapezoidal	4.250	-	1:1	2.5	2.25	0.014	1.00		
			41200-46300	10	Concrete	Trapezoidal	2.750	0.39	1:1	2.5	2.00	0.014	1.00		
1-L Minor of Khushab Disty	Khushab Disty	191	25500-35300	40	Concrete	Trapezoidal	8.500	0.20	1:1	2.5	3.50	0.014	1.00	1994-95	Work not yet started
			35300-43360	31	Concrete	Trapezoidal	4.750	-	1:1	2.5	3.10	0.014	1.00		
			43360-50300	13	Concrete	Trapezoidal	4.750	0.30	1:1	2.5	2.50	0.014	1.00		

Source: Khushab SCARP.

SEEPAGE MEASUREMENT TECHNIQUES AND ACCURACY

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ABSTRACT

In this paper we briefly discuss the three commonly used seepage measurement methods, and the accuracy that can be expected when they are used. The main emphasis of the paper is on the errors in seepage estimates derived from the inflow outflow method, using velocity area discharge measurements. Analysis of data collected from canals in India is presented. This shows that estimates of error margins in seepage rates will be unduly pessimistic when based on studies of errors in velocity area discharge measurement in natural rivers. The paper provides guidance on planning seepage measurements so that errors are minimised, and the maximum benefit obtained from expensive field data collection exercises.

INTRODUCTION

A significant proportion of the water diverted to irrigation canals is lost in seepage. Lining is often adopted to reduce seepage, but there is a growing body of evidence that lining constructed in developing countries has a very short effective life. For example data collected in the Indian Punjab, Makin 1989, suggests that the seepage rate in lined canals increases to the unlined value in the first few years following construction. High rates of seepage can result from a very small area of cracking in rigid lining, and a lining that may appear to be in reasonable condition from a cursory physical inspection could well be ineffective in controlling seepage.

At a time when there is increasing emphasis on lining as a water saving measure there is an increasingly important requirement for reliable estimates of actual seepage rates in lined and unlined canals. Accurate data is needed to guide planning and design of canal lining, to provide information on the performance and life of lining materials, and to target areas where maintenance is required.

Three methods of measurement are in common use at the present time, the Ponding Method, the Inflow-Outflow Method, and the Seepage Meter. Of these only the Inflow-Outflow Method can be used in both lined or unlined canals, without interrupting the flow. Many other seepage detection techniques have been used, (Koerner et al 1979), including chemical and radioactive tracers, microwave methods, piezometric surveys, seismic surveys, surface resistivity methods and remote sensing. All suffer from the disadvantage that they are indirect, and are therefore difficult to interpret to provide quantitative estimates of seepage rates. However, the methods, which are in common practice for measuring seepage losses along with their accuracy, are briefly discussed.

METHODS OF SEEPAGE MEASUREMENT

Ponding

Ponding is considered to be the most accurate method of seepage measurement, and it is frequently used as a standard with which to compare other methods. The procedure in principle is simple: a stretch of canal under investigation is isolated and filled with water - what is lost is seepage. The rate of seepage loss is determined by one of two methods, Falling Level and Constant Level.

In the Falling Level method the decreasing water level is either recorded at the beginning and end of a test, or at regular intervals throughout. The latter technique is preferable as it shows up any "wetting up" or "self sealing " effects. Water level readings are sometimes taken simultaneously at several points along a test reach to compensate for the effects of wind. Corrections also have to be made for leakage through bulkheads, rainfall, and evaporation. The most difficult of these is leakage. Whenever possible leakage effects should be minimised by making the test reach as long as is practicable, and by sealing the bulkheads with clay and/or plastic sheeting.

With the Constant Level method water is added continuously to maintain the initial level. The discharge is measured using a structure such as a weir, flume, or orifice. The remarks concerning leakage, evaporation, rainfall, and wind effects made for the Falling Level method also apply to this method.

In practice the ponding method has certain advantages:

1. The accuracy of measurement is not dependent on the length of the test reach provided it is sufficient to compensate for normal errors.

2. The requirement for trained manpower is small.

3. Sophisticated equipment is not required.

The disadvantages of the method are:

1. Costly water tight bulkheads must be built at each end of the reach if existing structures are not available.

2. The normal flow through the canal must be interrupted for the duration of the tests. Because of this, and the need for bulkheads, the method is usually restricted to small canals, and tests have to be carried out during relatively short closure periods.

3. The rate of seepage loss from the test section can vary with time because of the sealing effects of fine sediment settling out, or, in the case of a canal which is initially dry, because of the time taken to saturate the underlying formation, or a combination of both.

4. The rate of seepage loss determined by ponding can be very different from that measured in flowing water because of re-saturation or self sealing effects.

5. Large quantities of water are required if the canal under test is initially dry.

Seepage Meter

The Seepage Meter is used for localized measurements of seepage. In principle it is simple: an open metal cylinder with a conical cover (seepage bell) is pushed into the canal bed and the water level in the bell is allowed to fall to an equilibrium level creating a good seal. Water is then metered into the bell to maintain the water level equal to the canal water level. The rate of flow into the bell divided by the area of the bell gives the localized seepage rate.

Although it has been used successfully in large and small canals, see for example Pontin 1978, in practice the seepage meter suffers from some serious disadvantages when compared with other methods. These include the difficulty in ensuring a good seal between the bell and the canal bed, and the large number of measurements that are necessary if there are significant variations in seepage rates along canal reaches. Its use is restricted to unlined canals, and it will not function in sandy soils.

Inflow-Outflow Methods

After ponding the Inflow-Outflow method is the most commonly used method of seepage measurement. The discharges into and out of a selected reach of a canal are measured, and the rate of seepage derived from the difference. Methods available for the measurement of canal discharge can be divided into two classes, continuous and occasional. Here we consider gauging structures and Ultrasonic among the continuous methods of discharge measurement, and Velocity Area, and Dilution Gauging from among the occasional methods.

Continuous Methods

Continuous methods of seepage measurement usually require permanent structures. Standard gauging structures are ideally suitable, and can provide a highly accurate method of flow measurement if properly designed and maintained. In general such structures only exist on smaller canals and are usually built at the head and tail of a long reach for water management purposes, and hence can provide a bulk measurement of seepage loss. On larger canals purpose built measurement structures are rare, and usually water control structures such as cross regulators or drops have to be used for flow measurement.

For small canals a range of measurement structures are available.

Thin Plate Weirs

These depend for their accuracy on the maintenance of a sharp edge on the upstream face. Any rounding, rust pitting or damage can affect the discharge coefficient. It is also important that no sediment collects behind the upstream face thus altering the weir's geometry. Complete ventilation of the nappe is also essential if accuracy is to be maintained.

Long-based Weirs

These are more suitable for field use because of their robustness. (The name long-based is used following British Standards practice in preference to broad-crested, to avoid confusion as to which dimension is implied, i.e. the length of the weir crest in the direction of flow.) The accuracy of Long-based weirs falls off markedly at very low heads, and to overcome this they are either compounded or given a flat "V" profile.

Rectangular profile weirs are the simplest to build but suffer from certain disadvantages. Their calibration is sensitive to deterioration of the upstream edge, and they have a variable coefficient of discharge. Round-nosed long-based weirs perform better. They have a constant coefficient of discharge which can be predicted theoretically when the flow is modular but are somewhat more costly to construct.

Triangular Profile Weirs

These are now frequently used. The two dimensional Crump weir is relatively simple to construct and has a constant coefficient of discharge in the modular range. This type of weir cannot operate effectively over a wide range of discharges, hence the development of the flat "V" weir.

Flumes

Long throated flumes are rarely used in irrigation canals because of the high cost of construction. Short-throated flumes such as the "Parshall" or "Cut-Throat" are however cheaper to construct and hence more popular. These flumes do not have constant coefficients of discharge but in the case of the Parshall flume reference can be made to standard design tables. It is important to note that the design dimensions must be strictly adhered to during construction.

Rated Flow Control Structures

In large canals cross regulators or canal drops can be used to measure discharges, although these will usually require very careful calibration if the discharge estimates are to be used to derive estimates of seepage.

Ultrasonic Discharge Measurement

Ultrasonic methods have come into full prominence during the last two decades, although the method has been in use since the 1950's, Hershy et al 1978. The velocity of flow at a height above the bed is measured by transmitting acoustic pulses obliquely across the flow in both directions. The stream velocity can be derived directly from the difference between the time of travel of the acoustic pulses in the upstream direction to the downstream direction, or from the doppler frequency shift. Multiple transducers are used to determine mean flow velocities at a number of heights above the bed. Discharge is calculated as the product of the flow area, determined from the water level, and the mean velocity, determined from the velocity measurements. With automatic systems ultrasonic gauging gives a continuous record of discharge, does not obstruct the flow and can measure flow reversals.

Ultrasonic gauging has become much cheaper and more reliable in recent years, and could now be considered for seepage measurement applications, particularly in large canals that do not have suitable flow measurement structures. However ultrasonic systems can be effected by high concentrations of suspended solids, entrained gases and weeds, and so may not be applicable at some sites.

Global Budgeting

Global budgeting is often employed where there are existing structures which can be used to measure the flow into and out of long reaches or networks of canals. While the method can usually give a good assessment of the overall seepage it is not suitable for localized seepage measurement. A promising recent innovation is to combine Global Budgeting with a good hydrodynamic model, which includes a seepage component. This approach facilitates a continuous assessment of local seepage, and accounts for varying canal flows and channel storage effects etc. However, as with other methods, good discharge calibrations for canal control structures are essential.

Occasional Methods

Velocity Area

The Velocity Area method is the most widely used of all the occasional discharge measurement techniques. The area of flow is determined by sounding, and the mean velocity by current metering, the product of the two giving the discharge. Ideally the measurement reach should be straight, and free from obstructions, weeds or offtakes, and have a stable bed. Before beginning a discharge measurement a preliminary survey should be carried out to determine the bed profile, and to ensure that a well developed velocity distribution exists along the test reach. Furthermore a continuous record of velocities at selected points in the channel cross section should be obtained to determine the averaging time required for current meter readings.

The accuracy of a measurement depends mostly on the number of verticals used, and to a lesser extent on the number of points at which velocity is recorded in each vertical. If very accurate measurements of discharge are required, as is the case in seepage studies, it is essential that measurements are carried out by an experienced, well trained team.

Dilution Gauging

As far as the writers are aware Dilution gauging has not been used for inflow-outflow measurement. Nevertheless its potentially high accuracy makes it worthy of consideration, particularly for lined canals. Discharge is deduced from the concentration of a tracer injected into the flow at a known rate. There are two basic techniques, constant rate injection, and the sudden injection or "gulp" method. There are problems in applying dilution methods in natural channels because tracer loss and absorption in plants etc. In lined irrigation canals however there should be very little tracer loss or absorption, and provided that a tracer can be identified that is non-toxic and can be detected at very low concentrations is used, accuracy should be high.

ERROR ANALYSIS AND ACCURACY

In any investigation some or all of the physical properties of a system cannot be measured directly, but are determined from other independent variables, each of which is subject to both systematic and random errors. The usefulness of a measurement is greatly enhanced if an assessment of the error range accompanies the result. This is particularly important in seepage studies, where measured seepage rates can be subjected to large margins of error. An understanding of the sources of error can greatly improve the planning of measurement programmes, and ensure that maximum benefit is obtained from expensive field data collection exercises.

A detailed analysis of the errors associated with seepage measurement has been given in Weller 1981, and is only summarised here. Errors and accuracy of standard methods are quoted with an appropriate reference.

Ponding Method

Weller (1981) has shown that the rate of seepage loss per unit area of the wetted perimeter for the Falling Level Method is given by the following equation:

$$P_s = \frac{W_s}{W_p} \frac{(h_1 - h_2 - h_E - h_L + h_R)}{t} \qquad (1)$$

where

W_s is width of the wetted surface (m)

W_p is the width of the wetted perimeter (m)

h_1 is the initial level of the water surface

h_2 is the final level of the water surface

h_L is the fall in the water surface caused by leakage through the bulkheads (m)

h_E the fall in the water surface caused by evaporation (m)

h_R the rise in the water surface caused by rainfall (m)

Under normal circumstances the errors in measurement of water level, rainfall and time can usually be kept to within 1%. Care must be taken however with water surface width and/or wetted perimeter, since considerable variations can occur as the water level drops. It is also important that the water level in the test reach does not fall too far below the normal canal operating level. One way in which this can be achieved is by limiting fall to about 50 mm before refilling. However if this procedure method is employed care must be taken to ensure that the head difference term does not become too small, or the error will become large. Leakage rates through bulkheads is difficult to quantify, especially in earthen channels. The effects of leakage can however be reduced by using long test reaches. Estimates of evaporation can also have large errors if they are based on a class A pan.

The equation for the rate of seepage loss per unit area of wetted perimeter for the constant Level Method is given by Weller (1981) as follows:

$$P_s = \frac{\int_0^t q(t)\,dt}{W_s\,Lt} - \frac{(h_E + hL - h_R)}{t} \qquad \textbf{(2)}$$

Where

q is the rate at which water is added to the test reach (m^3/s)

L is the length of the test reach (m)

All other factors are as for the Falling Level Method. In this method of seepage measurement it is important that the surface level is kept constant and point gauges should be used to maintain accuracy. The inflow too must be measured with great accuracy and ideally an orifice or "V" notch weir should be used. The comments for the Falling Level method regarding leakage and evaporation also apply to the Constant Level case.

In general, if the canal water is clear of suspended sediment, and the flow is merely interrupted, ponding tests can be very accurate. With care accuracies in the order of 3.5% to 15% for the falling level method and 3% to 10% for the constant level method should be achievable. Equations for estimating the errors for both methods are given in Weller 1981.

If the canal water contains fine sediment, or the ponding test is carried out after the channel has remained dry for a considerable period, the test results should be carefully analyzed to ensure that self sealing or re-saturation effects are not distorting the estimate of seepage rate.

Seepage Meter

It is not possible to quantify the errors in the measurement of seepage by Seepage Meter because of the difficulty of obtaining a good seal between the seepage bell and the canal bed. The error associated with the degree of seal cannot be estimated, and there remains a considerable uncertainty about the result. More information is given by Pontin (April 1978, May 1978).

Inflow-Outflow

The error in an estimate of seepage derived from inflow-outflow measurements is derived by considering firstly the error associated with the individual discharge measurements, and then combining these to estimate the error in the seepage estimate. Errors in the measurement of discharge are considered first.

Errors in Discharge Measurement

Gauging Structures

It is not possible in a paper of this nature to list the discharge relationships of all gauging structures. The discharge calibration of most structures can however be represented by a general equation of the form:

$$Q = C_d\, b h^m \qquad (3)$$

Where

Q is the measured discharge (m^3/s)

C_d is the coefficient of discharge

h is the upstream head (m)

m is an exponent

b is the width of the crest (m)

By applying the Principle of the Superposition of Errors the equation for error in discharge measurement at the 95% confidence level can be expressed as:

$$X_Q = \pm(X_{Cd}^2 + X_b^2 + m^2X_h^2)^{½} \qquad (4)$$

Where

X_Q is the error in discharge at the 95% confidence level

X_{Cd} is the error in the coefficient at the 95% confidence level

X_b is the error in the width of the crest at the 95% confidence level

X_h is the error in the upstream head at the 95% confidence level

Ultrasonic Gauging

Errors associated with the Ultrasonic method of discharge measurement depend very much on whether a single path or multipath system is installed, and the conditions at the site. A detailed discussion of the associated errors is not appropriate without an extensive discussion of the method, which is not possible in this paper. British Standards (No 3680 Part 3G), give general guidelines on the selection of methods of discharge measurement, state that the minimum percentage error in the measurement of discharge by the Ultrasonic method is 5%.

Velocity Area Method

Errors associated with the Velocity Area method have been studied extensively, and are well known to engineers and researchers who use this form of discharge measurement (International Standards organization No 748, and Technical Paper No 7178). When more than ten verticals are used, and the partial discharges are almost equal, the error in the measured discharge is given by the following equation:

$$X_Q = \pm[X_m^2 + \frac{1}{m}(X_b^2 + X_d^2 + X_e^2 + X_p^2 + X_c^2)]^{½} \qquad (5)$$

Where

X_Q is the error in the measured discharge at the 95% confidence level

X_m is the error at the 95% confidence level resulting from the number of verticals taken

X_b is the error in the width measurement at the 95% confidence level

X_d is the error in the depth measurement at the 95% confidence level

X_e is the error in the measured velocity arising from the time of exposure of the current meter at the 95% confidence level

X_p is the error arising from the number of points taken on each vertical at the 95% confidence level

X_c is the error arising from the calibration of the current meter at the 95% confidence level

As the number of verticals used is increased the error resulting from the number of verticals used Xm becomes important, see equation 5. Herschy, (1978), in an analysis of 193 measurements made by the United States Geological Survey concluded that Xm decreases to 3% at 30 verticals and thereafter remains constant. However a problem with this analysis, when applied to discharge measurement in irrigation canals, is the very wide range of different velocity profiles in the data set on which the analysis was based. Velocity profiles in rivers are effected by bends and irregular cross sections to a much larger extent than is the case in typical canals, where cross sections are regular, and measurement sites can be chosen that are not influenced by bends. Use of data containing widely differing velocity profiles from natural rivers resulted in values of Xm for the number of verticals used that were larger than is the case in lined canals. This will be discussed further later.

For further information on the determination of errors in flow measurement reference should be made to ISO 5168.

Dilution Gauging

Discussion of the errors involved in discharge measurement by Dilution Gauging are confined to the Constant Injection Rate Method. The discharge equation is very simple and is as follows:

$$Q = qN \tag{6}$$

Where

Q is the discharge to be measured (m^3/s)

q is the rate of injection of the tracer (m^3/s)

N is the ratio of the concentration of the injected tracer to the concentration of the downstream sample.

Similarly the equation for the error in the computed discharge is:

$$X_Q = (X_q^2 + X_N^2) \tag{7}$$

Where

X_Q is the error in the measured discharge at the 95% confidence level

X_q is the error in the injection rate at the 95% confidence level

X_N is the error in the ratio of the concentration of the injected tracer to the concentration of the downstream sample at the 95% confidence level

Further information can be found in British Standards 3680 Part 3E.

Errors in Seepage Measurement

The seepage loss using the Inflow-Outflow method has been given by Weller (1981) as follows:

$$P_s = \frac{Q_1 - Q_2 - Q_A + Q_I}{W_p\, L} \tag{8}$$

Where

Q_1 is the input discharge to the test reach (m^3/s)

Q_2 is the output discharge from the test reach (m^3/s)

Q_A is the discharge abstracted from the test reach along its length (m^3/s)

Q_I is the discharge into the test reach along its length (m^3/s)

No terms allowing for rainfall or evaporation are included in equation 8 since these are usually insignificant. Moreover no correction for change in storage is given for simplicity. (Corrections for rainfall, evaporation and change in storage are given in Weller (1981).

By applying the principle of superposition of errors (ISO 5168) Weller (1981) has shown that the error in a seepage measurement is:

$$X_{Ps} = \pm \sqrt{\frac{X_{Q1}^2 + (\frac{Q_2}{Q_1})^2 X_{Q2}^2}{(1 - \frac{Q_1}{Q_2})^2}} \qquad (9)$$

Where

X_{Q1} is the inflow discharge error at the 95% confidence level

X_{Q2} is the outflow discharge error at the 95% confidence level

Determining the error in seepage is a two step process. The errors from the particular method of discharge measurement used must be computed from one of the equations given earlier, and then substituted into equation 9 which will give the final error. It should be borne in mind however that if Q_1 and Q_2 are both large, and the difference between them small, the denominator of equation 9 will approach zero, and the error in the measurement of seepage X_{Ps} will be very large.

Chidengar (1990) showed that even with careful measurements in a laboratory flume reliable seepage estimates could not be made if the seepage is less than 5% of Q_1. In consequence, where possible, the reach length should be computed from the following equation:

$$W_p \, LP_s \geq 0.05Q_1 \qquad (10)$$

If this is not practicable then a large number of determinations will be necessary to arrive at a reliable estimate of seepage. In this case the relationship between the true mean seepage Ps, and the mean seepage given after n determinations, is given by the following inequality:

$$P_s\left(1 - \frac{1.96X_{Ps}}{100\sqrt{n}}\right) \leq P_s \leq P_s\left(1 + \frac{1.96X_{Ps}}{100\sqrt{n}}\right) \qquad (11)$$

INDIAN CANAL DATA

Seepage measurements on three large canals in the Indian Punjab were carried out by the Irrigation and Power Research Institute, (IPRI), Amritsar, India, between

1983 and 1986. The velocity area method was used to compute seepage rates using the inflow outflow method. This data was supplied to HR Wallingford as part of a collaborative research study being carried out by the two institutions, and has been re-analyzed by the authors.

Ferozepur Feeder

The Ferozepur Feeder is a large canal in the Eastern Punjab, and has an essentially trapezoidal cross sections with radii at the corners equal to the full supply depth. It is partially lined with tiles over a cement and plaster layer. The tiles only play a structural role to prevent cracking of the cement and plaster layer beneath, which forms the impervious barrier.

Inflow-outflow surveys were carried out by the Irrigation and Power Research Institute between July 1981 and July 1983 over a test reach of 9.14 km, IPRI 1984. In total 113 pairs of measurements were made. Semi-permanent gauging sites were established and the Velocity Area Method was used with 40 verticals and six velocity measurements on each vertical. An array of six current meters were used on a streamlined aluminum section mast to reduce the measurement time. Sounding rods were used for depth measurement.

Each current meter used was individually calibrated, and the measurement teams were swapped over periodically to remove any bias that have been present due to minor variations in current meter calibrations, or the measurement technique adopted. A time lag was allowed between the upstream and downstream surveys to compensate for flow variations. With the measurement procedures used, and computation of discharge by the Mean Section Method it was anticipated that the accuracy of each discharge measurement would approach 1%.

The frequency distribution of the seepage estimates derived from the full data set is shown in Figure 1. This indicates that the range of values for both the Mid and the Mean Section Methods tend towards a normal distribution. The similarity to a normal distribution is a clear indication that the dominant errors are random, as assumed in the error analysis. The mean seepage rate obtained by averaging all measurements derived from the Mean Section Method was 0.226 m/day, ± an error of 21%, (individual measurement was ± 109%). Using the Mid Section Method, the mean seepage obtained was 0.233 m/day ± an error of 21%, (individual measurement ± 108%). As fewer verticals are used the computed seepage rate becomes less, and the errors greatly increase. This can be seen from Figure 2 which shows that with less than 20 verticals the Mean Section Method gives a negative estimate of seepage. The Mid Section Method on the other hand gives positive estimates of seepage down to 10 verticals, but with large variations in the estimate of seepage, and large errors.

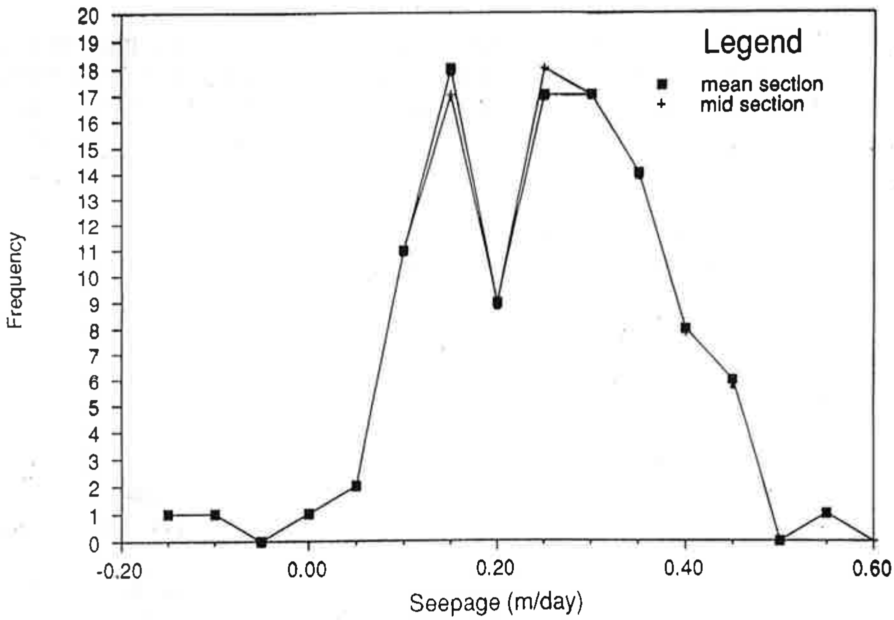

Figure 1. **Frequency Distribution of Seepage Using All Varieties Ferozepur Feeder.**

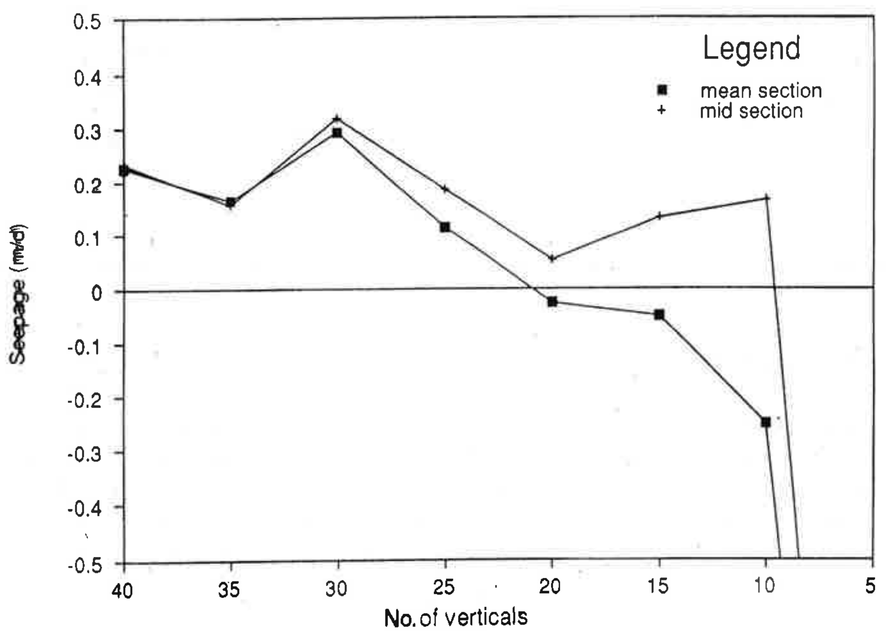

Figure 2. **Variation of Mean Seepage with No. of Verticals - Ferozepur Feeder.**

This extreme sensitivity to the number of verticals used can be attributed to two factors: too short a reach resulting in the seepage rate being as low as 0.7% of the upstream discharge; too short an averaging time for the individual current meter readings, resulting in random variations in the computed discharge with the number of verticals used. The latter is indicated in Figure 3, which shows the variations in the unit discharge across the channel for the upstream and downstream sites, and strongly reinforces the importance of determining the appropriate averaging time for the velocity measurements from a pre-measurement survey.

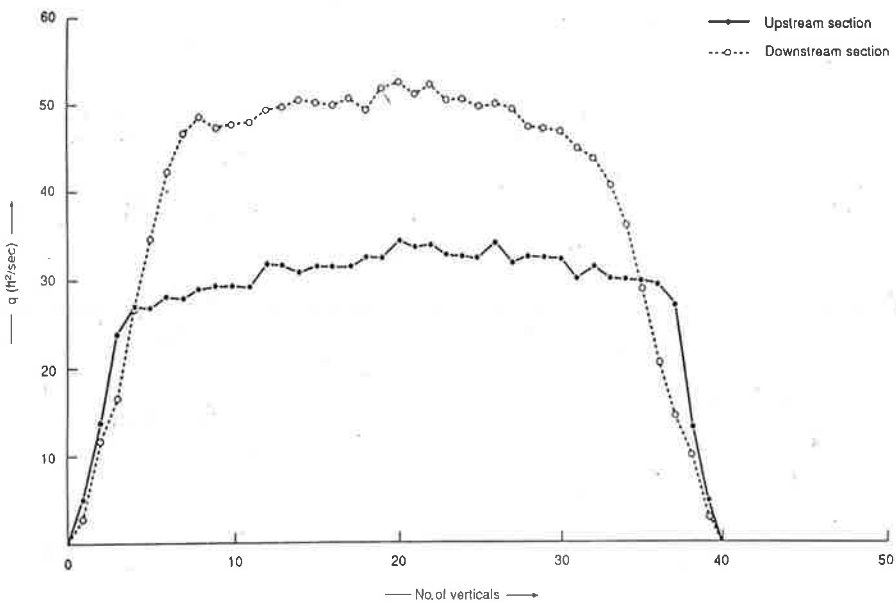

Figure 3. Specific Discharge Profile Across Canal - Ferozepur Feeder.

Bhakra Main Line

The Bhakra Main Line canal is lined channel consisting of a double layer of brick tiles separated by 9.5 mm of cement mortar. and 15.8 mm layer of cement plaster mortar. The canal has a full supply discharge of 353 cubic metres per second, and was commissioned in 1954. As in the case of the Ferozepur canal the cross section of the Bhakra canal is trapezoidal with corner radii equal to the full supply depth.

Data was collected between November 1985 and July 1986, and 126 pairs of discharge measurements are available, IPRI 1986. The reach length was 15.24

km, and the measurement procedure used was the same as for Ferozepur, except that only 28 verticals were used.

The frequency distribution of seepage estimates derived from the full data set is shown in Figure 4. The data again indicates that seepage estimates are normally distributed.

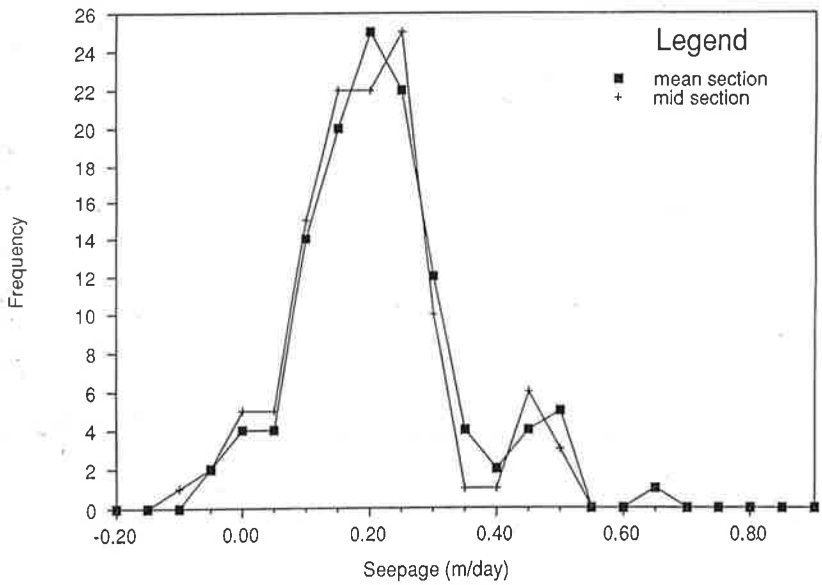

Figure 4. Frequency Distribution of Seepage Using all Varieties - Bhakra Main Line.

The mean value of seepage obtained by averaging all the results computed by the Mean Section Method was found to be 0.196 m/day with an error of ± 22%, (individual measurement ± 124%). This is somewhat larger than for Ferozepur, as fewer verticals were used. The corresponding mean seepage rate derived by averaging all the results computed by the Mid Section Method was 0.181 m/day ± 24%, (individual measurement ± 135%). The variation of the mean seepage with the number of verticals used for both the Mean and Mid Section Methods is given in Figure 5, which shows a surprising divergence as the number of verticals used is reduced. This example illustrates that when measurements are made over a short reaches, resulting in the seepage loss being less than 1% of the upstream discharge, the method of discharge computation has very unpredictable effect on the derived rate of seepage unless a large number of verticals are used.

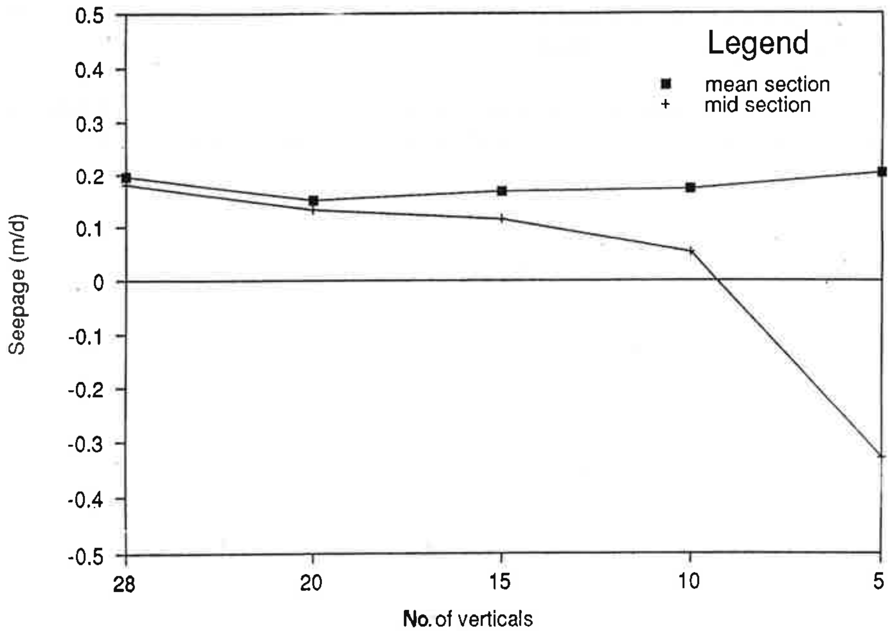

Figure 5. Variation of Mean Seepage with No. of Verticals - Bhakra Main Line.

Rajasthan Feeder

The Rajasthan Feeder was commissioned in 1959, and has a design discharge of 524 cubic metres per second. It is lined with a single layer of tiles on the bed, and a double layer of tiles at the sides. The cross section is trapezoidal with radii at the corners equal to the full supply depth. When first constructed tests on the Rajasthan Feeder showed that the lining was effective, and seepage rates were very low, Deacon (1984).

Data was collected using the same procedures as described earlier with 40 current metering verticals, however in this case the length of the test reach was increased to 28.45 km. IPRI carried out 111 pairs of inflow-outflow measurements of seepage over the period August 1984 to April 1985.

The frequency distribution of all the seepage measurements obtained by both the Mean and Mid Section Methods is given in Figure 6. The distribution has a definite skew, probably due to unrecorded abstractions.

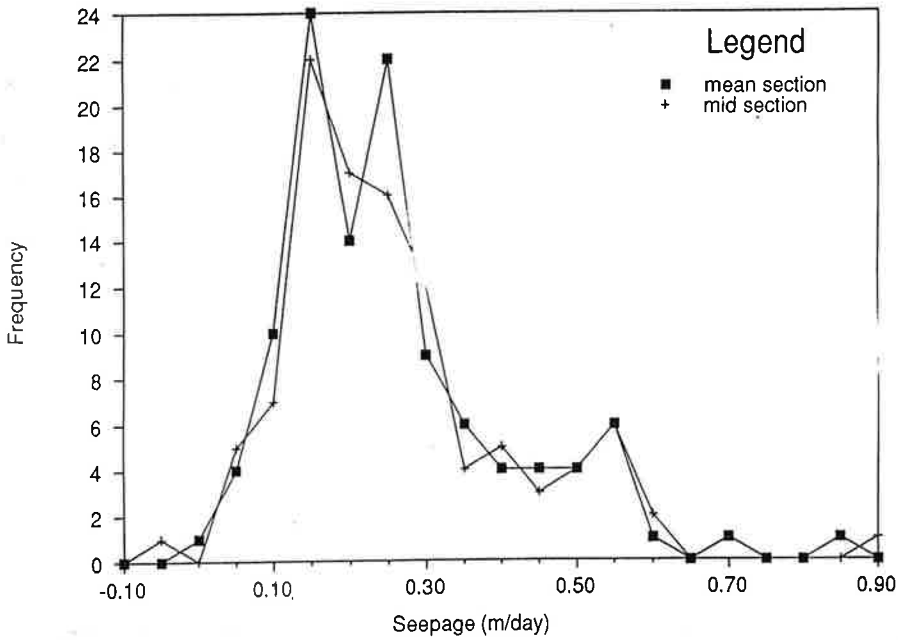

Figure 6. Frequency Distribution of Seepage Using all Verticals - Rajasthan Feeder.

Mean seepage rates estimated from 5, 10, 15, 20, 25, 30, 35, and all verticals for both the Mean and Mid Section Methods are shown in Figure 7. For the Mean Section Method the mean seepage rate remains with ± 4.2% of 0.238 m/day for 15 verticals and above. Moreover, the error for both 40 and 15 verticals is the same, namely ± 23%, and the errors for individual measurements are 126% and 124% respectively. The corresponding values of mean seepage using the Mid Section Method were 0.237 m/day and 0.259 m/day for all verticals and 15 verticals with errors of 25% and 26%. This represents a significant improvement over the results obtained from the Ferozepur and Bhakra surveys, and is undoubtedly due to the use of a longer test reach. The seepage loss in this case is 4.6% of the upstream discharge. A secondary contributing factors are the significantly smoother unit discharge profiles for the upstream and downstream sites, Figure 8.

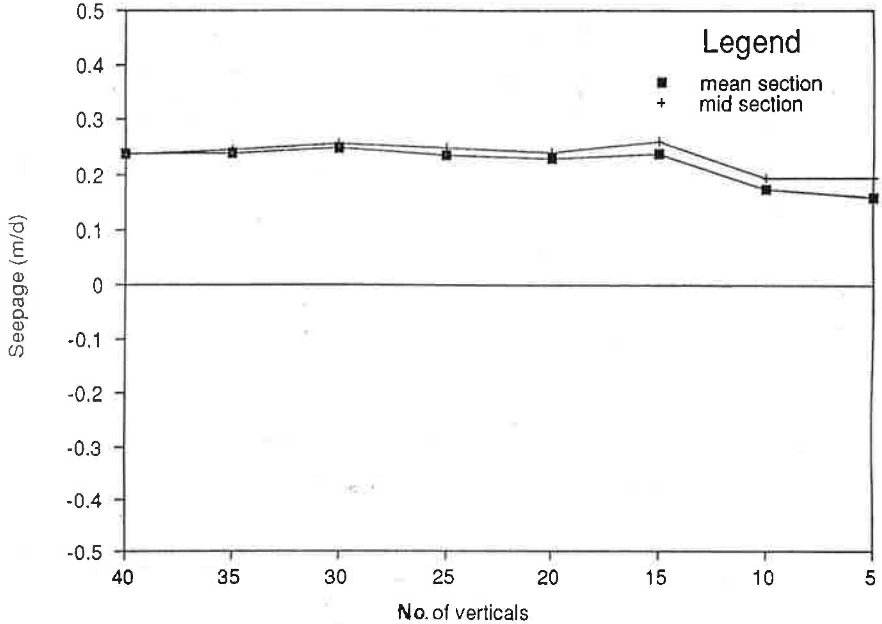

Figure 7. Variation of Mean Seepage with No. of Verticals - Rajasthan Feeder.

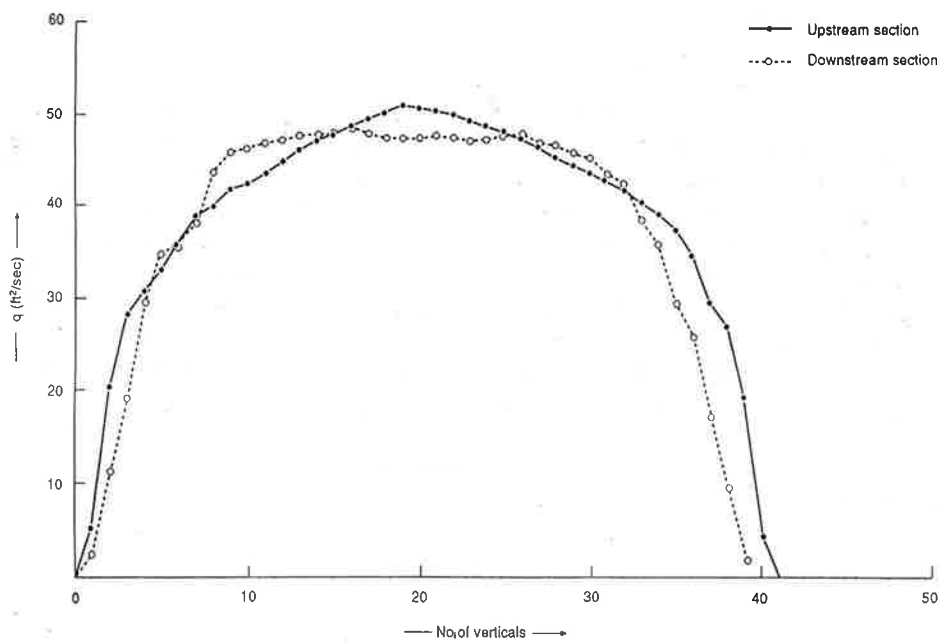

Figure 8. Specific Discharge Profile Across Canal - Rajastan Feeder.

COMPARISON OF ERROR ESTIMATES

In order to compare the results of the surveys with the results expected from the analysis given by Herschy (1978) and ISO 748, the discharges computed using different numbers of verticals were divided by the discharge computed using all the verticals, to establish the relative discharges. (The same procedure was followed by Herschy). The error associated with the number of verticals used can then be calculated if it is assumed that the discharge computed using all the verticals is the true discharge. The results are shown in Table 1, where Xm, (see section Errors in Discharge Measurement), is the error associated with the number of verticals used.

The data presented in Table 1 clearly show that the error Xm obtained from the surveys of lined canals in the Punjab are significantly less than values given by either Herschy or ISO 748. Herschy took the true discharge as that computed from more than 50 verticals in each case as compared with 40 verticals with the analysis presented here. Nevertheless the error difference between 10 and 40 verticals ranges between only 0.6 and 1.8%, and it is very unlikely on that basis that the error will exceed 1% or 2 % of the true value when 40 verticals are measured in lined irrigation canals.

Table 1. **Comparison of Values of Xm.**

Data Source	Number of Verticals								
	5	10	15	20	25	28	30	35	40
Bhakra	1.36	0.6	0.5	0.32	-	0	-	-	-
Ferozepur	1.13	1.13	0.85	0.52	0.53	-	0.34	0.33	0
Rajasthan	2.03	1.82	1.67	1.30	1.17	-	1.22	1.38	0
Herschy	20	10	7	5	5	-	3	3	3
ISO 748	15	9	6	5	4	-	3	2	2

The recommendation in ISO 7178 that Xm should be determined for each channel is particularly relevant when estimating seepage by inflow-outflow.

DISCHARGE COMPUTATION METHODS

When a comparison between the Mid Section and Mean Section Methods is made (Figures 9, 10 and 11), the analysis indicates that discharges computed by the Mid Section method converges to the true value quicker than the Mean Section method. No Improvement in the value of seepage is obtained however, because of the random way the errors arising from the computational procedure are propagated.

Finally Figure 12 compares the variation in relative discharge with number of verticals derived from the Rajasthan feeder, with Herschy's upper and lower bound curves. This figure again demonstrates the much smaller errors that can be expected from careful canal measurements that would be expected from Herschy's analysis.

CONCLUSIONS

The main conclusions drawn from the paper are summarised below:

- Ponding tests provide the simplest and usually most accurate means of assessing seepage rates in small canals provided the guidelines described in the paper are followed. However Ponding tests have a number of disadvantages, including the need to interrupt flows while tests are carried out, and some uncertainty that the seepage rates obtained are the same as those that apply when the canal is flowing.

- Inflow-outflow methods can provide continuous estimates of seepage in running canals. Discharges into and out of canal reaches can be measured using flow measurement structures, carefully calibrated flow control structures, or possibly by ultrasonic gauging. The paper outlines procedures that can be followed to assess the error in seepage estimates.

- The application of hydrodynamic models to canal networks to estimate seepage is a promising development.

- The inflow-outflow method based on velocity area methods to determine discharge can provide seepage rates that are more accurate than conventional error analysis based would suggest. The following recommendations are made:

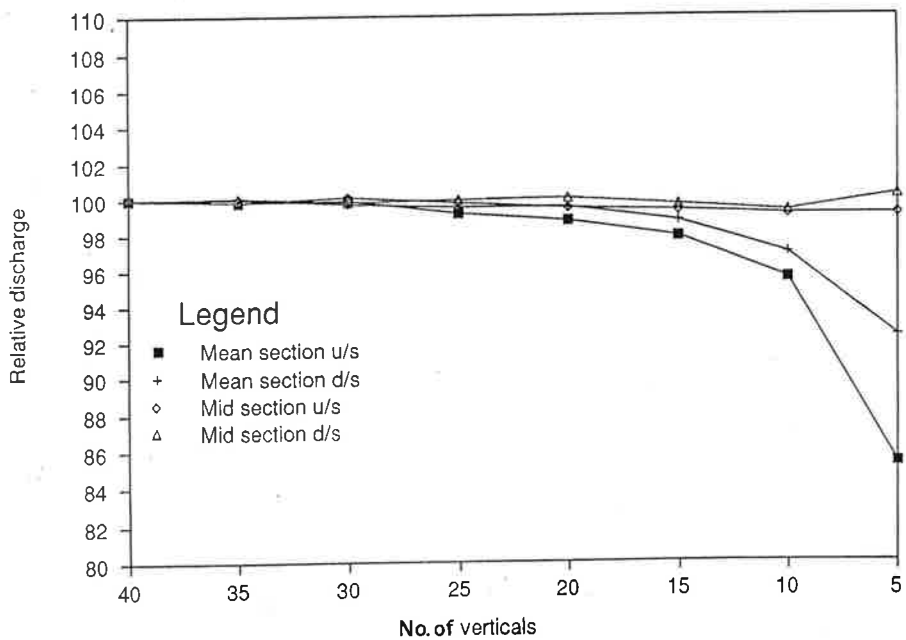

Figure 9. Comparison of mean and mid section methods of calculation - Ferozepur.

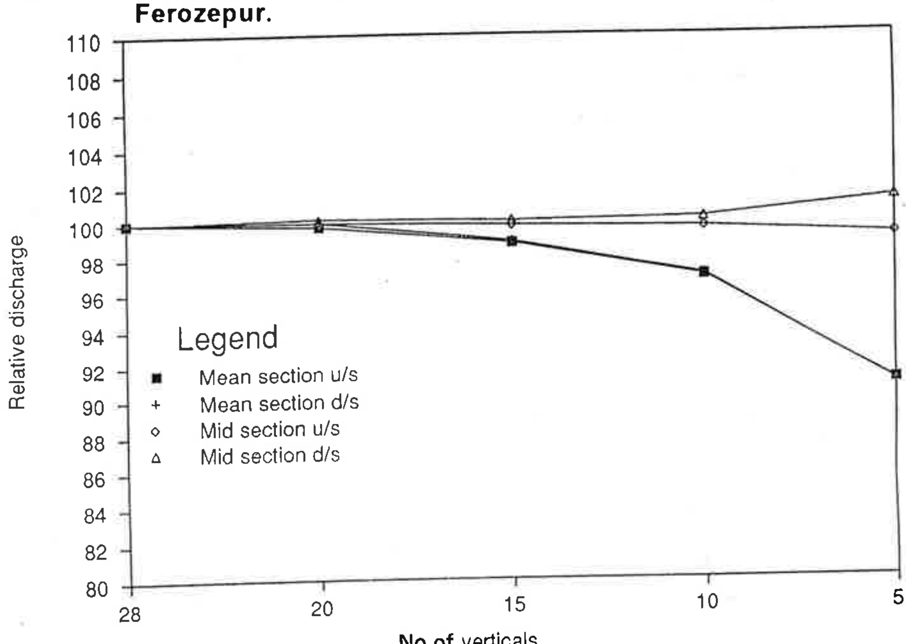

Figure 10. Comparison of mean and mid section methods of calculation - Bhakra.

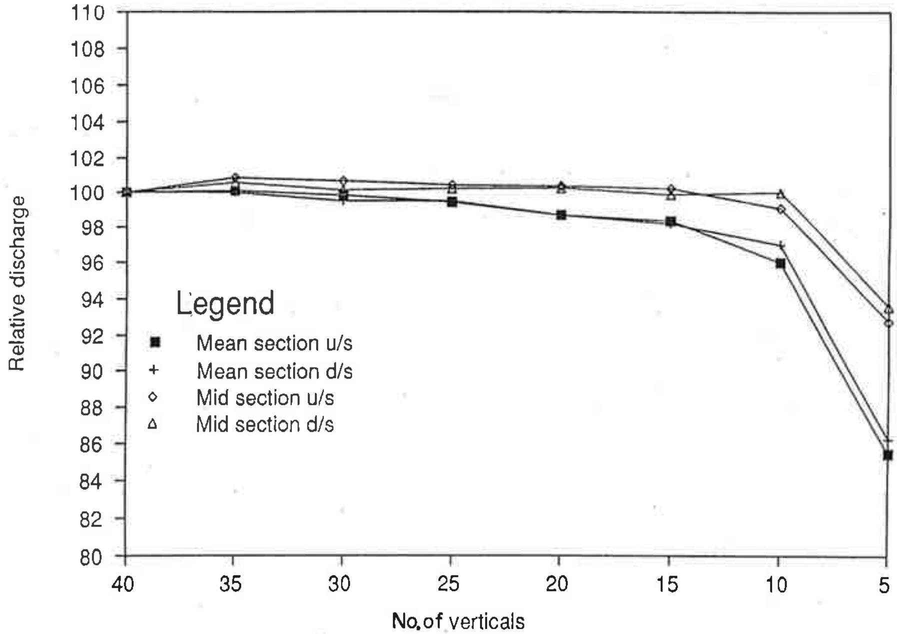

Figure 11. Comparison of mean and mid section methods of calculation - Rajasthan.

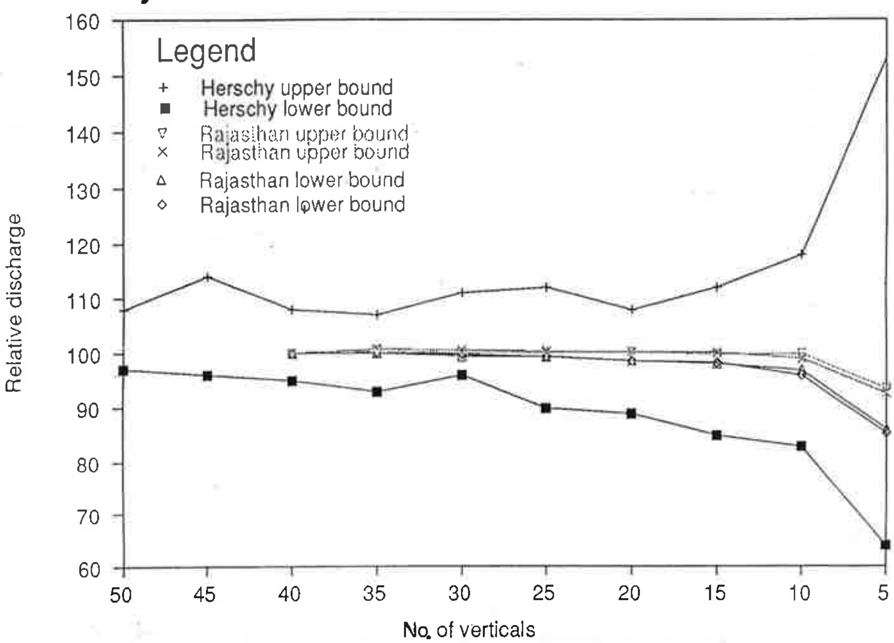

Figure 12. Comparison of Rajasthan data with Herschy's data.

* Before beginning an Inflow-Outflow measurement of seepage by Velocity Area method a detailed preliminary survey of the upstream and downstream sites should be carried out to ensure that uniform velocity distributions exist at both locations. Extended velocity surveys, with increasing averaging times, should be carried out at 20%, 60%, 80%, and 90% of the depth, on three of the deepest verticals to determine the averaging time necessary to obtain true mean velocities, as recommended in ISO 7178.

* Where possible, the length of the reach for the Inflow-Outflow determination of seepage should be long enough to ensure that the seepage loss in the reach is greater than 5% of the upstream discharge. Equation 10 should be used to determine the appropriate reach length providing that an initial estimate of the seepage loss can be made.

* Reach lengths so short that the seepage loss is less than 1% of the upstream discharge, such as were used in the Ferozepur and Bhakra surveys, should be avoided if possible because random errors become so large that very many determinations are necessary to achieve a mean seepage rate with an acceptable accuracy, and a large number of verticals must be used.

- In circumstances where short reaches must be employed for Inflow Outflow measurements of seepage with the velocity Area Method, the results from Indian canals show that not less than 40 verticals should be used.

- The results of the Rajasthan survey show that when the seepage loss is a significant proportion of the upstream discharge (4.6% in the case of Rajasthan), fewer than 40 verticals need to be used in the determination of seepage by Inflow-outflow with the Velocity Area Method. The mean seepage obtained using the Mean Section Method remained constant within 4.2% for 15 verticals and above. Moreover the accuracy of the mean seepage computed from 15 verticals was the same as for 40 verticals. This shows that the errors in discharge measurement are no longer dominant, and that the errors in the mean seepage stem from some other source, probably unsteady effects and or unidentified abstractions. If possible this result should be confirmed with more tests.

As the number of verticals used in the Velocity Area Method of discharge measurement increases, the error Xm resulting from the number of verticals taken becomes the dominant component in the total measurement error. However results from Indian canals show that error analysis based on results from river data give gross overestimates of the likely error in discharge, and thus an overestimate of errors in seepage estimates.

A comparison of the Mid Section and Mean Section Methods of discharge computation from Indian canals indicate that for a single discharge determination, the Mid Section method converges more quickly to the true discharge as the number of verticals increase than the mean section Method. This does not result in an improvement in accuracy when employed for seepage estimates because of the random way errors in the numerical computation are propagated.

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SEEPAGE LOSS MEASUREMENTS ON CHASHMA RIGHT BANK CANAL

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ABSTRACT

Chashma Right Bank Canal had severe seepage problems in its Stage I, particularly in the unlined reach. A number of remedial measures were taken, and the problem is under control now. The canal was regularly monitored by the Alluvial Channels Observation Project for seepage loss. Analysis of the data collected during 1990-92 shows that the 95% confidence interval for average seepage loss rate in the project area for earthen reaches of the canal is 4.381 ± 0.344 cfs/msf, and that for the lined reaches is 2.971 ± 0.306 cfs/msf of wetted area. For the sake of comparison, it may be recalled that the loss rates adopted in the design were 8 cfs/msf and 2 cfs/msf for unlined and lined parts of the canal respectively. Using the seepage rates found in this investigation, the expected total seepage loss from the project may be revised downward, from 385 to 327 cfs. The seepage loss rate determinations have been examined critically for errors, and it has been concluded that they fulfil desired standards of accuracy. The observations show that the difference between average seepage from brick lined and plane-cement-concrete lined parts of the canal is practically insignificant. The measurements also show that there is little correlation between seepage loss rate and inflowing discharge in the canal.

INTRODUCTION

The Chashma Right Bank Canal (CRBC) is an interprovincial canal, which has been designed to irrigate 570,000 acres of land in the North West Frontier Province and Punjab Province of Pakistan. The CRBC offtakes from the right side of Chashma Barrage on Indus River with a design discharge of 4879 cfs at the head. Stage I of CRBC Project (RD 0+000 to RD 260+000) was commissioned in 1978, and stanching activities for various canal segments of Stage II (RD 260+00 to RD 380+000) are underway since 1990. Stage III of the Project (RD 380+00 to RD 846+000) has yet to be implemented. Except for the first 24 miles and the last 26 miles segments, the Chashma Right Bank Canal has been designed to be a lined canal. Excluding a short brick lined segment in Stage I, the rest of lined part of the canal has to be provided with plain-cement-concrete (PCC) lining.

Stage I of Project, especially the first 24 miles unlined segment of the canal was beset by severe seepage problems. On the request of the project authorities, the

Alluvial Channels Observation Project has been monitoring the canal from its inception. Of particular interest has been the measurement of seepage losses in the lined and unlined parts of the canal in Stage I. The objective of this paper is to present the results of these measurements, discuss their accuracy and apply them to prepare a revised estimate of absorption losses to be expected in this project.

SEEPAGE PROBLEMS OF THE CANAL

The lined reach of CRBC in Stage I did not pose any significant problems. However the unlined reach, which was stanched before the lined reach, was fraught with acute seepage problems, baffling the project authorities for quite some time.

The canal alignment in the unlined reach of Stage I runs in the flood plain of Indus River made up of fine sand with silt and clay cover of varying thickness. The natural ground level is 5 to 10 feet below the design bed of the canal in this reach, as shown in Figure 1. Here, the canal section was formed by constructing two parallel embankments, without providing any filling in the bed. The ultimate bed level is to be attained by inducing sedimentation in the canal. The design is based on Lacey's Regime Theory with side slope of 1.5:1. The compaction of embankment has been restricted to the prism in contact with water while the outer part was left un-compacted. A typical unlined canal section is shown in Figure 2.

Soon after water was admitted into this reach in January 1987, the seepage water appeared in the borrow pits on both sides of the canal, and began rising with the passage of time. The condition worsened to the point that continuous stretches of ponded water could be seen on both sides of the canal right from RD 10+000 to the Combined Structure at RD 97+500. The seepage water entered the cropland, destroyed houses and aroused public fury requiring the Prime Minister to personally visit the affected area and quell the unrest.

Seepage occurred through banks and toe of embankments. Wet spots and dampness was seen at many places on the bank slopes and on pushatas, and the bearing capacity of banks became too low to support a standing person. Boiling action was noticed at a number of places. Cracks running parallel to the length of embankment, and ending towards either inside or outside were noticed on the top of banks, which posed the danger of breaching by bank slippage.

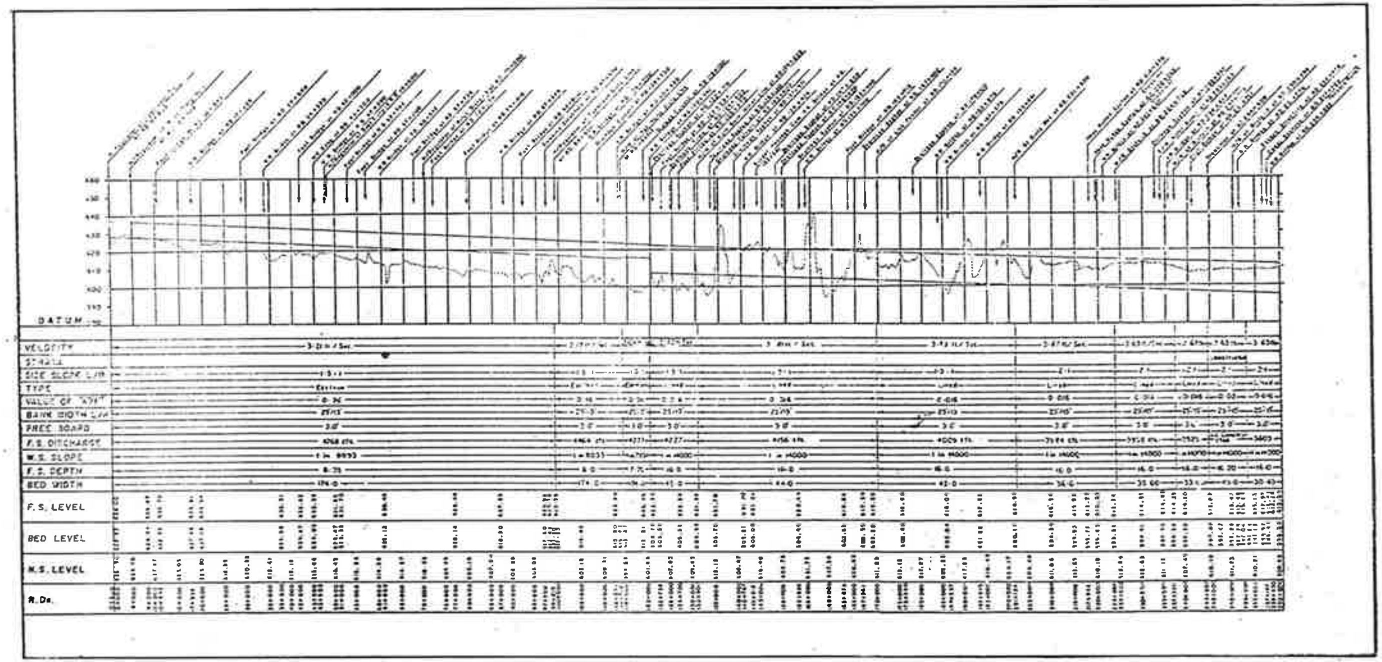
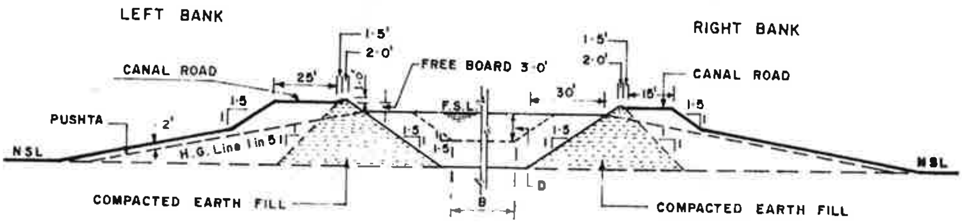
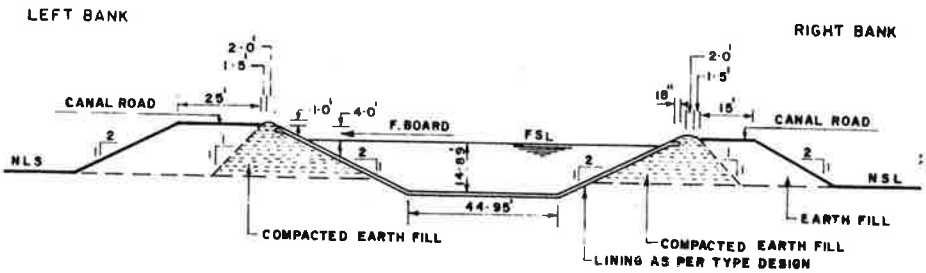


Figure 1. Longitudinal Section of C.R.B.C Canal (Stage I).



(a) Typical Section (Earthen)
(From RD 0+000 to RD 120+000)



(b) Section (Lined)
(From RD 210+000 to RD 260+000)

Figure 2. Typical cross sections of Chashma Right Bank Canal.

REMEDIAL MEASURES

Remedial measures taken by the project authorities to overcome these problems consisted of:

(i) Placement of pit-run gravel on the outer-side of both banks to stabilize them against the seepage water oozing out of banks.

(ii) Pumping out of water at places where the seepage rate was excessive, to avoid damage to property and crops.

(iii) Lowering of water level in the canal to reduce the head across and seepage.- A temporary bund, constructed initially at RD 119+000 to raise water level and feed the offtaking channels, had to be lowered, and offtaking structures modified to enable the diversion of water with parent channel running at less than full supply level.

(iv) Churning of silt into the canal.- It was realized that initial operation of canal started at a time when the water was short of sediment required to seal the voids and reduce the seepage. To augment sediment contents of canal water, sediments from the bed and banks of exiting Paharpur Feeder was re-entrained into the canal by compressed air and by manual means.

(v) Placing fine clayey material on the inner slopes of canal banks.- This remedial measure was particularly adopted in the canal segments where pit-run gravel was used in the construction of embankments.

(vi) Killa-bushing for berm formation.- Naturally formed berms are considered essential to minimize seepage. Construction of killa-bushing spurs and killa bushing along canal banks has been carried out to induce sedimentation of fine material for bank formation.

(vii) Tree plantation to strengthen banks and berms.

(viii) Construction of cross stone walls in the head reach.- In the head reach, a number of stone walls, about 3.5 feet high, were constructed across the channel prism, at intervals of 500 feet up to RD 20+000. Primarily meant for checking the bed erosion and induce siltation, these walls have also facilitated berm formation and seepage reduction.

The foregoing measures have by and large controlled the seepage problems of Chashma Right Bank Canal. At high discharge close to design, seepage water occasionally appears in the borrow pits but this has not been found to be detrimental to the safety of canal.

SEEPAGE LOSS MEASUREMENTS PROCEDURE

In addition to the remedial measures described above, a constant watch has been kept on the seepage losses occurring from the Chashma Right Bank Canal by the project authorities. For this purpose ACOP was engaged, inter alia, to conduct periodic observations of seepage losses since the commissioning of the canal in 1987. The measurements made during 1990-1992 are of particular interest since both lined and unlined segments of Stage I were simultaneously covered in these three years. The data collected provides an opportunity to compare the seepage losses occurring from lined and unlined canal segments operating in nearly similar hydro-geological and climatological conditions.

Seepage loss can be computed with the help of this data using inflow-outflow method by using the discharge measurements made on the main canal and offtakes.

Study Reaches for Seepage Evaluation

As shown in Figure 3, the canal has been divided into 5 study reaches, 3 in the unlined part and 2 in the lined part, for the purpose of seepage loss evaluation.

Reach I, II, and III cover the unlined part of the canal. Reach I, from RD 5+000 to 51+175, is approximately 9.235 miles long without any offtaking channels or outlets. Reach II, from RD 51+175 to 98+000, is also 9.365 miles long without any offtaking channels except for an Escape Channel which is controlled from the Combined Structure at RD 97+500. The Escape Channel, however, was operational only in 4 out of 23 measurements made on this test reach. Reach III, from RD 98+000 to RD 120+900, is 4.580 miles long with two distributaries and three minors. On the average, the total discharge of all offtakes was less than 12 percent of inflowing discharge at the head of the reach. It may by mentioned that Reach III includes an insignificant length of lined canal also. However, for all practical purposes, this does not make any difference in the seepage computation since the wetted area contributed by lined part is less than 2 percent. Reach IV and V cover the lined part of the canal. Reach IV, from RD 120+900 to RD 189+200, is 13.66 miles long with three offtaking channels. However, the total discharge of all offtakes on the average was less than 10 percent of discharge at head of the reach. Reach V, from RD 189+200 to RD 256+000, is over 13.36 miles long.

This reach has three distributaries and a number of outlets which must be measured to find the seepage loss. The total discharge of all offtake remains below 19 percent of the discharge at the head of the reach, on the average. It may be mentioned that the major part of Reach IV, i.e. from RD 135+000 to RD 189+200, has brick lining while the major part of Reach V, i.e. from RD 211+000 to RD 256+000, has been provided with PCC lining.

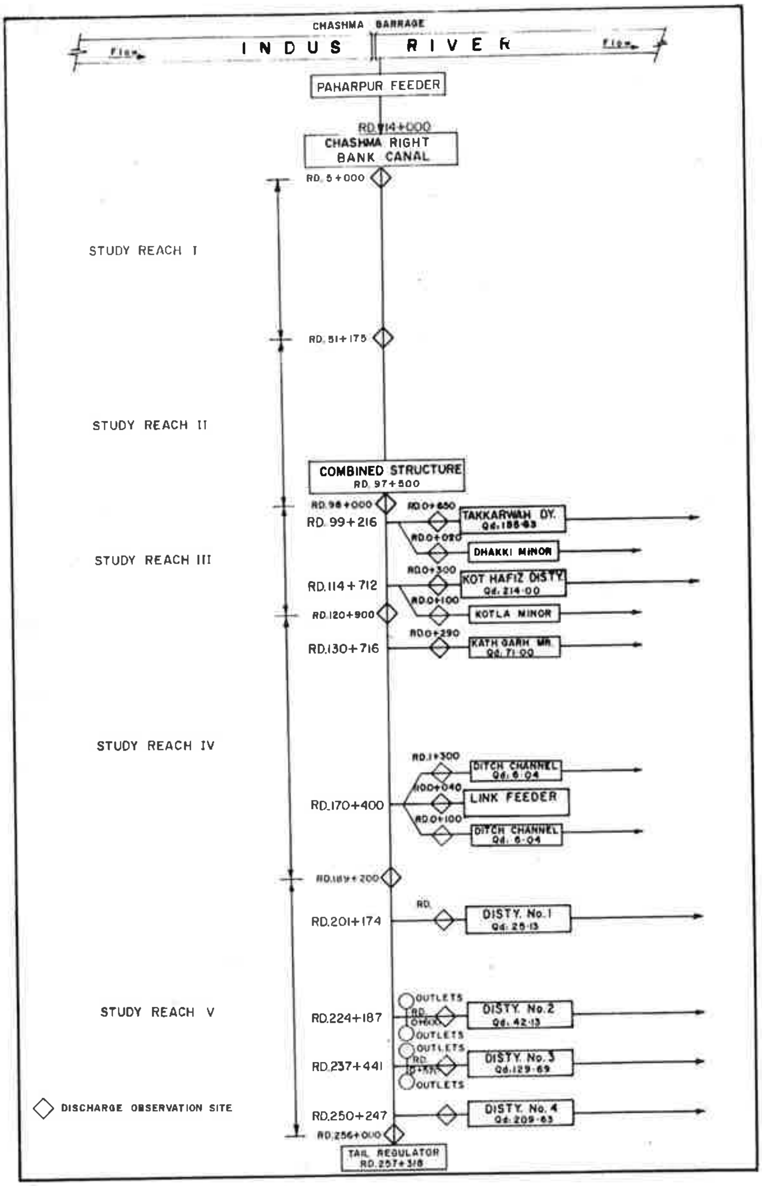


Figure 3. Flow diagram.

Measurement of Discharges

Discharge measurements at the upstream and downstream section of each study reach were made by means of boat method. Care was taken to use the same current meter (Price Meter) for all measurements, except for offtakes and outlets where other meters were used. With the exception of small outlets, the number of verticals for discharge measurement was generally equal to or greater than 20 in each section. Also with the exception of pygmy current meter measurement, the two point method (0.2 D and 0.8 D) was used to find the average velocity in each vertical. Discharge was computed using the Mid Section Method, which has smaller procedural error than Mean Section Method. Gage readings were noted in the beginning and at the end of all measurements; the measurements used for seepage evaluation did not show any variation in the water level. It may also be mentioned that, in many of these observations, the time difference between discharge measurements at the upstream and downstream section was by and large equal to the travel time of water in the study reach.

Measurement of Wetted Area

In order to express the seepage loss in the popular units of cfs/msf (cubic feet per second per million square feet of wetted area), the wetted area of the study reach at the time of measurement must be found out. This can be computed using the coordinates of appropriately spaced cross sections, and water surface levels observed in the study reach at the time of measurement.

Except for end sections of study reach where wetted perimeter was computed using depth soundings made at the time of measurement, the wetted perimeters at other sections of the study reach were found using morphological surveys of the canal carried out in June 1990, June 1991 and February 1992. Thus three sets of coordinates of cross sections at intervals of 5000 feet are available to define wetted areas for each study reach. Wetted area for a given observation was computed as the weighted sum of the two sets of computations for wetted areas using available surveys made before and after the measurement; the survey nearest in time to a given observation was given greater weight. However, for all of the observations made in 1992, the survey of February 1992 was used for computing wetted area.

Water surface levels were read at a number of points at different structures (e.g. bridges) in each study reach at the time of a seepage observation. These levels have been used to interpolate the water surface level for intermediate cross sections and define their wetted perimeter. The average wetted perimeter of two adjoining sections multiplied by the distance between them, provides the partial wetted area. The summation of partial wetted areas for all sets of adjoining sections in the study reach gives the total wetted area required to compute the seepage rate in conventional units.

It may be mentioned that while the water surface levels were measured at a number of structures in the unlined study reaches in the majority of observations, they were measured at only end sections of lined study reaches in most cases. In the latter case, straight line interpolation between water levels of the end section was done to find the water levels at intermediate sections and compute the wetted area. This is justified on the grounds that the lined study reaches do not have any drop structures and bed is generally clear of sediment deposition; therefore the water surface is expected to be reasonably straight for interpolation. A sensitivity analysis also showed that the straight line interpolation introduced only a marginal error in the computation of wetted area.

ACCURACY OF INFLOW-OUTFLOW METHOD

Most of the criticism levelled against inflow-outflow method stems from the errors in discharge measurement. Even though care is taken in making the measurements, the differences in flow may sometimes indicate a gain if the seepage loss is small. Therefore special efforts must be made to minimize errors from different sources, if this method is to be used for seepage loss determination.

Errors in Discharge Measurements

Errors in discharge measurement may be grouped as random, systematic, spurious, and procedural.

Random errors are indicated whenever the deviation of observations from the mean is in accordance with the law of chance such that their distribution approaches a normal distribution. Random errors can be minimized by repeating the measurements.

Systematic errors may be introduced in discharge measurements from a number of sources; e.g. sag in the tag-line in a boat measurement, existence of oblique currents, non-verticality of sounding line, changes in the physical characteristics of current meters etc. These errors cannot be reduced by increasing the number of observations. The sources of systematic errors must be identified, and proper correction applied to remove such errors.

Spurious errors are due to human error or instrument malfunction and cannot be statistically analyzed. The observations with such errors must be discarded.

Procedural errors are introduced in the measurement process, when a continuous variable is discretized and an integral is replaced by summation, or a function other than true function is used. Example of procedural errors in discharge measurement are: estimation of area of cross section from discrete measurements of depth at a number of verticals, estimation of average velocity in a vertical by two point method, evaluation of discharge from discrete observations.

If the true value of discharge Q is estimated from a discrete measurement process as $\hat{Q}$, the relative procedural error ϵ_{pQ} may be defined as

$$\varepsilon_{pQ} = \frac{Q - \hat{Q}}{Q} \tag{1}$$

The relative procedural error in discharge measurement has been expressed by Masood (1976) as

$$| \varepsilon_{pQ} | = \frac{K_1 C_V}{N^{\beta}} \tag{2}$$

Where:

K_1 and ß are coefficients evaluated respectively as 13.0 and 1.63 from ACOP data.

N is the number of verticals used in discharge measurement.

C_V is coefficient of variation evaluated from discrete values of depth d_i using Eq.(3) and (4) given below.

$$C_V = \frac{\left[\frac{1}{N} \sum_{i=1}^{N} (d_i - \mu_d)^2 \right]^{\frac{1}{2}}}{\mu_d} \tag{3}$$

$$\mu_d = \frac{1}{N} \sum_{i=1}^{N} d_i \tag{4}$$

Applying his total error model for a single discharge measurement, Masood (1976) has shown that procedural error constitutes the largest component (typically greater than 85 percent) of the total error excluding, of course, any systematic error. If the number of verticals is increased, this component of error will decrease, but the random error component may be increased. Therefore it is necessary to use an optimum number of verticals for a minimum total error.

Errors in Seepage Loss Derived from Inflow-Outflow Method

Since the seepage loss Q_s must be evaluated as the difference of inflow Q_1 and outflow Q_2 in a given reach, the error in the seepage loss is the quadratic sum of original errors provided they are independent and random:

$$\delta Q_s = \sqrt{(\delta Q_1)^2 + (\delta Q_2)^2} \qquad (5)$$

Where δQ_1 and δQ_2 are respectively the original errors in inflow and outflow, and δQ_s is error in seepage loss. In any case the error in the seepage loss is never larger than the ordinary sum of original errors,

$$\delta Q_s \leq \delta Q_1 + \delta Q_2 \qquad (6)$$

Where there are diversions or outlets in the test reach, error are further added to seepage loss. Therefore test reach with minimal offtakes should be selected to achieve better accuracy.

Eq. (5) dictates that for acceptable accuracy in seepage loss determination, long test reaches of canal must be selected. This is demonstrated in Figure 4 which shows the length of test reach required to attain certain accuracy or percentage error in the seepage loss. For this example (hypothetical) it has been assumed that:

(i) the expected loss rate is 8 cfs/msf of wetted area,

(ii) the discharge at the head of the test reach is 5000 cfs,

(iii) there are no diversion from the canal,

(iv) the discharge could be measured with an accuracy of 2 percent,

(v) the wetted area can be found from Lacey's Regime Formula and the measured length of reach with negligible error,

(vi) errors in discharge measurement are independent and random in both sign and magnitude. It can also be noticed that where seepage loss rate is low, test reach should be even longer.

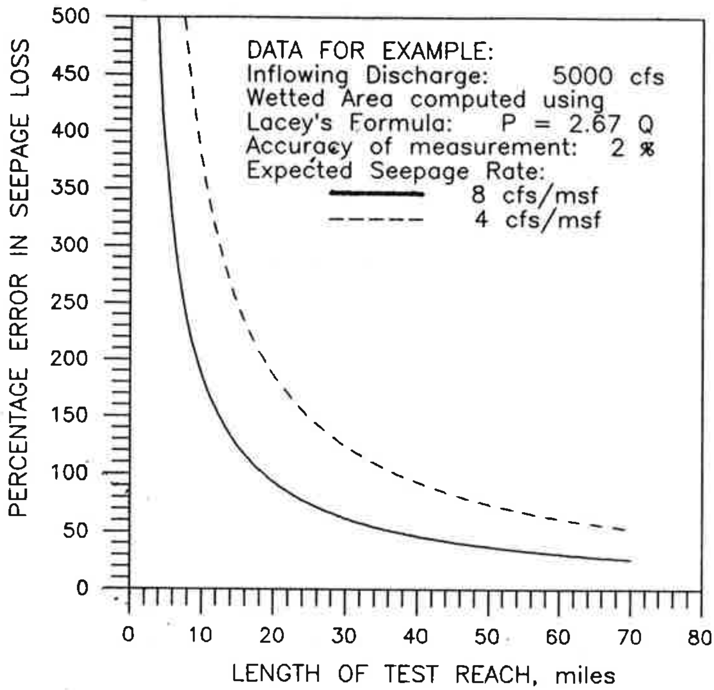


Figure 4. Plot of error in seepage loss vs. length of test reach.

For practical measurement of seepage losses, the length of test reach indicated by Eq. (5) is too long and thus too restrictive. Fortunately shorter test reaches can often be used in seepage measurement under special conditions as explained in the next section.

Sign of Error and Accuracy

As pointed out by Rohwer and Stout (undated), the sign of errors in inflow and outflow measurements plays a crucial role in the accuracy of a seepage loss determination. If Q_1 and Q_2 are respectively the true inflow and outflow, and ϵ_1 and ϵ_2 are corresponding errors expressed as ratios (which may be either positive or negative), then the true loss is $(Q_1 - Q_2)$, and the measured loss is

$$Q_1(1 \pm \varepsilon_1) - Q_2(1 \pm \varepsilon_2) \tag{7}$$

The difference between true and the measured loss is

$$[Q_1 - Q_2] - [Q_1(1 \pm \varepsilon_1) - Q_2(1 \pm \varepsilon_2)] = \mp \varepsilon_1 Q_1 \pm \varepsilon_2 Q_2 \qquad \textbf{(8)}$$

Eq. (8) indicates that if the error in both measurement is same in magnitude and sign, i.e. if $\epsilon_1 Q_1 = \epsilon_2 Q_2$, then there is no error in the result. If the percentage error is same in both measurements, then

$$\varepsilon_1 = \varepsilon_2 = \varepsilon, \quad \textit{so that} \quad \mp \varepsilon_1 Q_1 \pm \varepsilon_2 Q_2 = \mp \varepsilon (Q_1 - Q_2) \qquad \textbf{(9)}$$

or the percentage error of the result is the same as the percentage error in the measurement. Thus if the percentage error in the measurement is small, it will be small in the difference also. If, however, the errors differ in magnitude and sign, then

$$(\mp \varepsilon_1 Q_1 \pm \varepsilon_2 Q_2) \rightarrow (\mp \varepsilon_1 Q_1 \mp \varepsilon_2 Q_2) \qquad \textbf{(10)}$$

The error in the result, therefore, becomes the sum of actual errors in the measurement which may easily exceed the loss. Therefore depending upon the sign, the errors in the measurements may either materially increase the loss, or change it into a gain.

From the above discussion it is clear that accuracy in seepage loss determination by inflow-outflow method hinges upon the sign of the errors. Therefore special efforts must be made to obtain the same sign of the errors in the discharge measurements. This can be facilitated by adopting the following precautions:

(i) Both inflow and outflow measurements should be made by the same observer.

(ii) Same current meter and same method of measurement should be used for inflow and outflow.

(iii) Similar gaging stations (which are free of obstruction and which have stable control) should be chosen for inflow and outflow measurements.

(iv) Test reaches with large diversion should be avoided.

Discharge measurement for seepage loss determination should be desirably duplicated with two different current meters. For small outlets or leaks, a triangular weir is preferable.

COMPUTED LOSS RATES

Seepage loss was computed for CRBC as the difference of inflow and outflow from each study reach and adjusted for offtakes if any. Corresponding wetted area was also computed following the procedure outlined in section 4.3 above. It was then possible to express the seepage loss rate in terms of cfs/msf of wetted area.

Appendix-A lists the seepage loss determinations made for different study reaches of earthen part of canal, while Appendix-B lists those for lined part. For earthen part there are 82 determination of seepage loss rate; 31 in the first study reach, 28 in the second and 23 in the third. For lined part there are 43 such determination; 22 in the fourth study reach and 21 in the fifth.

Statistics of computed seepage loss rate for each study reach are summarized in Appendix-C for the 3 years of observation. Statistical analysis shows that there is little difference in the mean seepage loss rate for the three earthen reaches at 95 percent significance level. Similarly the mean seepage loss rate from reach IV and reach V are not different from each other at 95 percent significance level, although reach IV is predominantly brick lined (79 percent length brick lined) while reach V is predominantly PCC lined (67 percent length is PCC lined). In order to estimate seepage loss from lined and unlined part of the canal, it was decided to combine all measurements in lined and unlined groups, considering them homogeneous in their respective group.

Statistics of seepage loss rates for both lined and unlined parts of the canal are summarized in Table-1. It may be observed that the uncertainty in the mean seepage rate (as indicated by its standard error) differs from year to year, probably due to changes in staff etc. in various years. Therefore weighted average seepage loss rates for the two parts of the canal were computed by giving greater weight to the mean values with lesser uncertainty as follows (Taylor,1982):

$$\textit{Weigted Average Seepage Loss Rate} = \frac{\sum_{i=1}^{K} w_i x_i}{\sum_{i=1}^{K} w_i} \qquad \textbf{(11)}$$

Where

x_i = mean seepage loss rate for i-th year

$w_i = 1/(SE_i)^2$

SE_i = standard error of mean loss rate for i-th year, i=1,2,...,K.

The uncertainty SE_{avg} in the weighted average value was computed as

$$SE_{avg} = \left(\sum_{i=1}^{K} w_i \right)^{-\frac{1}{2}} \quad \textbf{(12)}$$

The weighted average seepage loss rate for the earthen part of canal was found as 4.381 cfs/msf while that for lined part was computed as 2.971 cfs/msf. For the sake of completeness, maximum and minimum rates observed in the two parts have been include in Table 1. However it may be cautioned that the maximum and minimum values are likely to contain the largest observational errors. For example the maximum seepage loss rate observed in the unlined part of the canal is 11.015 cfs/msf. By applying the Chauvenet's criterion (Taylor, 1982) this observation can be shown to be highly improbable and fit for rejection.

Table 1. Statistics of Seepage Loss Rate for Chashma Right Bank Canal.

Year	No. of Obs.	Mean cfs/msf	σ cfs/msf	CV %	SE cfs/msf	Maximum cfs/msf	Minimum cfs/msf
Earthen Study Reaches							
1990	32	4.483	1.303	29	0.230	7.833	0.800
1991	30	4.479	1.696	38	0.310	11.015	1.807
1992	20	3.710	2.136	58	0.478	9.135	1.022
1990-92	82	4.293	1.714	40	0.189	11.015	0.800
Weighted Average	-	4.381	-	-	0.172	-	-
Lined Study Reaches							
1990	15	2.783	0.858	31	0.222	4.720	1.724
1991	20	3.262	1.152	35	0.258	6.322	1.281
1992	8	2.895	1.047	36	0.370	4.444	1.377
1990-92	43	3.026	1.062	35	0.162	6.322	1.281
Weighted Average	-	2.971	-	-	0.153	-	-

Variation in the seepage loss rates expected as a consequence of random errors in the measured rates as well as due to changes in physical variables affecting seepage such as water table, driving head etc., can be described by the coefficient of variation CV, which is the ratio of standard deviation to mean expressed as percentage. For earthen reaches the coefficient of variation is 40 percent, and for lined reaches it is 35 percent.

Statistically speaking, the standard deviation σ characterizes the average uncertainty of separate measurements, while the mean value represents a judicious combination of all measurements such that it will be more reliable than any measurement considered separately. The uncertainty in the mean is described by the standard deviation of the mean, or standard error:

$$SE = \frac{\sigma}{\sqrt{N}}$$

where N is the number of measurements. We can be 68 percent confident that the computed mean lies within ±SE of the true mean, and 95 percent confident that the computed mean lies within ± 2 SE of the true mean. Using this jargon, the confidence intervals on the mean seepage rates can be reported as follows:

Earthen Reaches:

68 percent confidence interval: 4.381 ± 0.172 cfs/msf
95 percent confidence interval: 4.381 ± 0.344 cfs/msf

Lined Reaches:

68 percent confidence interval: 2.971 ± 0.153 cfs/msf
95 percent confidence interval: 2.971 ± 0.306 cfs/msf

Plots of seepage rate versus inflowing discharge have been made for earthen and lined study reaches in Figure 5 and 6 respectively. These Figures show that there is little correlation between discharge and seepage rate as noticed by Patten et al (1963) also.

For the sake of comparison it may be mentioned that loss rates assumed at the design stage of the project were 8 cfs/msf for unlined reaches, and 2 cfs/msf for the lined reaches, so that total absorption losses for the three stages of the project were estimated as 385 cfs. Using the loss rates found in this investigation, the estimate for total absorption losses will be reduced to 327 cfs.

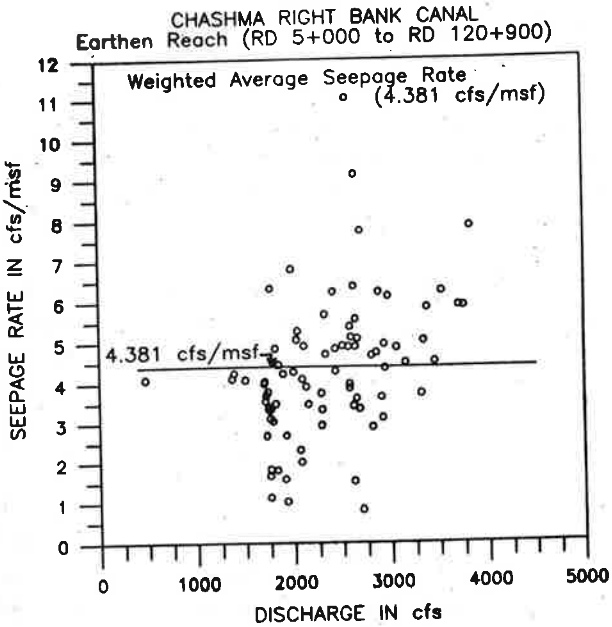


Figure 5. Scatter Diagram: Discharge vs. Seepage Rate in Earthen Reaches.

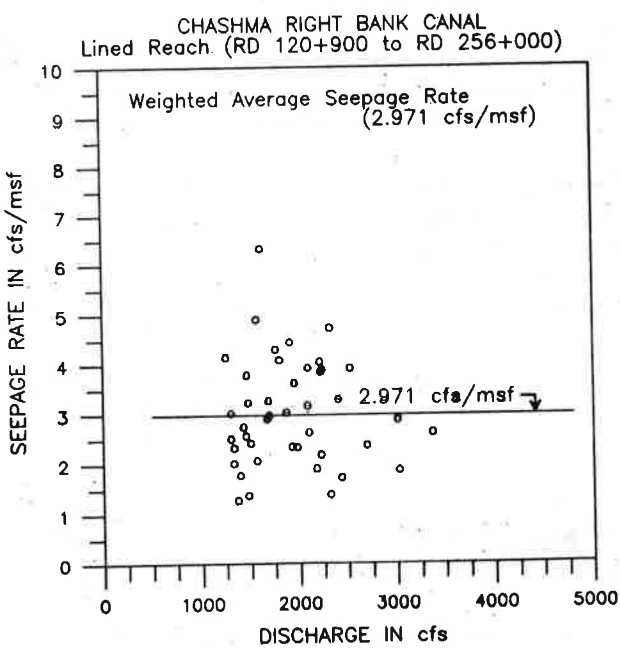


Figure 6. Scatter Diagram: Discharge vs. Seepage Rate in Lined Reaches.

EVALUATION OF THE RESULTS

Except for discharge measurements made on small outlets, most of the measurements employed in this study can be rated from excellent to good within an error margin of 2 to 5 percent. The measurement made on small outlets were also made carefully, and may be safely rated as good with an error margin of 5 to 10 percent.

Ideally, the discharge measurement at each section should have been repeated to minimize the random errors. Unfortunately this was not possible in the same day schedule, unless the number of verticals was reduced. It was preferred to use greater number of verticals, and reduce the procedural error which constitutes the major part of measurement error. ACOP's standards require that, except in small outlets, the number of verticals should range between 20 to 25 for acceptable accuracy.

With the exception of pygmy current meter measurements for outlets, the two point method (0.2 D and 0.8 D) was used to find the average velocity in each vertical. It may be remarked that the two point method gives better accuracy and recommended for seepage loss determinations. Discharge was computed using the Mid Section Method, which has smaller procedural error than Mean Section Method.

To achieve the same sign in the errors, all discharge measurements were made by the same party/observer with the help of the same current meter, excepting the measurements made on offtakes and small outlets.

Ideally, the gage observations at both upstream and downstream section of study reach should have been recorded to find out any changes in the volume of water in the study reach over the period of observation. This was not done in these measurements. This deficiency, however, has been mitigated to a great extent by the following two conditions:

(1) The gage did not vary during the period individual measurement was made either at the upstream section or at the downstream section of the study reach.

(2) In many of the observations (46 percent of the total) the travel time of water in the study reach was equal to the time difference between upstream and downstream measurements.

In other words the downstream discharge measurement was completed such that the water parcels which began their travel in the time period during which the upstream measurement was completed, were still passing from the downstream section. Under these conditions the requirement of constancy of gage during a seepage measurement can be relaxed. Moreover, the changes in the discharge in irrigation canals are allowed only slowly, so the gage values may be expected to be reasonably constant during measurements.

The study reaches selected for seepage loss determination are sufficiently long to overcome the influence of local variation in permeability of soil strata, and at the same time provide a measurable difference between inflow and outflow. In addition, the number of offtakes are minimal, and most of them are large enough to be measured with sufficient accuracy. These conditions add to the accuracy of seepage measurements.

Seepage rates found for earthen part of Chashma Right Bank Canal are relatively lower than those reported by Patten et. al. (1963) for canals in "Thal Doab" on the left side of the Indus River. The probable reasons are:

(i) Soils in CRBC Project are relatively fine textured. The project area in Stage-I comprises of following textural groups of soil (refer to Figure 7):

Coarse textured	15%
Moderately coarse textured	7%
Medium textured	41%
Moderately fine textured	36%
Others	1%

(ii) Depth to water table in CRBC project area is also lower as shown in Figure 8. The water table was only 3 to 10 feet deep along the alignment of CRBC in 1980. It has risen further after the commissioning of the canal requiring additional drainage measures such as intercepter drains on the left side of the canal.

For the reasons described above, it may be concluded that seepage loss rates obtained from these measurements are sufficiently reliable and representative of the conditions obtaining in the project area.

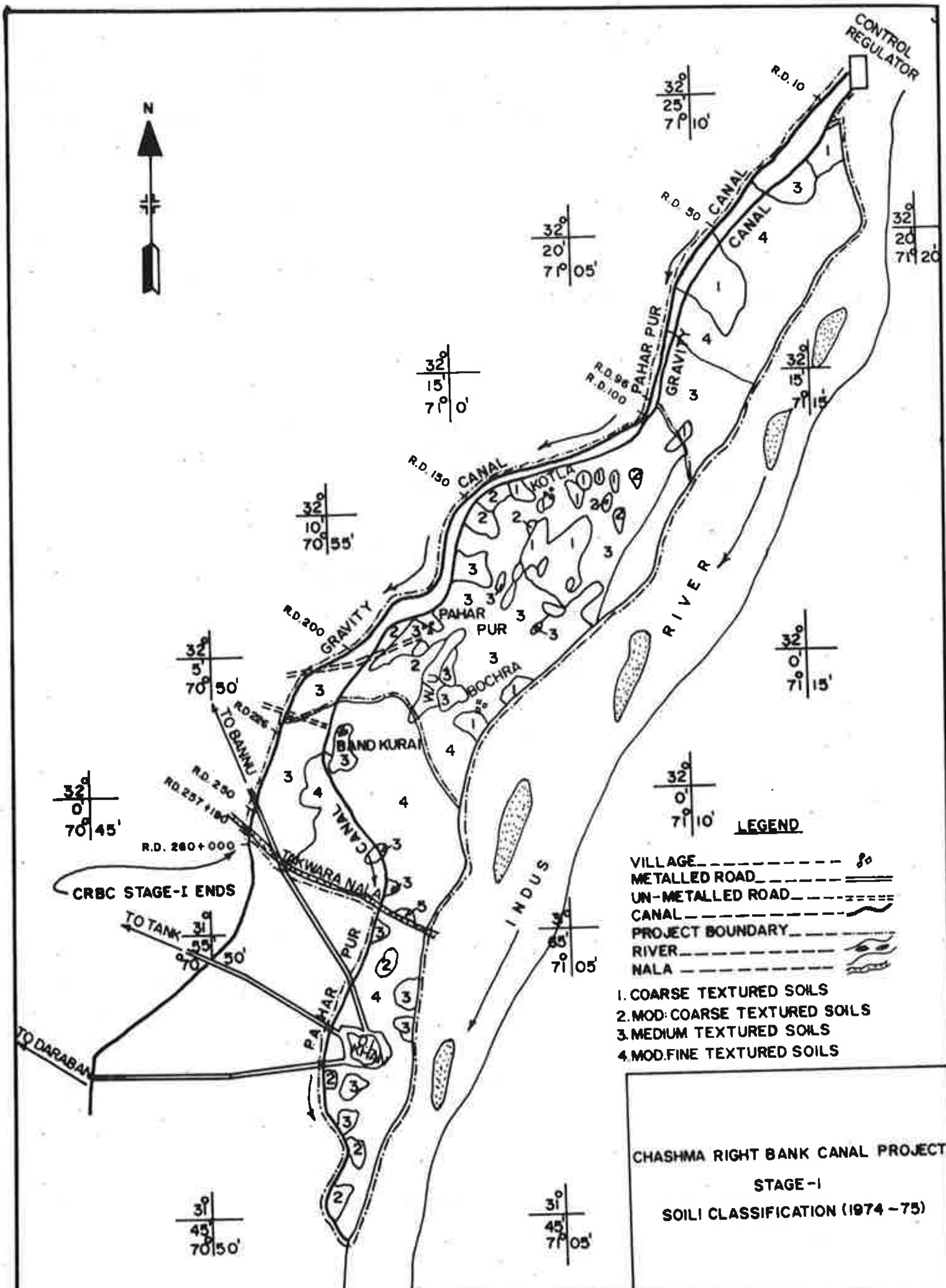


Figure 7. Textural Classification of Soils in CRBC Project.

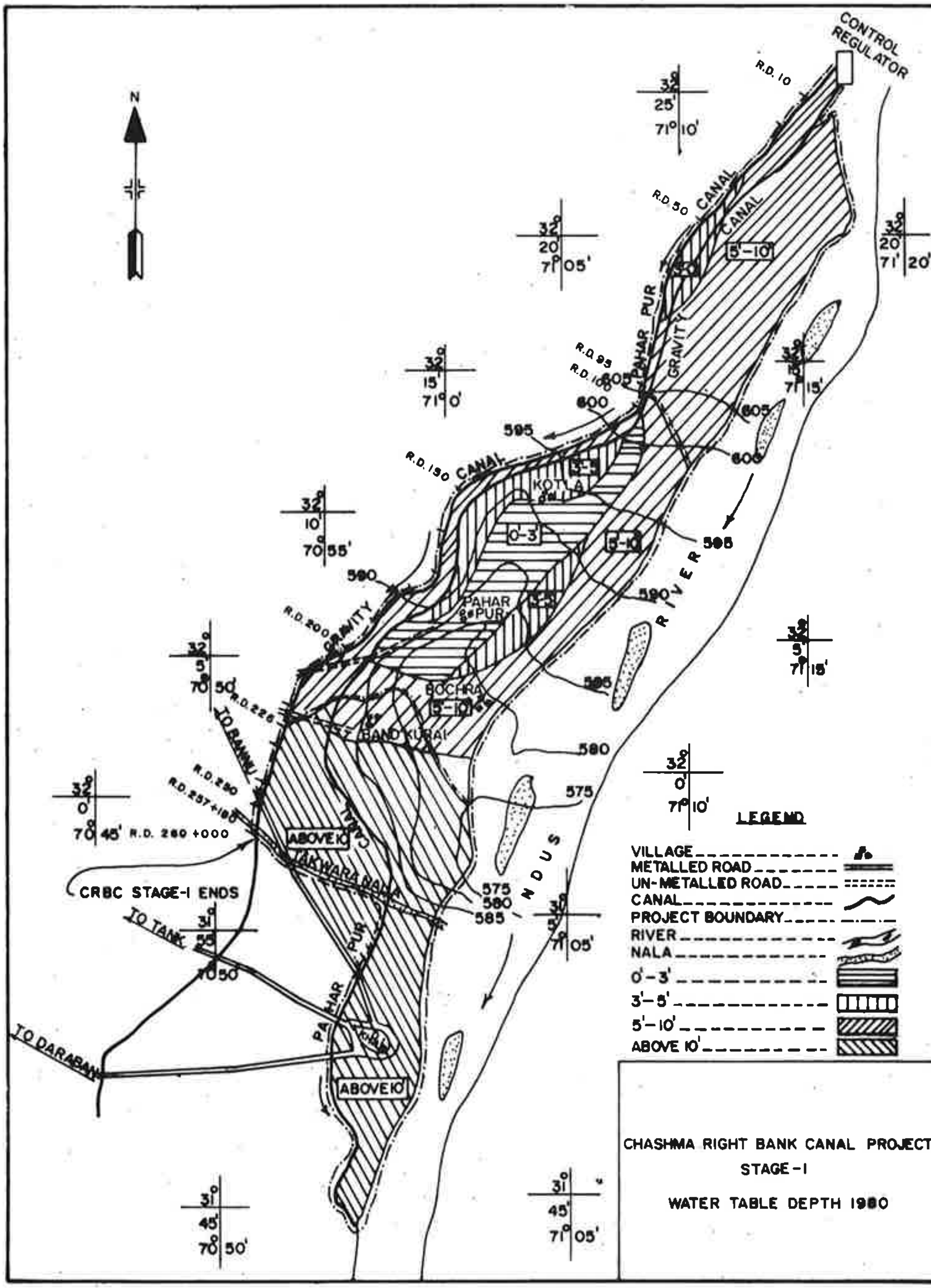


Figure 8. Watertable Depth, 1980.

ACKNOWLEDGMENTS

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APPENDIX – A

SEEPAGE LOSS OBSERVATIONS ON CHASHMA RIGHT BANK CANAL: EARTHEN STUDY REACHES

Study Reach I (RD 5+000 to RD 51+175)

Sr No.	Date		Qin cfs	Qout cfs	Qoff cfs	Qseep cfs	Wetted Area msf	Loss Rate cfs / msf
1	19-02-90	*	1499.50	1465.41	0.00	34.09	8.417	4.050
2	24-02-90	*	2083.03	2042.01	0.00	41.02	10.067	4.075
3	13-03-90	*	1386.97	1352.49	0.00	34.48	8.182	4.214
4	06-06-90	*	2590.66	2541.30	0.00	49.36	9.682	5.098
5	17-06-90		2656.32	2606.46	0.00	49.86	9.847	5.063
6	14-07-90		2937.66	2894.48	0.00	43.18	9.929	4.349
7	26-07-90		3341.56	3291.09	0.00	50.47	10.038	5.028
8	26-08-90		3825.81	3746.56	0.00	79.25	10.117	7.833
9	13-09-90		3529.87	3467.01	0.00	62.86	10.085	6.233
10	25-09-90		2932.82	2887.29	0.00	45.53	9.221	4.938
11	20-10-90		1846.29	1810.14	0.00	36.15	8.175	4.422
12	06-11-90		2573.33	2540.56	0.00	32.77	8.500	3.855
13	16-12-90		2676.10	2647.48	0.00	28.62	8.560	3.343
14	21-02-91		1714.56	1685.43	0.00	29.13	7.942	3.668
15	23-04-91		1783.52	1759.44	0.00	24.08	7.937	3.034
16	18-05-91		1889.44	1856.08	0.00	33.36	7.920	4.212
17	16-06-91		2408.81	2358.66	0.00	50.15	8.056	6.225
18	16-07-91		2646.87	2616.46	0.00	30.41	8.467	3.592
19	20-08-91		2980.68	2920.81	0.00	59.87	9.783	6.120
20	21-09-91		2850.46	2804.61	0.00	45.85	9.703	4.725
21	21-10-91		2422.84	2380.29	0.00	42.55	8.830	4.819
22	25-11-91		2126.64	2095.15	0.00	31.49	8.120	3.878
23	17-12-91		2104.72	2065.22	0.00	39.50	8.074	4.892
24	23-02-92		470.95	440.63	0.00	30.32	7.426	4.083
25	09-06-92		2287.02	2260.08	0.00	26.94	8.108	3.323
26	24-06-92		2578.03	2533.72	0.00	44.31	8.257	5.366
27	21-07-92		2614.15	2600.87	0.00	13.28	8.753	1.517
28	08-09-92		3151.76	3107.41	0.00	44.35	9.901	4.479
29	16-09-92		1753.40	1728.68	0.00	24.72	7.956	3.107
30	18-10-92		1756.44	1741.62	0.00	14.82	7.984	1.831
31	28-11-92		1918.14	1896.32	0.00	21.82	8.137	2.682

Study Reach II (RD 51+175 to RD 96+000)

Sr No.	Date		Qin cfs	Qout cfs	Qoff cfs	Qseep cfs	Wetted Area msf	Loss Rate cfs / msf
1	25-02-90		2042.18	1988.08	0.00	54.10	10.304	5.250
2	14-03-90	*	1361.66	1327.99	0.00	33.67	8.257	4.078
3	18-06-90		2633.72	2588.89	0.00	44.83	9.195	4.875
4	15-07-90		2901.89	2867.62	0.00	34.27	9.445	3.628
5	28-07-90		3314.02	3276.42	0.00	37.60	10.124	3.714
6	27-08-90		3754.86	3694.12	0.00	60.74	10.352	5.867
7	15-09-90		3452.24	3405.77	0.00	46.47	10.324	4.501
8	21-10-90		1814.81	1779.77	0.00	35.04	10.127	3.460
9	11-11-90		2613.87	2579.08	0.00	34.79	10.188	3.415
10	19-12-90		2147.97	2114.66	0.00	33.31	9.638	3.456
11	23-02-91		1703.81	1670.49	0.00	33.32	9.433	3.532
12	20-03-91		1735.29	1704.01	0.00	31.28	9.376	3.336
13	24-04-91		1744.93	1713.92	0.00	31.01	9.190	3.374
14	19-05-91		1823.26	1806.42	0.00	16.84	9.318	1.807
15	17-06-91		2279.87	2251.55	0.00	28.32	9.661	2.931
16	17-07-91		2561.64	2512.52	0.00	49.12	10.097	4.865
17	25-08-91		2912.99	2676.33	204.95	31.71	10.169	3.118
18	23-09-91		2799.47	2580.39	171.79	47.29	10.167	4.651
19	22-10-91		2424.76	2180.10	201.35	43.31	10.158	4.264
20	26-11-91		2071.53	1877.81	174.48	19.24	9.588	2.007
21	18-12-91		2029.28	1981.19	0.00	48.09	9.545	5.038
22	10-06-92		2279.57	2242.04	0.00	37.53	10.060	3.731
23	27-06-92		2573.63	2533.40	0.00	40.23	10.185	3.950
24	22-07-92		2646.56	2553.41	0.00	93.15	10.197	9.135
25	09-09-92		3062.40	2725.61	287.03	49.76	10.257	4.851
26	19-09-92		1717.28	1691.98	0.00	25.30	9.459	2.675
27	19-10-92		1753.08	1744.26	0.00	8.82	7.854	1.123
28	29-11-92		1904.69	1888.94	0.00	15.75	9.995	1.576

Study Reach III (RD 96+000 to RD 120+900)

No.	Date		Qin cfs	Qout cfs	Qoff cfs	Qseep cfs	Wetted Area msf	Loss Rate cfs / msf
1	28-02-90	*	2060.60	1936.24	113.59	10.77	4.650	2.316
2	19-06-90		2699.69	2247.17	446.57	3.95	4.938	0.800
3	16-07-90		2808.87	2383.59	410.90	14.38	4.988	2.883
4	28-08-90		3704.76	3423.45	250.75	30.56	5.191	5.887
5	16-09-90		3379.32	3149.99	199.22	30.11	5.161	5.834
6	27-09-90		2640.38	2396.00	216.76	27.60	4.969	5.554
7	22-10-90		1768.19	1523.29	215.58	29.32	4.647	6.309
8	12-11-90		2499.01	2292.17	182.95	23.89	4.885	4.890
9	20-12-90		1995.99	1694.61	281.22	20.16	4.748	4.246
10	24-02-91		1694.36	1480.07	196.17	18.12	4.580	3.956
11	21-03-91		1765.63	1490.90	259.45	15.28	4.568	3.345
12	25-04-91		1733.05	1432.53	283.64	16.88	4.501	3.750
13	20-05-91		1812.56	1439.97	350.80	21.79	4.508	4.834
14	16-06-91		2319.51	1925.73	367.56	26.22	4.628	5.666
15	26-08-91		2881.36	2490.20	360.52	30.64	4.923	6.224
16	27-09-91		2565.21	2285.77	225.84	53.60	4.866	11.015
17	23-10-91		2323.79	2072.18	229.25	22.36	4.770	4.688
18	27-11-91		1965.12	1727.07	227.23	30.82	4.538	6.792
19	28-06-92		2621.32	2221.54	369.45	30.33	4.769	6.360
20	23-07-92		2699.97	2233.58	429.79	36.60	4.731	7.736
21	20-09-92		1699.73	1665.22	16.84	17.67	4.409	4.008
22	20-10-92		1750.49	1475.15	268.14	7.20	4.350	1.655
23	30-11-92		1921.63	1815.14	101.87	4.62	4.521	1.022

Note * Discharge measurement sites are slightly different from those of standard locations.

APPENDIX – B

SEEPAGE LOSS OBSERVATIONS ON CHASHMA RIGHT BANK CANAL: LINED STUDY REACHES

Sr No.	Date	Qin cfs	Qout cfs	Qoff cfs	Qseep cfs	Wetted Area msf	Loss Rate cfs / msf
Study Reach IV (RD 120+900 to RD 189+200)							
1	21-03-90	1395.80	1295.21	90.36	10.23	5.761	1.776
2	20-06-90	2176.17	1898.70	265.71	11.76	6.172	1.905
3	17-07-90	2432.79	2169.50	252.41	10.88	6.312	1.724
4	30-07-90	3023.32	2760.88	250.25	12.19	6.534	1.866
5	29-08-90	3368.26	3145.18	205.25	17.83	6.806	2.620
6	29-09-90	2321.54	2108.22	183.69	29.63	6.278	4.720
7	17-11-90	2404.74	2203.68	180.05	21.01	6.388	3.289
8	22-12-90	1674.42	1500.38	156.54	17.50	6.034	2.900
9	25-02-91	1470.47	1314.58	134.05	21.84	5.771	3.784
10	24-03-91	1505.32	1368.75	122.31	14.26	5.896	2.419
11	27-04-91	1457.52	1300.13	142.52	14.87	5.788	2.569
12	21-05-91	1431.26	1244.92	170.57	15.77	5.750	2.743
13	19-06-91	1927.62	1656.21	257.26	14.15	6.042	2.342
14	21-07-91	2088.18	1855.76	213.02	19.40	6.138	3.161
15	27-08-91	2527.99	2278.80	224.08	25.11	6.416	3.914
16	25-09-91	2104.43	1945.28	142.81	16.34	6.215	2.629
17	30-10-91	1770.01	1577.39	166.81	25.81	6.002	4.300
18	28-11-91	1807.49	1628.74	154.12	24.63	6.028	4.086
19	29-06-92	2218.67	1934.68	258.83	25.16	6.220	4.045
20	26-07-92	2238.26	1968.98	245.16	24.12	6.204	3.888
21	21-09-92	1695.80	1566.80	111.36	17.64	5.926	2.977
22	21-10-92	1477.54	1346.30	123.20	8.04	5.837	1.377

Sr No.	Date	Qin cfs	Qout cfs	Qoff cfs	Qseep cfs	Wetted Area msf	Loss Rate cfs / msf
Study Reach V (RD 189+200 to 256+000)							
1	22-03-90	1304.35	1111.73	176.27	16.35	6.492	2.518
2	18-07-90	2221.59	1757.60	449.05	14.94	6.855	2.179
3	31-07-90	2693.76	2353.89	323.70	16.17	6.825	2.369
4	30-08-90	3010.29	2670.59	319.50	20.20	7.023	2.876
5	30-09-90	2097.10	1764.13	306.37	26.60	6.777	3.925
6	19-11-90	2222.23	1940.86	254.94	26.43	6.869	3.848
7	23-12-90	1479.24	1108.27	349.36	21.61	6.686	3.232
8	26-02-91	1334.48	1073.71	245.41	15.36	6.609	2.324
9	25-03-91	1370.09	1153.33	208.31	8.45	6.594	1.281
10	28-04-91	1302.75	982.85	300.20	19.70	6.527	3.018
11	23-05-91	1256.44	913.84	315.65	26.95	6.507	4.142
12	20-06-91	1690.57	1302.73	365.99	21.85	6.693	3.265
13	25-07-91	1872.54	1495.49	356.59	20.46	6.748	3.032
14	29-08-91	2317.82	1969.13	339.24	9.45	6.815	1.387
15	26-09-91	1955.66	1616.68	314.58	24.40	6.740	3.620
16	31-10-91	1620.77	1312.53	265.99	42.25	6.683	6.322
17	30-11-91	1571.62	1270.74	268.32	32.56	6.652	4.895
18	30-06-92	1917.23	1458.14	428.77	30.32	6.823	4.444
19	27-07-92	1981.06	1577.31	387.75	16.00	6.847	2.337
20	22-09-92	1570.16	1303.33	252.82	14.01	6.760	2.072
21	22-10-92	1332.78	941.12	378.26	13.40	6.642	2.017

Appendix-C. STATISTICS OF SEEPAGE LOSS FOR DIFFERENT STUDY REACHES

Year	No. of Obs.	Mean cfs/msf	σ cfs/msf	CV %	SE cfs/msf	Maximum cfs/msf	Minimum cfs/msf
Study Reach-I (RD 5+000 to RD 51+175)							
1990	12	4.887	1.163	24	0.336	7.800	3.233
1991	11	4.620	0.985	21	0.297	6.431	3.187
1992	7	3.818	0.868	23	0.328	5.329	2.581
1990-92	30	4.540	1.116	24.57	0.204	7.800	2.581
Study Reach-II (RD 51+175 to RD 98+000)							
1990	8	4.001	0.752	19	0.266	5.782	3.435
1991	10	3.716	0.646	17	0.204	4.853	2.745
1992	5	4.105	0.669	16	0.299	4.851	3.066
1990-92	23	3.900	0.709	18	0.148	5.782	2.745
Study Reach-III (RD 98+000 to RD 120+900)							
1990	11	4.689	1.319	28	0.398	6.833	2.424
1991	8	4.976	1.208	24	0.427	6.781	3.555
1992	5	5.218	1.519	29	0.679	7.715	3.586
1990-92	24	4.895	1.345	27.5	0.274	7.715	2.424
Study Reach-IV (RD 120+900 to RD 189+200)							
1990	8	2.436	0.996	41	0.352	4.506	1.324
1991	10	3.130	0.648	21	0.205	4.279	2.547
1992	4	3.067	1.083	35	0.541	4.088	1.336
1990-92	22	2.867	0.933	32.6	0.199	4.506	1.324
Study Reach-V (RD 189+200 to RD 256+000)							
1990	8	2.939	0.666	23	0.235	4.046	2.178
1991	8	3.073	0.977	32	0.345	4.382	1.551
1992	4	2.801	1.184	42	0.592	4.586	1.299
1990-92	20	2.965	0.922	31	0.206	4.586	1.299

AN OVERVIEW OF CANAL LINING EXPERIENCE IN PAKISTAN

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ABSTRACT

On 14th of October, an invitation was received to attend the Workshop. Time was too short to prepare a note on some aspects of the lining. It was decided to acquaint the audiences with the problems of Canal Lining of this country, design of lining adopted, their present conditions, causes for their damages and some suggestions about their rectification; an estimate of seepage loss under the present condition was also mentioned.

LINED CANALS CONSTRUCTED IN PAKISTAN

Punjab province has the largest number of Lined Canals. Their location is marked in Figure 1 by red lines.

The earliest lined canal Haveli was constructed in 1937. It was designed to carry 5200 cusecs in a length of 48 miles. The lining was constructed of two layers of tiles with ½ inch thick 1:3 cement sand plaster. The slope of sides was kept 1:1 (h:v) in Figure 2(a).

Section of this lining is exhibited. It was followed by 31 miles of Thal Main Line Upper constructed in 1944. The lining was of cement concrete 4" thick with mix ratio of 1:3:6. The canal was designed for 7,000 cusecs. Another canal a branch of Thal canal was Khizar or Mohajar Branch of 19 miles lined in 1945. It also had the same specifications as the Thal Main Line Upper. Its sides were 5 inches in thickness.

Other lined canals are:

(a) Thal Main Line Lower Constructed in 1950
(b) Bambanwala Ravi Bedian Link in 1952-53
(c) Balloki, Sulemanki Link No.1 in 1955-58
(d) Sidhani, Mailsi Bhawal Link in 1965
(e) Chashma Right Bank Canal (CRBC) Stage-I and II between 1987 to 1993.

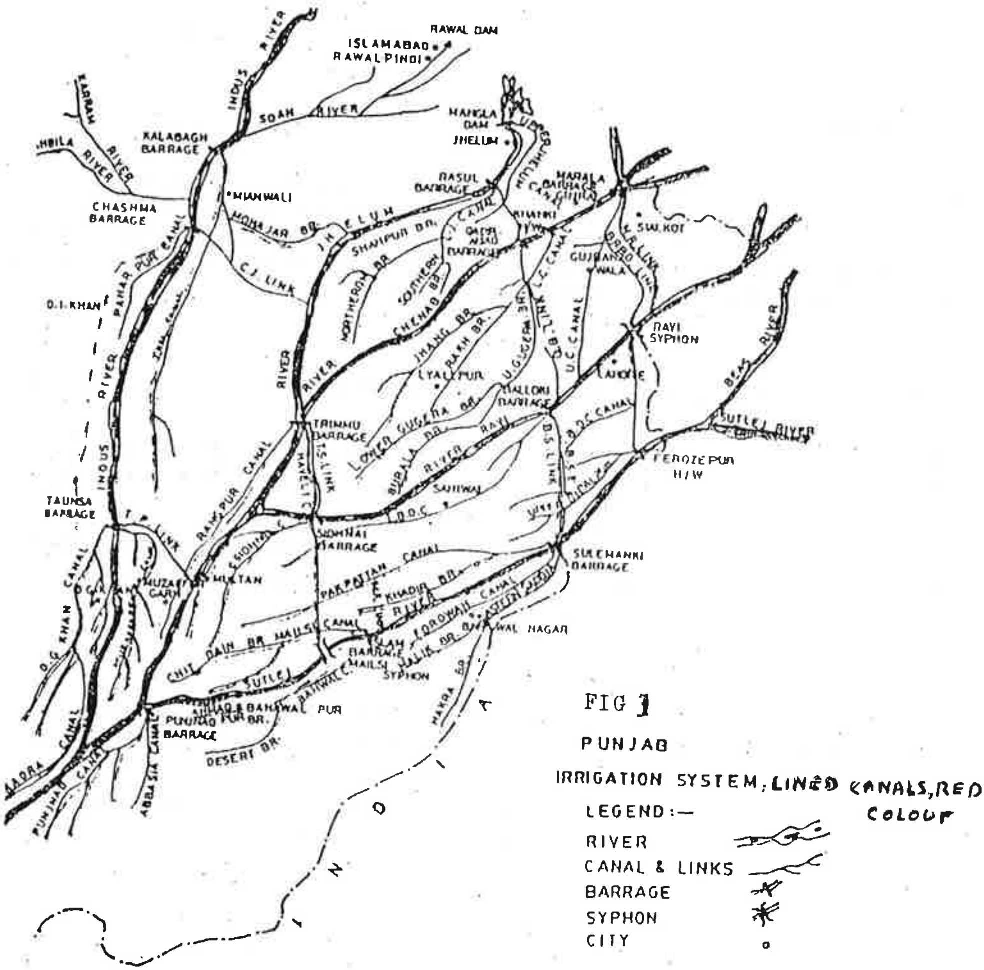

Figure 1. Punjab Irrigation System, Lined Canals, Red Colour.

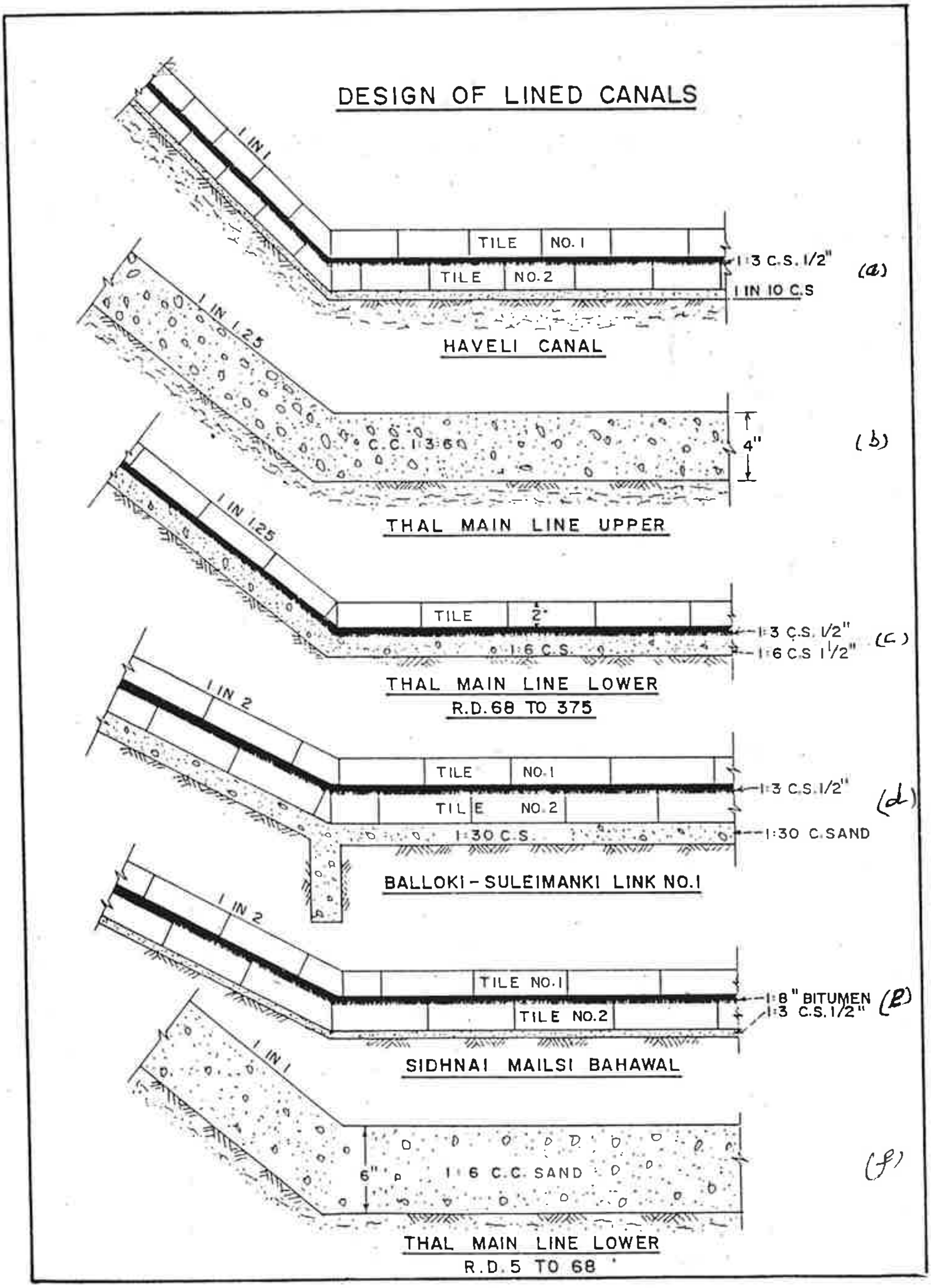

Figure 2. Design of Lined Canals.

DESIGN ASPECT OF LINED CANALS

Lining of Thal Main Line Upper, Mohajar Branch and a small portion of CRB Canals of Stage I and II were constructed with cement concrete. In all other canals tiles were mainly used and some minor changes in design were tried.

As to the side slope, we started with I:1 for Haveli, changed it to 1.25:1 for Thal and Mohajor, 1.5:1 in Bambanwala Ravi Bedian and 2:1 in case of Balloki Sulemanki and Sidhani Mailsi Link.

The problem of drainage of soil behind lining was started in case of Balloki Sulemanki when 3 inches thick permeable layer of stabilized sand was used. At the bottom toe of the sides, nine inches bore hole reaching down to the groundwater and filled with permeable sand and connected to the sides filter were provided every 50 feet apart. The detail of this system can be seen is Figure 3. This design of bore-hole and filter continued to be installed in lined canals such as CRBC Stage-I and a part of Stage-II and other lining of canals in SCARP Projects such as SCARP-VI.

Lining is not 100 percent impervious. During operation of the canal, seepage water found a quick mean to reach the groundwater which rose at a comparatively quick rate.

DAMAGE TO LINED CANALS

After about 20 years of lining of Thal Main Line Upper and Mahajor Branch the groundwater particularly at digging reach rose so high that at each closure the lining started to be damages due to back water and wet soil pressure.

This damage continued to appear in other canals like Balloki Sulemanki for about a length of 7.6 miles, and in Haveli where the groundwater has risen much above the lined bed. The existence of unlined links along these canals added to the quick rise of groundwater and increased water pressure. The present condition of damaged lining of a few canals are shown in Figure-4, a,b,c and d.

NEW DESIGN OF LINING ADOPTED FOR CRBC STAGE-II

In 1989, it was noticed that lining of CRB Canal Stage-II showed development of a thin horizontal crack about 4 feet above toe of the canal.

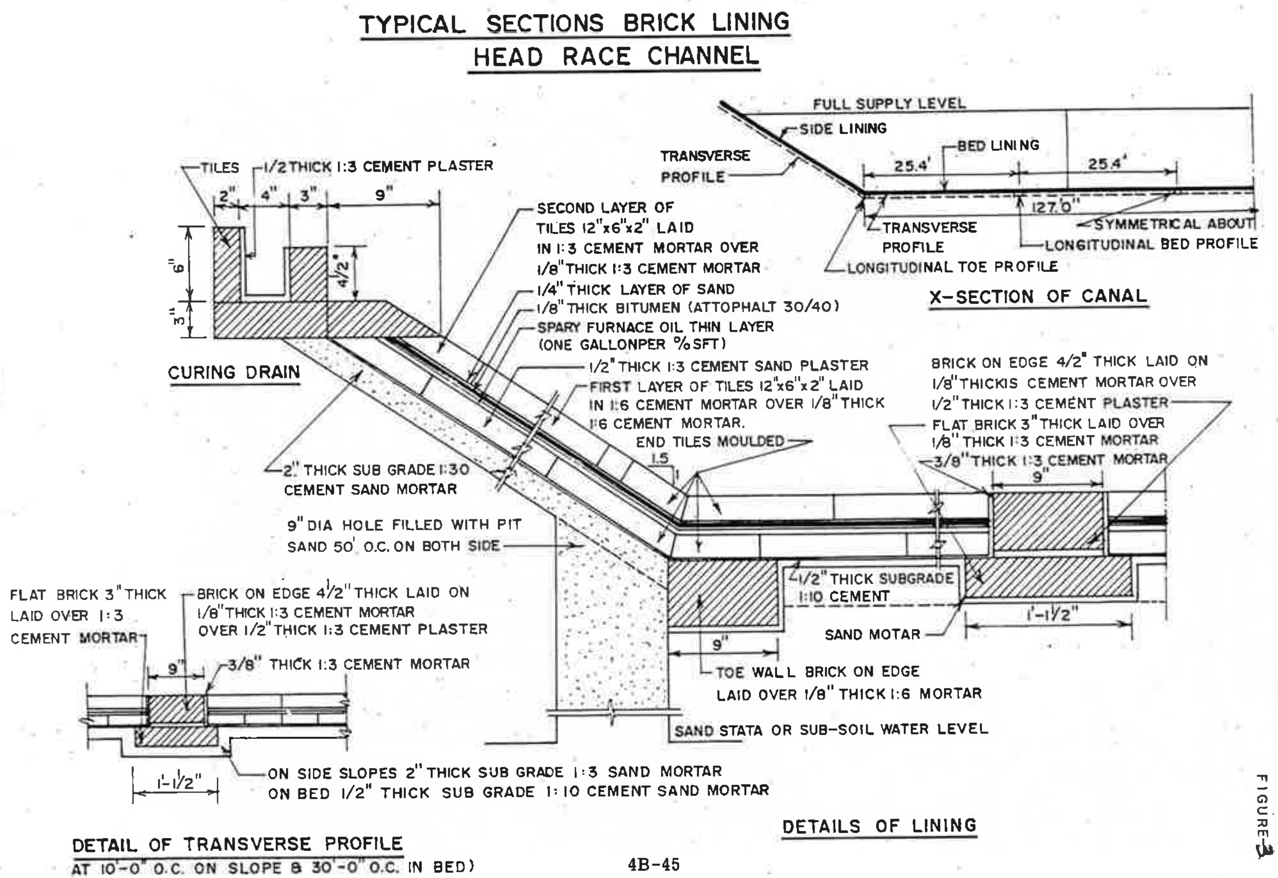

Figure 3. Typical Sections Brick Lining Head Race Channel.

Figure 4A. Lined Bed of Haveli Canal Lift-up by Water Pressure.

The Consultants of Asian Bank called in two experts from Bureau of Reclamation America for advise. They recommended the construction of lining with four inches thick slab of concrete of 1:2:4 mix ratio, laid directly on compacted soil.

Figure 4B. Specimen of Damaged Lining of Thal Main Line Upper.

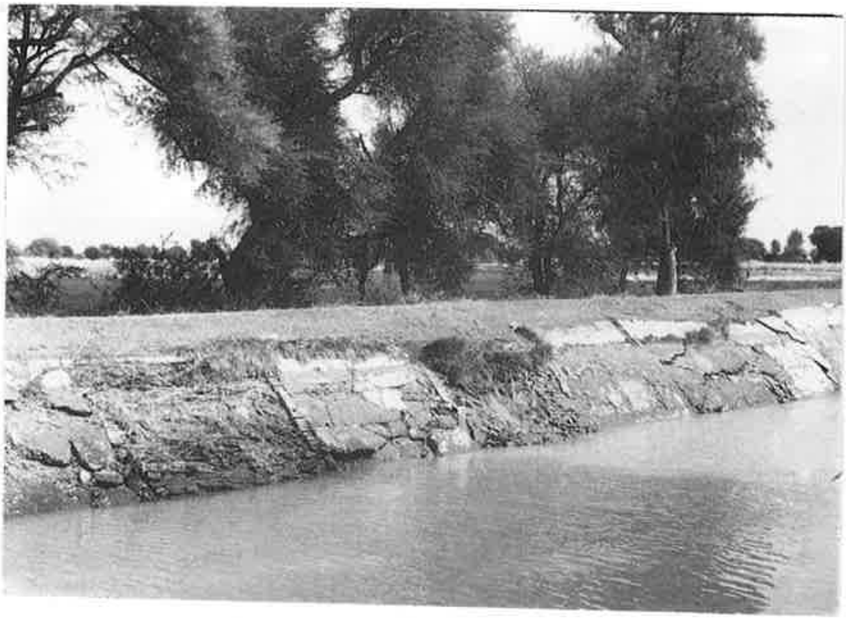

Figure 4C. Damaged Lining of Mohajar Branch.

Figure 4D. Damage to Plaster Used to Repair Lining Mohajar Branch.

The side panels 10 feet wide and 33 feet long were to be laid on soil without a profile of brick or concrete. The 33 feet long slab were to have no joints. In each side panel a hole 2.5 feet above the toe, 2.5 sq. feet and 2 feet deep was to be kept filled with pervious sand and grit and having a slotted two inches bore pipe protruding on the surface of the lining (see Figure 5). The side slope was to be kept 1.5 to 1. This design has been constructed at site. After few months, cracks have started to appear similar to those for which the advise was sought.

The formation under the lining is very typical of the area. It has 5 to 10 percent sand, about 30 percent silt and rest is clay. Angle of internal friction gave value of 16 to 20 degree for which the stable slope is 1 in 3. The ends of panel resting on soil and being not completely impervious, the seeping water will wet the soil which will be sucked away by flowing water and creating cavity at the site. The area is such which gets high intensity floods which may cause quick rise of groundwater. It is time that we may take effective counter-measure. This lining is such that under back water pressure the full slab will be damaged as unlike tile lining the slabs 10 ft. by 33 feet have no joint.

LINING OF MINORS AND DISTRIBUTARIES

A programme of lining of very small Minors and Distributaries has been in progress. Recently data of about 210 miles of these canals have been putforth The design of lining includes placing of 3.0 inches thick 1:2:4 cement concrete. Its cost was Rs. 1.8 million per mile. How much seepage water has been saved is still unknown as at no site the loss was determined from the unlined and lined canal. In fact it is unfortunate that the loss has never been estimated from a lined channel at any period of its operation.

SEEPAGE LOSS FROM DISTRIBUTARIES AND MINORS

Seepage loss from irrigation unlined canals was started to be determined in 1865. Estimate of seepage by Bentin, Higham, Kennedy is reported in Table 4B-7. It includes the results of modern advisers such as IACA, Harza and Huntings. Their estimate of loss through main canals and branches for Northern Zone is 20 percent and through distributaries and minors equal to 7 percent. On this basis estimates of seepage loss per mile was worked out. This information for only 17 canal commands of the Punjab is given in Table 4B-13. The loss per canal miles through Distributaries and Minors is about 0.2 to 0.25 cusec. Their lining as stated above cost Rs. 1.8 million per mile. Thus to save one cusec of water we have to invest Rs. 7.2 to 9 millions.

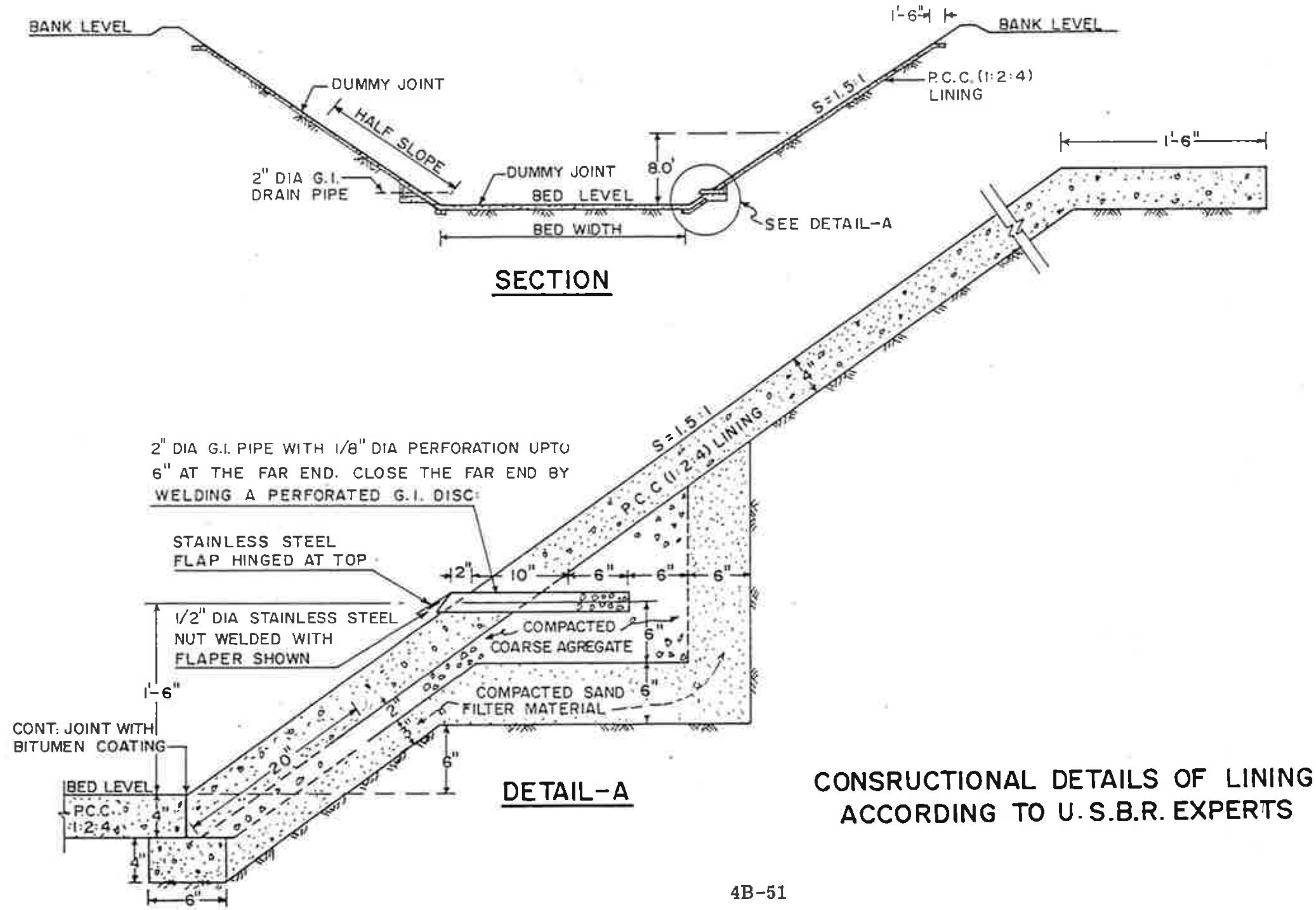

Figure 5. Constructional Details of Lining According to U.S.B.R. Experts.

SEEPAGE LOSS THROUGH LINED CANALS

So far the loss through a lined canal has never been determined. It is a custom to adopt 2 cusecs per million square feet of surface as seepage loss. There are no observational data. Loss from an unlined canal is taken as 8 cusecs per million square feet of wetted surface so that while determining the advantage of a lined canal, a saving of 6 cusecs per million sq. feet of area is adopted.

Seepage loss through unlined Main Canals and branches also needs a review. Using the data of Table 1, seepage loss per mile of these canal was also determined as per Table 2. Very few canal gave an estimate of 8 cusecs per million sq.ft. In the progress report of IWASRI for 1991-92 observed data for Gugera Canal is given which corresponds to 13 cusecs per m.sq.ft. Data for other main canals observed by Pattan are also recorded. The loss order is as much as 20 cusecs per m.sq.ft. How to relate the results of seepage loss estimated on the basis of Table 1 and given in Table 2, still needs explanation. It may also be noted that the recent report of WSIP Vol-IV which gives data of seepage loss of each canal command on basis of monthly diversion. Those results correspond with Table 1.

LOSSES FROM THE EXISTING LINED CANALS

Some of the existing lined canals are of such condition that their repair or rectification is a big problem. The main cause for deterioration is the back pressure of high groundwater and wet soil. In many cases the present groundwater level is much above the bed of canal, so that the present difference between full supply and groundwater is very nominal. Apparently the seepage loss may be very low. Can any organization in Pakistan determine the present seepage loss of deteriorated lined canals? The repair to damaged lined canal is very difficult. If the loss is found very low under the present condition why not adopt some measure to keep the damaged lined canal in operation and repair only that portions which obstruct the flow of the canal.

LINING OF PROPOSED GHAZI GHARIALA HYDRO POWER CHANNEL

A new channel for Hydro Power is planned to be constructed. This is to take off from the Indus about 7 km downstream of Tarbela. Its proposed capacity is about 7,0000 cusecs. It is to be a reinforced lined channel having 230 ft. bed width and 30 feet deep.

Table 1. Comparative Statement of Conveyance Losses in the Indus Basin Irrigation System.

Authority	Canal(s) System	Main Canals and Branches	Disty	Water Course	Farm	Total
(Losses as percent of Head Diversion)						
Kennedy	Upper Bari Doab Canal (Rabi)	20.0	6.5	21.0	13.0	60.5
Benton	UBDC	17.5	6.5	21.5	10.5	56.0
Higham	UBDC (Main Line)	12.1-14.0				
Blench		20.0	7.0	20.0	-	-
Khangar	Lower Chenab Canal	15.6	6.0	11.0	-	-
	Lower Jhelum Canal	14.0	6.0	11.0	-	-
Khana's Handbook		15-20	6.7	17.5-21.0	8.5-25.0	-
Irrigation Research Institute	Dipalpur Canal (8 Water courses)	-	-	8-14	-	-
	LCC (2 Water courses of Upper Gugera Branch)	-	-	5-10	-	-
	LCC (2 Water courses of Jhang Branch)	-	-	10-15	-	-
IACA	North Zone	30.0	-	7.0	19.0	56.0
	South Zone	20.0	-	7.5	20.5	53.0
HARZA	North Zone	29.0	-	7.0	8.0	44.0
	South Zone	25.0	-	8.0	8.0	41.0
LIP	South Zone	20.0	-	7.5	20.0	53.0

Table 2 **Seepage Losses (Cusecs Per Mile) From Main Canals Plus Branches (C + Br) and From Distributaries Plus Minors (DY + MR.) for Various Canal Commands (Punjab)**

S.No.	Canal Command	Diversion (MAF)	Losses (C+Br) @ 20% of Diversion		Losses (Dy.+Mr.) @ 7% of Diversion		Length of (C+Br) Miles	Loss (C+Br) Cusecs/ Mile	Length (Dy+Mr) Miles	Loss (Dy+Mr) Cusecs/Mile
			(MAF)	(Cusecs)	(MAF)	(Cusecs)				
1.	U.Depalpur	0.771	0.1542	213	0.054	74.5	106.5	2.0	375.0	0.2
2.	Ravi Syphon	1.420	0.284	392	0.0994	137.3	214.0	1.83	591.0	0.23
3.	Raya Branch	0.435	0.087	120	0.03045	42.1	-		390.3	0.11
4.	U. Chenab	1.912	0.3824	520	0.1338	185.0	72.6	7.16	1130.0	0.164
5.	M.R. Link	0.644	0.1288	178	0.0451	60.4	-	-	190.0	0.32
6.	Sadiqia East	2.971	0.5942	820.6	0.208	278.5	131.6	6.24	771.4	0.361
7.	Fordwah	0.775	0.155	214	0.0543	73.0	95.7	2.24	410.5	0.18
8.	Pakpattan	3.730	0.746	1030	0.261	349.5	264.6	3.89	878.6	0.40
9.	Lower Depalpur	1.540	0.308	425	0.1078	144.3	49	8.70	730.0	0.20
10.	L.B.D.C.	4.962	0.992	1370	0.347	479.0	146.0	9.38	1376.0	0.35
11.	Jhang	3.427	0.685	946	0.240	331.0	200.0	4.73	901.0	0.37
12.	U.Jhelum	1.495	0.299	413	0.105	145.0	128.4	3.22	601.4	0.241
13.	L.Jhelum	3.215	0.643	888	0.225	311.0	277.5	3.20	1289.0	0.240
14.	Gugera	3.954	0.791	1092	0.245	338.0	315.6	3.46	1568.0	0.201
15.	Bahawal	1.565	0.313	432.2	0.110	152.0	107.0	4.04	569.0	0.270
16.	Mailsi	2.665	0.533	736	0.187	258.0	61.8	11.9	921.4	0.280
17.	Sidhnai	2.154	0.431	595.2	0.151	209.0	134.2	4.44	872.8	0.240

It will be lined with 1:2:4 cement concrete five inches thick at bed and six inches at sides. The lining will be constructed of concrete slabs, at bed 32 by 41 feet and along sides 41 ft. square. The ends of each slab is to be provided with a water stop. Thirty two miles of lined canal will have such stops throughout its length.

Each slab will be laid on a filter made of two grades, coarser grade touching the lining and finer grade at bottom. This filter will have four inches perforated pipes every 66 ft. apart to carry the seeping water into a ten inches horizontal slotted pipe. This pipe will discharge into a sump provided with a submersible pump to lift the seeped water back into the canal. At every 820 ft. a sump will be provided.

This arrangement will be on both sides of the channel. Some idea about the sump, submersible pump and discharging water can be had from Figure 6. The arrangement about sumps 10 inches horizontal slotted pipe and 66 feet apart slotted pipes at the bed filter is exhibited in Figure 7.

Besides any seepage from reinforced concrete lined canal, these measures are adopted to deal with rain water, the annual intensity of which is twenty two inches and groundwater slopes on left side of canal is about 100 feet per mile. The present depth of groundwater in a considerable length of the channel is about 10 feet above bed level. On right side of the canal the groundwater becomes very flat and its drainage is towards the river-Indus.

MAIN PROBLEMS OF LINED CANAL IN PAKISTAN FOR WHICH ADVISE OF THE EXPERTS IS NEEDED

Design Characteristics of Pakistan Lined Canals

(a) Lined canals have been commonly constructed with two layers of tiles with impregnation of ½ inch thick cement sand plaster of mix ratio 1 in 3. In one canal a coating of bitumen 1/16 inch thick on the cement sand plaster was also used. In a few canals the bottom layer of tiles was replaced by 1 in 6 cement sand mortar of the same thickness as the tile.

(b) Two canals such as Thal Main Line Upper and Mohajar Branch were lined with four inches or five inches thick 1:3:6 cement concrete and in case of Chashma Right Bank Canal a small portion was lined according to the above mentioned design and large length has been constructed with four inches thick cement concrete of mix ratio 1:2:4.

(c) Sides slopes equal to 1:1, 1:1.25, 1:5 and 1:2 have been used.

(d) No systematic provision has been adopted to release the high back water pressure during canal closure.

(e) No provision was made to record the changes in groundwater outside the canal and to check its rise beyond a certain limit.

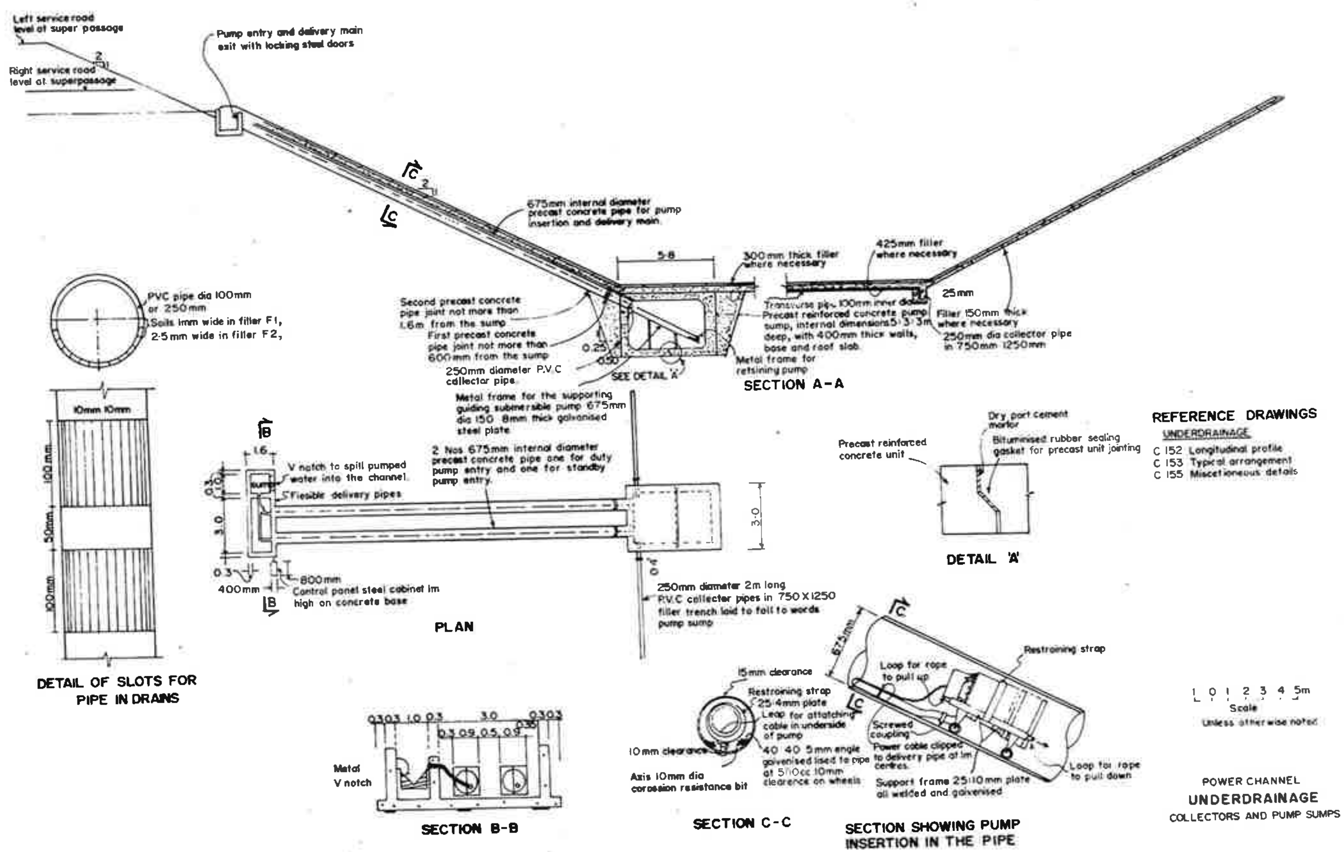

Figure 6. Power Channel Under Drainage Collectors and Pumps Sumps.

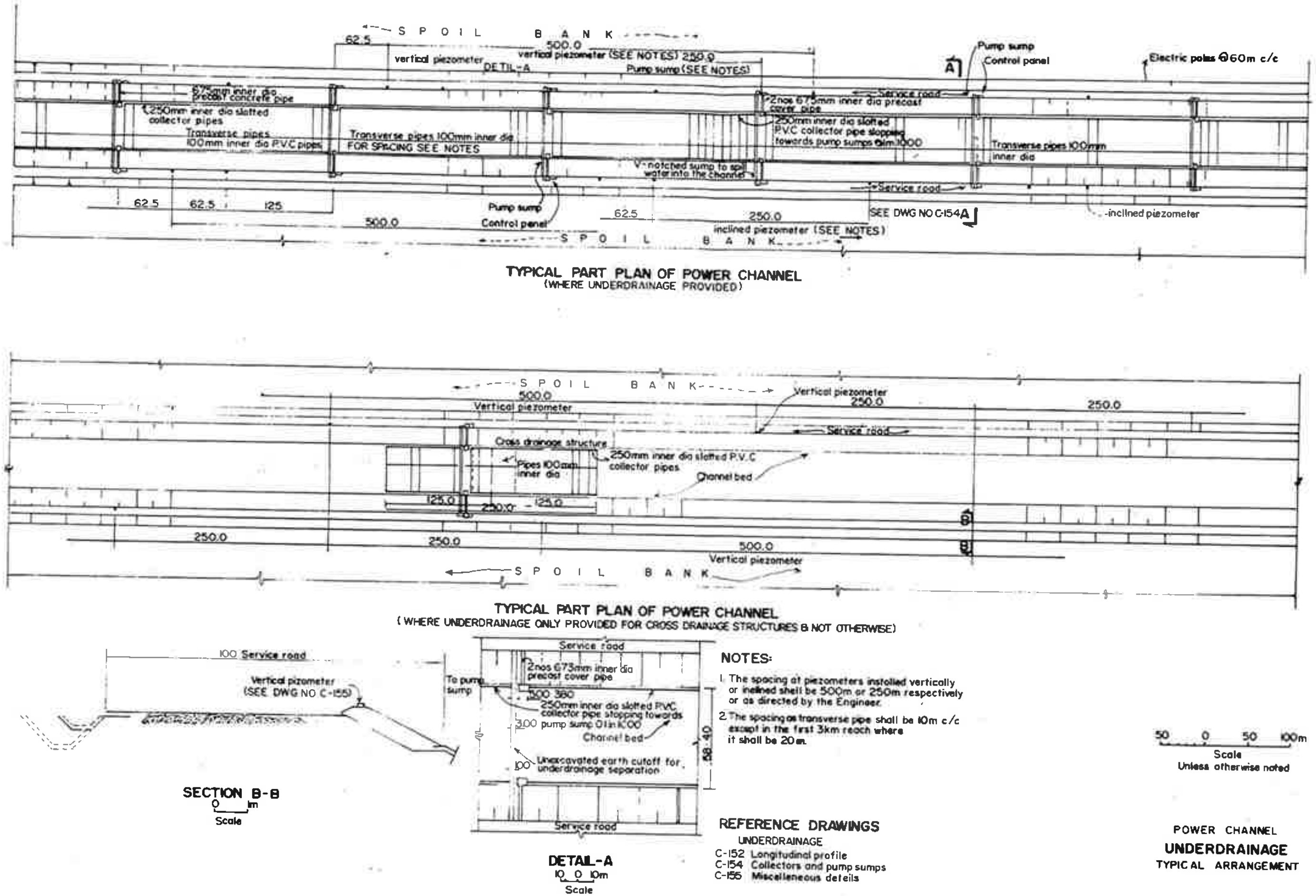

Figure 7. Power Channel Under Drainage Typical Arrangement.

Estimate of Seepage from a Lined Canal

(a) The seepage from a lined canal is taken as 2 cusecs from an area of 10^6m. sq.ft. and 8 cusecs from an unlined canals of the same area, thus saving 6.00 cusecs from 10^6m.sq.ft. of wetted area. There are no records for fixing this order of loss from a lined canal.

(b) About 5 miles length of Thal Main Line Upper, full 18 miles length of Mohajar Branch, about 6.5 miles length of Balloki Sulemanki Link No.1 and a large portion of Haveli lining have been seriously damaged. The main cause is the back water pressure which exerted pressure at the time of canal closure.

Suggestions for Repair to Damaged Lined Canals

A lined canal under operation cannot be closed for more than a year. The time of repair is too short. It will not be easily possible to repair 60 to 90 percent damaged lining. Canals with high groundwater may not be a source of high order of percolation. What is the suitable alternation for repair of such damaged lined canals. May need be advised.

Future Safe Design of a Lined Canal

(a) New lined canal in progress is CRBC. It has no provision to check the rising groundwater, no provision for drainage of back pressure during canal closure, the soil formation is characteristics of the area with practically no sand and low angle of internal friction and low moisture release. What can be the advise of the experts about its safety and stability.

(b) A new design of lining for Ghazi Ghariala canal is proposed. This design is quite different from the lined canal constructed so far in Pakistan. It will be worthwhile to conduct model experiments to check the proposed expansion joints between each slab, necessity of providing submersible pump eight hundred feet aparts and on both sides of the canal and the effectiveness of the filtre provided with perforated drainage pipe.

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SESSION REPORT:
DESIGN AND SEEPAGE MEASUREMENTS

Dr. Muhammad Abid Bodla
IWASRI, Lahore, Pakistan.

The session comprised five papers. Main points covered under each presentation are indicated below:

Paper "*A Country Paper on Canal Lining, The Egyptian Experience*" by Yehia Abdel Aziz

Efficiency of canal linings is experienced to be limited in terms of reduction in seepage losses.

Paper "*Recent Experience of Lining on Small Channels in Punjab Province with Particular Reference to Irrigation Systems Rehabilitation Project*" by Muhammad Ehsan et. al.

The benefits of canal lining were not visible because only hydraulically inefficient channels were selected for these projects and seepage reduction was not considered as the design objective.

Paper "*Seepage Measurement Techniques and Accuracy*" by P. Lawrence et. al.

To get realistic estimation of seepage losses, ponding method is shown to be the most reliable and is recommended to be preferred over other methods.

Paper "*Seepage Loss Measurements on Chashma Right Bank Canal*" by Dr. Muhammad Siddique et. al.

Field measurement indicated that about 30% of the seepage losses were reduced in the sections which were lined as compared to the unlined sections.

Paper "*An Overview of Canal Lining Experience in Pakistan*" by Dr. Nazir Ahmad

The author argued that in general seepage loss rate per canal mile is 0.2 cusecs for distributary canals in Pakistan. To control the seepage about 1.8 million rupees are needed per mile of the distributary canal which may not be an economical option.

TECHNICAL SESSION: PERFORMANCE OF LINING

INFLUENCE OF SURFACE PERMEABILITY ON CONCRETE DURABILITY

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ABSTRACT

By testing permeability, carbonation, corrosion of reinforcement, freezing and thawing deterioration, and analyzing some important engineering examples, the influence of surface permeability on concrete durability has been studied. Surface permeability of concrete controls the ease with which gases, liquids and dissolved deleterious substances can penetrate the concrete, as a result, it determines the performance such as carbonation, corrosion and resistance to freezing and thawing etc. Therefore surface permeability of concrete is one of the most important factors influencing the durability of concrete. In this paper, some technical measures have also been discussed for improving the surface performance of concrete. It has a guidance to concreting.

Keywords: surface permeability, concrete durability, resistance to freezing and thawing, carbonation, deterioration, corrosion.

INTRODUCTION

Though concrete has become the great quantity of use and the most universal, economical and indispensable building material, concrete durability is still an important problem which puzzles structural engineers and material scientists. Because just like all other building materials, concrete is susceptible to deterioration and corrosion in the external environment. Concrete durability is a kind of performance to keep the concrete in service under the affecting of internal or external, anthropogenic or natural factors during the service.

In the past several decades, the study of concrete durability has been given an universal attention in many countries. Since 1960, many symposiums on concrete durability have been held, such as the two International Concrete Durability Conferences held in 1961 and 1968; the 6th, 7th, 8th and 9th International Symposiums on Chemical of Cement held since 1968; and five International Conferences on Durability of Building Materials and Components held after 1978;

etc. As a matter of fact, Concrete durability is one of the indispensable focus topics for discussion in every international concrete conference since the 60's. Civil engineering reconstruction on large scale started in 50's in China; however, some constructions were in a state of facing the problem of repairing and treatment in 70's. From then on, some academic associations, such as Chinese Civil Engineering Society, China Hydraulic and Hydroelectric Engineering Society etc, have done many experimental testing on concrete durability and have organized many national and regional academic workshops on concrete durability. With the accumulation of practical experience of concrete engineering, people are paying more and more attention to the important impact of surface performance on concrete durability.

Concrete is a kind of complex permeable porous material. Many performances of concrete relate to the porosity, pore-structure and the permeability to some certain extent. Concrete surface play a protective role while the physical and chemical corrosion of concrete structure by the environmental factors start from the surface. So concrete surface performance is closely related to concrete durability. For the above reason, the influence of surface permeability on concrete durability and some effective treating techniques have been explored by testing surface permeability, carbonation, corrosion of reinforcement, freezing and thawing and also by analyzing some important engineering examples.

Comparatively speaking, hydraulic structures are all located in those places with poor environmental conditions and are more easily damaged by environmental factors. The investigation of diseases of hydraulic structures indicate that the diseases of all kinds of hydraulic structures, such as canal, gate, dam, spillway, pipe culvert, pole and beam etc, appear on the surface. So surface performance, especially surface permeability has an important significance on the durability of hydraulic concrete structure.

CONCRETE DURABILITY AND ITS INFLUENCE FACTORS

Concrete durability is influenced by many factors which can be classified into two categories: one is the internal factors such as the quality of materials, the water to cement ratio, the cement to aggregate ratio, The adhesive bond developed between the cement paste and aggregates, the air content, the degree of compaction/vibration, the adequacy of curing and the presence of cracking due to primary or secondary stresses (caused by shrinkage, creep, temperature etc) etc; the another is the external factor such as temperature, humidity, acidity, carbon dioxide concentration of sewage or air, thermal shock and loading etc. Here we only discuss some internal factors which influence concrete durability and some basic performances to which concrete durability related.

Selection of Materials and Mix Proportions

1. Cement: 525# Portland cement from JiDong Cement Plant.
2. Sand: Yellow sand from market. Its specific gravity is 2.61 and its fineness modulus is 2.3.
3. Stone: Small stone from market. Its gravity is 2.75.
4. Admixture: Air-entraining agent AE from market.

In order to make the carbonation test easier, first gradation was used. The maximum diameter of stone was 15mm. The water to cement ratios were 0.45, 0.55 and 0.65 separately. The mix proportions are shown in Table 1.

Table 1. Mix Proportions.

No.	Cement kg/m^3	Sand Kg/m^3	Small stone kg/m^3	Air entraining agent ‰	Water kg/m^3	Sand (Sand+ stone) %	Water Cement	Slump cm	Air Content %
TW201	451	611	1133	--	203	35	0.45	6.1	--
TW202	369	671	1143	--	203	37	0.55	6.8	--
TW203	315	726	1135	--	203	39	0.65	5.1	--
TY121	406	596	1107	0.050	183	35	0.45	6.0	7.0
TY122	336	651	1108	0.038	185	37	0.55	6.4	7.0
TY123	282	706	1104	0.040	183	39	0.65	5.3	6.5

Description of Experiment

Water Absorption

When the specimens of 40×40×160mm were cured due date, put them in a drier and dried them at 80°C until the weight was constant as G_o. Then put the dried specimens into water. Weighed their weights G' three hours later. The three-hours' water absorption can be calculated by the following equation:

$$\lambda = \frac{G' - G_0}{G_0} \times 100\%$$

Rate of Water Permeation

In order to show the surface permeability of concrete more clearly, the rate of water permeation was measured. Fixed the 70×80×30mm specimens cured due date on to the mortar permeater and measured the depths of water permeation after six hours under the pressure of $6kg/cm^2$. Calculated the rate of water permeation:

$$v = \frac{h(mm)}{t(\min)}$$

Carbonation

Put the specimens, which had been cured for 28 days, in the drier and dried for one day. Then did the express carbonation test on the national standard basis named as [The Test Methods of Long-term Performance and Durability for Ordinary Concrete](GBJ83-85).

Corrosion of Reinforcement

The specimens were exposed to the weather with a relative humidity of 75 percent. After 520 days, broke the specimens and observed the corrosion of reinforcement.

Resistance to Freezing and Thawing test of freezing and thawing was carried out according to the test rules of hydraulic concrete which was named as [Test of Resistance to Frost on Concrete (Fast)]. The resistance can be judged by measuring the loss of weight.

Analysis and Discussion of Test Results

The test results of surface water absorption, water permeation rate and carbonation depth are given in Table 2.

Table 2. Water Permeation Rate and Carbonation Depth.

	TW201	TW202	TW203	TY121	TY122	TY123
Water absorption %	4.27	4.43	4.75	3.55	3.86	4.06
Water permeation rate mm/min	0.13	0.138	0.245	0.089	0.132	0.145
Carbonation depth (28d) mm	4.29	7.73	12.01	3.05	5.44	8.40

According to the test data of Table 2, we can find out: both the water absorption of surface and the rate of water permeation increase with the increase of water to cement ratio. For specimens with the same water to cement ratio, the air-entrained specimens have lower water absorption of surface and slower water permeation rate. So with the increase of water to cement ratio, the concrete density will decrease and the porosity and permeability will increase. But with the entraining of just the right amount of closed air bubble, the water absorption of surface and the rate of water permeation will decrease.

During the carbonation test, the method of express carbonation was adopted to measure the depth of carbonation of 28 days (correspond to 50 years). The carbonation test results demonstrate that: With the increase of permeability, the carbonation depth of corresponding specimens of 28 days will increase. So the surface permeability of concrete is one of the important factors influencing the rate of carbonation. The high alkalinity of concrete makes the surface of reinforcement inactive. The higher the surface permeability, the easier carbon dioxide, chloride ion and other deleterious substances will penetrate the concrete. Carbon dioxide penetrated the concrete reacts with strongly alkaline calcium hydroxide always presented in concrete to make the concrete carbonation. This carbonation process greatly reduces the alkaline environment of concrete. With the decrease of the alkalinity of the concrete, the inactive surface of reinforcement will become unstable or even be damaged. Thus the reinforcement that is out of protection will be easily corroded by the deleterious substances which penetrate the concrete. The penetrating deleterious substances can also corrode the concrete itself and make it deterioration. If some dense treatment techniques, such as trowelling or other methods, are adopted to increase the drag of surface permeating and reduce the surface permeability, the carbonation process will be slowed down.

There were 6mm reinforcements in the center of the concrete specimens which were used to test the reinforcement corrosion. The specimens were separated into two groups: one group was carbonated overall and the another group was not carbonated. The two groups of specimen were put into the same environment with a relative humidity of 75 percent. The test results of reinforcement corrosion are presented in Table 3. The data of reinforcement corrosion indicate that: the reinforcements in the not carbonated specimens have not been corroded at all, while the reinforcements in the fully carbonated specimens have all been corroded to different extent. So concrete carbonation can meet the condition of reinforcement corrosion, for there is always enough water meeting the need of corrosion in concrete.

Table 3. Results of Reinforcement Corrosion (RH=75 Percent, for 520 days).

		TW201	TW202	TW203	TY121	TY122	TY123
The ratio of loss in weight %	Carbonated	0.037	0.077	0.127	0.053	0.083	0.253
	Not be carbonated	0	0	0	0	0	0

A summary of the freezing test results is presented in Table 4. The data of Table 4 indicate: with the increase of water to cement ratio, surface water absorption and permeability increases and the resistance to freezing and thawing of concrete will be reduced. But the entraining of just the right amount of closed air bubbles will greatly enhance the concrete resistance to freezing and thawing. This is because that the separated and closed air bubble added to concrete not only make it difficult to saturate the concrete by reducing the surface permeability, but also provide escaping boundary for water pressure when water held in capillary pores freeze and ease up the tendency of expanding, thus the resistance to freezing and thawing is greatly improved.

Table 4. Freezing Test Results.

	TW201	TW202	TW203	TY121	TY122	TY123
Freeze and thaw circle	100	75	75	300	300	150
Weight percent	93.5	92.5	90.3	93.9	93.5	92.3

Though there are many internal factors that influence the concrete durability, in the final analysis, these factors influence two important essential characteristics: permeability and strength. Carbon dioxide, which permeate in concrete, reacts with the alkaline calcium hydroxide and leads to concrete carbonation; the cover damaging of carbonation and the penetrating of the deleterious substances lead to reinforcement corrosion; the penetrating of all kinds of deleterious substances lead to concrete corrosion; and with the freezing of water held in capillary pores under the negative temperature, the water molecules will expand and cause freezing and thawing damage. Being exposed to the environment, the surface of concrete play a protective role. And concrete surface permeability controls the rate with which all kinds of gases, liquids and dissolved deleterious substances penetrate the concrete structure. So concrete surface permeability is one of the most important factors influencing the durability of concrete.

ANALYSIS OF ENGINEERING EXAMPLES

Durability is an essential and important performance of concrete. With proper designing, suitable raw materials and mix proportions and good concreting, concrete is originally a kind of good building material with good durability. But if there are defects in the designing, raw materials, mix proportions and quality of concreting, some problems will quickly appear in early stage. Especially all irrigation works are exposed to adverse circumstances condition and disease appear easily. In the past, we have investigated many reservoirs, canals, gates and dams, and have done protecting and repairing work for many irrigation works too. We find out that most disease are surface damages or internal damages led by the surface damage except a few structural damages. Figure 1 shows the condition of being full of cracks and peeling off on the surface of U-shaped thin aqueduct bridge that is located at HaiZhi village of Beijing suburb.

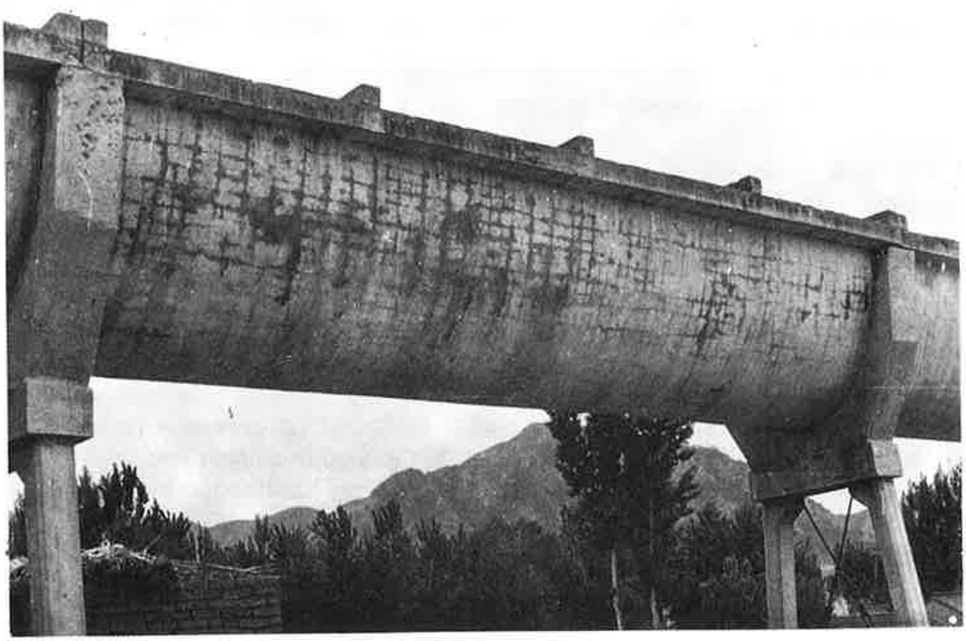

Figure 1. HaiZhi Aqueduct Bridge Being Full of Cracks and Peeling off.

Figure 2 shows the state of peeling of the prestressed wire concrete pipe that is located at Ban Cheng Zhi Reservoir after corrosion of steel mesh reinforcement.

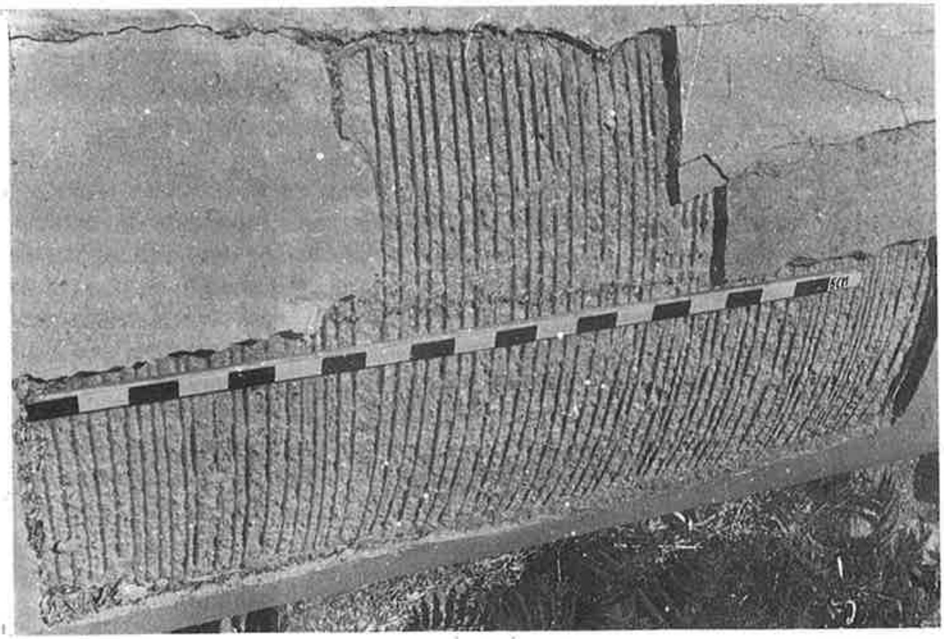

Figure 2. Ban Cheng Zhi Reservoir Prestressed Wire Concrete Pipe Peeling and Corrosion of Steel Mesh Reinforcement.

Figure 3 shows the situation of bulging and scaling in part of the right concrete slope protection of YuLin West Gate. And Figure 4 shows the condition of spelling on large scale of the spillway apron of HaiZhi Reservoir that is located at suburb of Beijing. The reasons which cause damages are complicated and are the results of combining effects of various factors. The main reason is that the unqualified raw materials, poor concreting and curing cause the surface density decrease and permeability increase, and thus leave hidden troubles in concrete. Under the condition of adverse environment, it will be full of cracks and leakage, or damage the cover by carbonation and then lead to reinforcement corrosion and scaling, or be damaged by freezing and thawing and then lead to bulging and scaling in part or spelling on large scale. During the investigation, besides the investigation and analysis of damage condition of common engineering, we have made a full analysis of carbonation zone on the engineering which was being demolished and rebuilt. HuaiRou Reservoir, which was built in 1958 and located at suburb of Beijing with a capacity of 98 million cubic meters, plays an important role in controlling flood and serving agriculture of north mountain area. The east spillway were rebuilt in 1964.

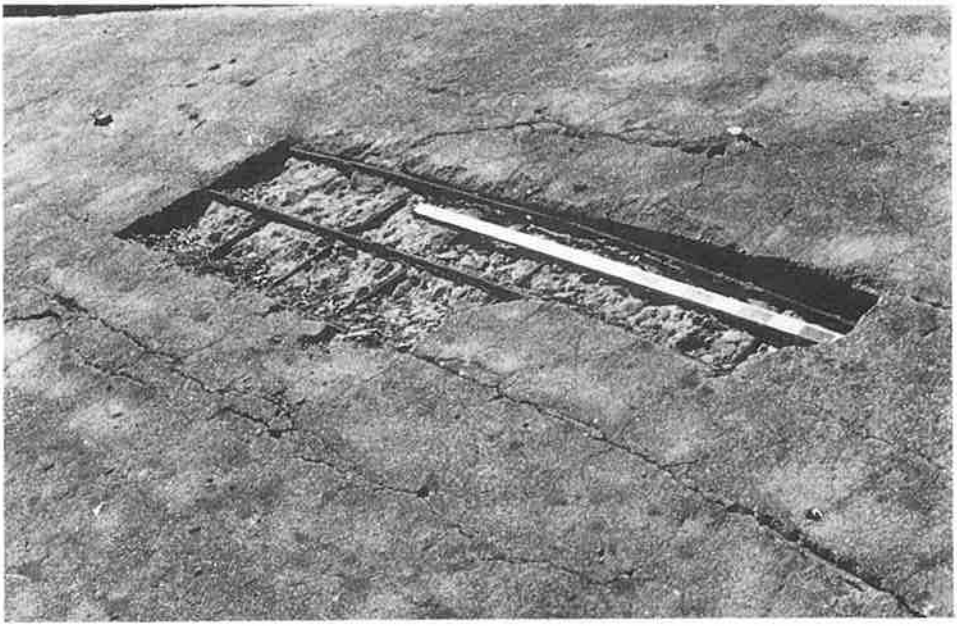

Figure 3. YuLin West Gate Bulging and Scaling.

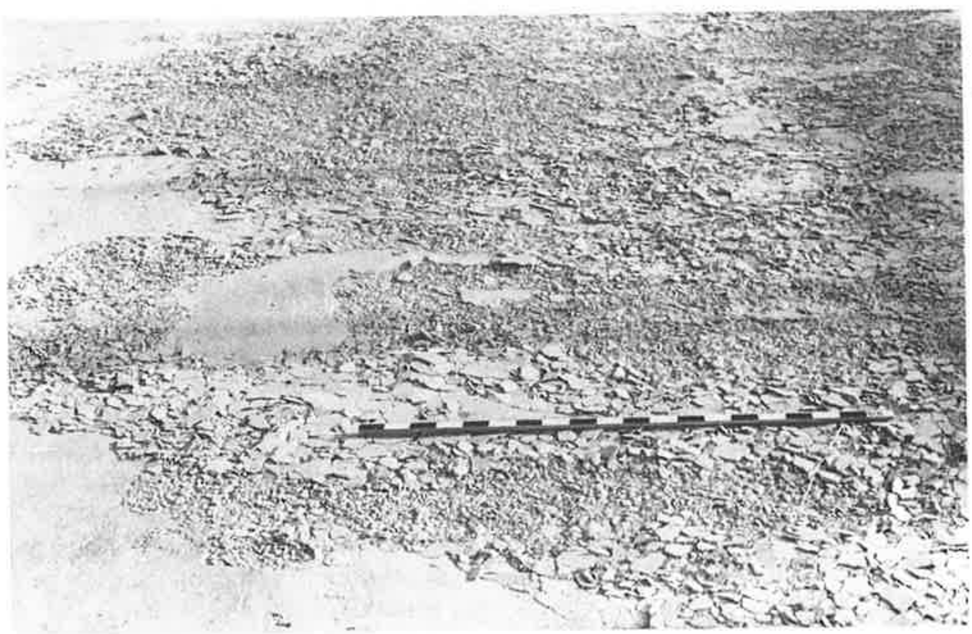

Figure 4. HaiZhi Reservoir Spillway A pron Spelling on Large Scale.

In order to meet the need of developing of modern agriculture and controlling flood in north mountain area, HuaiRou Reservoir was further expanded in the late 1980's, and east spillways were expanded in 1989 again to increase its discharging capacity.

By this rare chance, we made an all-round careful investigation on the demolishing site of this important irrigation work which had been on service for twenty five years. Figure 5 shows photograph of the treated demolishing section of right bier of east spillways. The carbonation zone had reached a depth of 32-43mm.

Figure 5. Right Bier of East Spillways of Huai Rou Reservoir.

This is because that the unsuitable concreting, propping mould and forming stripping make the density decrease, meanwhile the permeability of the right bier increase and then quicken up the carbonation rate. The treated demolishing section of weir crest of east spillway chamber floor is shown in Figure 6. For the repeatedly vibrating and trowelling when the weir crest was casted, it has better density and smaller permeability and the carbonation depth is only 3-5mm after twenty five years. The actual investigation of the whole spillway indicates that: for the impact of quality of concreting and curing, the different components at the same strength grade even the different parts of the same component have a great difference in their carbonation rates. Especially, some components such as the beams, biers, columns etc have poor density, high permeability and fast carbonation rate for the unsuitable propping mould, forming stripping and the poor curing.

Figure 6. Weir Crest of East Spillway Chamber Floor of HuaiRou Reservoir.

TREATMENT TECHNIQUES

According to the research achievement in laboratory and the practical experience of engineering, in order to improve the durability of concrete structure, we should consider all kinds of factors overall, for example: the assortment and quality of such raw materials as cement, aggregate and admixture, the variety and mix proportion of concrete, especially the water to cement ratio and the concreting quality, environmental condition and so on. In addition, we can take some surface treatment techniques to increase the density and permeating resistance to enhance concrete structure's durability. In connection with concrete during placement:

1. The aggregates should have enough strength and resistance to permeation and freeze, and should not contain harmful quantity of organic and inorganic matters. The water to cement ratio has an important influence on concrete permeability. To get suitable workability and dense vibrocast concrete, enough cement mortar and fine powder are necessary. We can reduce water by adopting water reducer and air-entrainer to improve the concrete pore structure and avoid shrinkage. While the air-entrained concrete keep a constant mix proportion and an increasing slump, its impermeability will be improved for air entrainment. Because small amount of air entrainment can produce many small but stable and separated air

bubbles. After casting, the existence of the air bubble can reduce the freely moving water and the water secretion to cut off the capillaries which are generally linked up with each other by stopping water raising and using up parts of water by themselves. So the adopting of superplastisizer and air-entrainment is the essential workable measure to decrease permeability and improve durability.

2. During the construction, the construction regulations should be followed to enhance the density of casting and vibrating and the constructing quality. The technique of vacuum absorbing can also be adopted to remove the excessive water and the surface water to increase the surface density and decrease surface permeability.

3. During the construction, we must rigorously follow the curing regulations. Curing agent and surface hardening agent can also be adopted to improve the condition of construction and curing, improve the ability of containing water and to accelerate the surface hardening and improve the curing condition of concrete especially concrete surface.

Once a concrete structure is in place, the only feasible method of reducing water permeation is to seal the exposed surface. Special surface soakings and coatings are often used effectively today to reduce the surface permeability and both to improve the durability of new structures and to slow down the rate of further deterioration of old structures. We propose that further research work should be strengthened and the understanding on concrete surface performance should be deepened to further guide engineering practice in the future.

CONCLUSION

1. Surface permeability of concrete controls the ease with which gases, liquids and dissolved deleterious substances can penetrate the concrete. As a result, it determines the performance such as carbonation, corrosion, reinforcement corrosion and resistance to freezing and thawing etc. Therefore the surface permeability is one of the most important factors influencing the durability of concrete constructions. Water to cement ratio is the most essential factor influencing concrete permeability. The entraining of just the right amount of small closed air bubble can reduce concrete permeability and greatly improve the resistance to corrosion, carbonation and freezing and thawing, as well as improve the durability of concrete.

2. On the practical works especially hydraulic constructions, except few structural damages, most diseases are surface deterioration, scaling or internal damage which are led by the surface damages, greatly lower the durability of concrete structure.

3. Both study achievement and practical experience show that, in order to enhance concrete structure durability, we should take into consideration all factors: the assortment and quality of raw materials such as cement, aggregate and admixture etc, the classifications and mix proportion of concrete especially the water to cement ratio and the concreting quality, environmental condition etc. In addition, in connection with placing concrete, the technique of vacuum absorbing or superplastisizer, air entrainment, curing agent and surface hardening agent can be adopted to improve the surface performance and concrete durability. As for the concrete in place, special surface soaking and coating can be used to reduce concrete surface permeability so as to improve the durability of new structures and to reduce the rate of further deterioration in old structures.

4. In the future, the study of concrete surface performance should be further strengthened.

ACKNOWLEDGMENTS

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ROLE OF DESIGN AND CONSTRUCTION TECHNIQUES IN CANAL LINING

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INTRODUCTION

The author had the privilege of planning designing or supervising construction of over 500 miles of channels spread all over Pakistan. Details of such channels are listed in Table 1. He has already contributed two papers on the forum of Pakistan Engineering Congress on the various aspects and experiences on Lining. However, in this Workshop specific topics have been allocated to different authors. The author, being directed to write on "Roll of Design and Construction Techniques in Canal Lining", will try to restrict the narrations to this designated topic.

WHY TO LINE THE CHANNELS

Conservation of water supplies is becoming increasingly important all over the world due to increased pressure on land and water resources by unchecked growth of population. New sources of supply are becoming scarcer. In Pakistan we have almost fully exploited our natural resources through run-of-the river and storage Projects. Since new storage reservoirs are not likely to be constructed in the near future due to geo-political reasons apart from long gestation period and prohibitive costs, naturally, emphasis is being laid on methods for salvaging the supplies already being lost within the irrigation systems in the form of seepage. One of the most important ways for optimum utilization of water supplies for agriculture could be through reduction in the amount of water lost by seepage during transportation to farmer's field by lining the system channels and reduction of evapotranspiration losses by control of vegetation on channel berms and weeds in the farms. Estimated water losses in unlined conveyance systems of different countries in the world varies from 25% to 50% of total diversions (Table 2). Thus the savings from seepage losses can save huge quantities of water from within the systems depending upon the type and efficiency of the lining selected under particular field conditions. So canal lining is a potential tool to generate very valuable quantities of water for crops by reducing percolation losses from the channel prism. This tantamounts to saving water from within the canal systems for increasing irrigation intensity and in turn the yield of agriculture produce per acre and hence the justification for lining.

Table 1. List of Lined Channels Designed or Built under the Supervision of Author.

S.No.	Name of Channels	Millage	Location
1.	Distributaries and Minor in Command Water Management Project, under Shahkot, Pakpattan, Niaz Beg and 6-R (Hakra) Subprojects.	298.88	Punjab Province
2.	Distributaries and Minors in Command Water Management Project, under Sehra/Naulakhi Subproject.	140.00	Sindh Province
3.	Lining of Warsak Lift Canal under Command Water Management Project.	28.82	NWF Province
4.	Lining of Minors of Lasbela Canal under Command Water Management Project.	16.20	Balochistan Province
5.	Chashma Right Bank Canal-Stage-II	24.00	NWF Province
6.	Warsak Gravity Canal	4.00	NWF Province
	Total	511.90	

Note:- The design discharges of these channels vary from 5 cusecs to 4,000 cusecs.

WHERE TO LINE THE CHANNELS

Channels may be lined where

i) Seepage losses in the canal are generally greater than 4 cusecs per million sq.ft. of the wetted perimeter of the canal or the soil is very porous/sandy.

ii) The bed of the channel is above the prevailing water-table (water-table higher than the bed level of the channel makes lining process extremely difficult and costly apart from the fact that it will burst the lining in the bed or sides when there is a sudden draw-down as can happen during a breach).

iii) The quality of groundwater is saline and the water lost in seepage can not be recovered by tubewells.

iv) Value of water saved can economically balance the investment on lining. According to an author - "ordinarily, expenditures involved in reducing canal seepage losses to values as low as 5 percent of total conveyed water are economically justified only in regions where water supplies are insufficient and crop products are unusually valuable". Balochistan province in Pakistan is typically such a case.

Table 2. Estimated Water Losses in Unlined Conveyance Systems.

S.No.	Reference	Country (Project)	Water Losses in Percent of Total Water Diverted	Remarks
1.	U.S. Bureau of Reclamation (A12).	46 irrigation Projects in the U.S.A.	3-86 (average 40)	Records from 46 irrigation Projects including seepage water taken up by uncontrolled vegetation in the canals and evaporation losses of canals.
2.	Khangar Maasland, M.	West Pakistan	18- 44	Seepage Losses only.
		West Pakistan-Indus River Basin	35	Mean figure of total conveyance losses.
3.	Kennedy	West Pakistan-Bari Doab Canal.	20	Canals and branches.
			6	Distributaries.
			21	Watercourses (ditches)
			47	Total losses
4.	Barona, F.	Mexico	26	Less pervious soils.
			35- 50	More pervious soils.
5.	Doneen, L.D.	Turkey-Konya Cumra Plain	40	
		Turkey- Menemen Plain	30	
6.	Lauritzen, C.W.	U.A.R. -Nile Delta area.	8 - 10	Low because of silting effect of Nile water.
		U.A.R. -New canals in desert areas.	50	
7.	Sharov, I.A.	U.S.S.R.	20 - 35	Mains and distributaries.
8.	Sain, K.	India, Ganges Canal	15	Main canals and branches.
			7	Distributaries.
			22	Watercourses.
			44	Total seepage losses.
9.	EPTA Report No.1519 1962.		Maximum 40% average year	Total seepage losses.
		Pakistan	5.7	Main canals.
		Kushita unit of the Ganges-Kobadak	7.3	Secondary canals.
		Irrigation Scheme	12.0	Tertiary canals.
			25.0	Total Seepage losses.
10.	Hekket, H. 1969	Iran Garmsar Irrigation project	40	Main and secondary canals.
11.	Ministry of Public Works Chile.	Huasco Valley Project	54 (ca. 2.2 per km)	Canal of 25 km length having about 1 cumecs discharge capacity.

Source: Irrigation Canal Lining by D.B. Kraatz, F.A.O, Rome-1971.

Lining should not be done where:

i) Seepage losses in the canal are generally less than 4 cusecs per million sq. ft. of the wetted perimeter of the channel or the soils are comparatively impervious, formed of clayey loams.

ii) The groundwater is fresh/sweet and can be easily extracted by private tubewells. Under such conditions where water lost through canal seepage may be recovered and used within the project area, the total cost of prevention of such seepage should not be charged to the benefit side of the economic comparison.

iii) The watertable is higher than the bed level of the proposed lined channel even after marginal adjustment in the bed width and depth ratio.

HOW TO LINE THE CHANNELS

Several types of canal lining are in vogue all over the world which are listed in the subsequent sub-paragraphs. The most suitable type can be selected for the conditions prevailing in the area under consideration.

Hard-Surface Lining

1. Reinforced cement concrete,
2. Plain cement concrete,
3. Shotcrete,
4. Prefabricated cement concrete units,
5. Brick or tile,
6. Asphaltic concrete,
7. Stone,
8. Soil-cement and
9. Compacted/stabilised earth.

Exposed Membranes

1. Asphaltic material,
2. Polyvinyl Chloride,
3. Synthetic rubber butyl or EPDM rubberised membrane,
4. Resin and
5. Fiberglass.

Buried Membranes

- Pre-fabricated asphaltic membrane,
- Polyethylene and
- Bentonite layer.

Commonly Used Types of Lining in Pakistan

Most commonly adopted linings in Indo-Pak. Sub-continent during the last half century are the following two types:

i) Cement concrete lining (Plain cement)
ii) Brick/Tile lining (with or without reinforcements)

DESIGN OF LINED CHANNELS

The section of lined channels are designed by the popular Manning's Equation given below:

$$V = \frac{1.486 \times (R)^{\frac{2}{3}} \times (S)^{\frac{1}{2}}}{n}$$

where:

V = Mean velocity in the cross-section (ft/sec.)

R = Hydraulic Mean Radius= $\frac{A}{P}$ (ft)

A = Water area (ft)

P = Wetted perimeter of the channel (ft.)

S = Water Surface Slope (ft/ft.)

n = Manning's Coefficient of roughness

The discharge of the channel (Q) = VxA (cusecs.)

The value of "n" used in the Manning's Equation varies according to the type of lining and the finish obtained during construction. Various values given by different authorities based on text books and actual experience are given in Table-3.

Table 3. Manning's Coefficient of Roughness 'n' for Lined Channels.

TYPE OF LINING	VALUE OF 'n'
Portland cement concrete lining	0.014
Asphaltic concrete lining (machine placed)	0.014
Brick lining covered with cement plaster	0.014
Soil cement, well finished	0.015
Soil cement, rough as a gravel surface	0.016
Exposed prefabricated asphalt material	0.015
Precast concrete-block lining	0.015-0.017
Brick lining, with exposed brick surface design value: Haveli Canal)	0.0146
Actual measured with value of 'n' on the same lining after gradual deterioration (Haveli Canal)	0.018
Shortcrete lining, smoothed	0.016
Shotcrete lining, average	0.017
Compacted earth lining, small canals	0.025
Compacted earth lining, large canals	0.020-0.0225

FACTORS AFFECTING THE DESIGN

Some of the major factors which need a very careful consideration in the design of lined channels comprise but not limited to the following:

i) Cross Section

ii) Subgrade

iii) Subgrade Sterilization

iv) Coefficient of Roughness

v) Embankments

vi) Subgrade Drainage

vii) Design Water Velocities

viii) Prevention of Silt Deposits in Canals

ix) Thickness of Lining

x) Joints in Lining

These are discussed hereunder in seriatim.

Channel Cross Section (Geometry)

Side Slopes

In order to have the most economical lined section the geometry should be such that it has the least perimeter for a given area. A semi-circle has, theoretically, the smallest perimeter for a given area but its construction is not practical because the top portions of the sides are too steep to be easily constructed and maintained. Moreover forming and screeding of such a section is very difficult. The steepest satisfactory side-slope for most canals from both construction and maintenance point of view is 1.5:1.

Steeper slopes could be used on small channels where the soil materials remain stable. Some of the major failures in lining have been noticed where the side slope was kept steeper than the natural angle of repose of the soil under saturated conditions. For example the lining of Haveli canal with a side slope of 1:1, apart from the other considerations failed immediately after construction due to slippage of the sides. So major limitations to the steepness of side slopes for hard surface linings are slippage of the lining and soil stability. Slippage may be caused by insufficient friction between the lining and the subgrade in combination with effects on external hydrostatic pressure during sudden drawdown in the channel.

Successful performance of Sidhnai-Mailsi-Bhawal Link Canal after 27 years of construction is mainly due to a flatter side slope of 2:1, in addition to a better design of lining. However, in case of flatter side slopes and low velocities in the channel or during partial running of the canals some siltation and vegetation growth has been noticed in certain canals just above the water level.

Bed Width to Depth Ratio

Canals provided with a hard surface lining are usually designed with a finished bed width to water depth ratio of 1 to 2.

Small channels normally have a ratio of 1, while this ratio for large canals may exceed 2. Some large canals in the Indo-Pak. sub-continent have ratio upto 10.

Freeboard

Designs of canals must specify free boards of sufficient height to prevent overtopping of the banks during sudden rises in water levels.

The magnitude of freeboard in lined canals depend on size of the canal, condition of flow, curvature of alignment, entry of storm water into the canal, wind and wave action, increase in flow due to wrong regulation, variation in friction coefficient, accumulation of silt and anticipated method of operation.

The normal freeboard for hard surface linings ranges from 6 inches for small canals to over 2 ft. for larger ones. The height of the canal bank above the top of lining usually ranges from 1 to 2 ft. depending on the size of canal and local conditions. Figure 1 could be used as a guide.

Design Characteristics of Some Lined Canals

Design characteristics of some lined canals in Pakistan, India and U.S.A. are shown in Tables 4 through 6. These tables give an idea about the side slopes, bed width to depth ratio and 'n' values adopted in some very prominent canals in the world and can serve as a guide in future design of channels.

Subgrade

Compaction of Subgrade

A primary pre-requisite to the success of most hard surface linings is a firm foundation in order to reduce the amount of cracking and the danger of failure due to settlement of the subgrade.

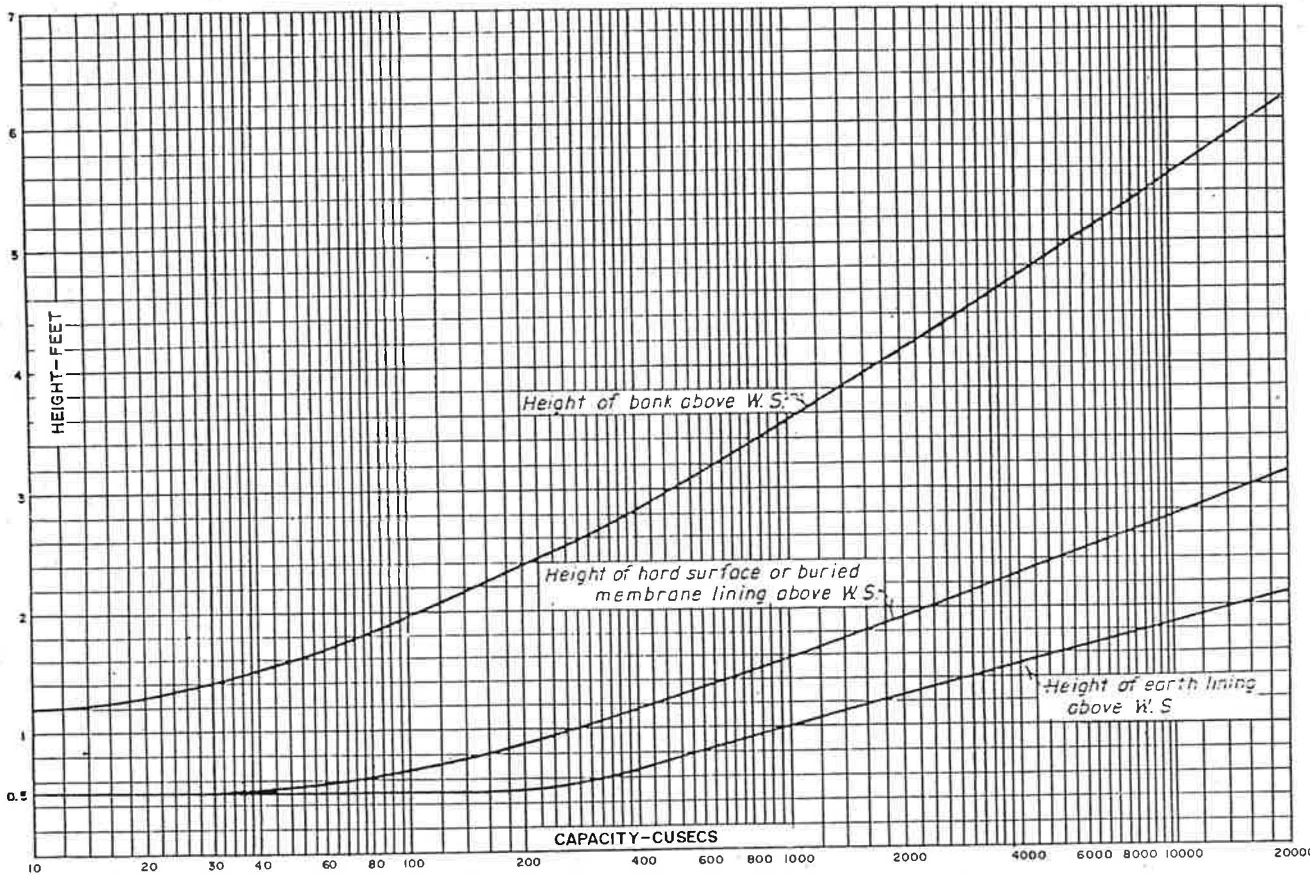

Figure 1. Bank Height for Canals and Freeboard.

Table 4. Design Characteristics of Lined Canals in Pakistan.

Canal	Type of Lining	Discharge (Cusecs)	Bed Width (ft)	Side Slope H:V	Depth (ft)	Bed Slope	Velocity (ft)	Manning's 'n'	
								Design Value	Measured Value
SIDHANI-MAILSI-BAHAWAL (S.M.B.) LINK	BRICK	10,100	100	2:1	18.0	1:10,500	4.1	0.0200	-
S.M.B. LINK	BRICK	8,900	90	2:1	17.7	1:10,500	4.0	0.0200	-
S.M.B. LINK	BRICK	4,700	50	2:1	16.0	1:10,500	3.5	0.0200	-
S.M.B. LINK	BRICK	4,000	40	2:1	15.9	1:10,500	3.5	0.0200	-
THAL MAIN CANAL UPPER (MEASURED DATA)	BRICK	7,250	-	-	12.2	1:11,700	4.6	-	0.017
THAL MAIN CANAL LOWER (MEASURED DATA)	BRICK	4,850	-	-	10.0	1:10,286	4.9	-	0.015
HAVELI MAIN LINE (MEASURED DATA)	BRICK	5,200	-	-	11.4	1:13,193	4.2	0.0146	0.018
AKRAM WAH (MEASURED DATA)	BRICK	2,560	-	-	11.1	1:14,789	3.6	-	0.014
CRBC STAGE-II	CONCRETE	3,600	37	-	16.0	1:14,4000	3.7	0.0160	-
BALLOKI-SULEIMANK LINK-I	BRICK	12,000	112	-	16.4	1:8,000	5.1	0.0170	0.018
HAVELI MAIN LINE	BRICK	6,000	84	1:1	12.0	-	-	0.0146	0.018
LASBELA MAIN LINE	PRECAST CONCRETE TILES	90	-	-	-	-	-	0.0150	0.022
PEHUR HIGH LEVE CANAL	BRICK	750	11	-	10.8	1:5,000	6.5	0.0150	-
WARSAK LIFT CANAL	CONCRETE	200	9	1.5:1	4.3	1:2,000	4.2	0.0150	-
-DATA NOT AVAILABLE									

Table 5. Design Characteristics of Lined Canals in India.

Canal	Type of Lining	Discharge (Cusecs)	Bed Width (ft)	Side Slope H:V	Depth (ft)	Bed Slope	Velocity (ft)	Manning's 'n'
Dhansiri, Main	Concrete	2,000	66.4	1.5:1	5.3	1:1,500	5.1	0.021
Banas, Left Bank	Sandwiched Brick	1,100	16.3	1.5:1	8.0	1:2,500	4.9	0.018
Damanganga, Right Bank	Concrete	1,230	14.8	1.5:1	8.5	1:2,500	5.2	0.017
Karjan, Left Bank Main	Concrete	1,000	13.1	1.5:1	8.9	1:3,00	4.3	0.019
Mahi, Right Bank	Sandwiched Concrete	7,000	54.0	1.5:1	20.4	1:7,000	4.0	0.025
Narmada	Concrete	39,700	248.0	1.5:1	24.9	1:12,500	5.6	0.018
Ukari, Left Bank	Double Tile	1,236	21.3	1.5:1	9.8	1:8,000	5.5	0.016
Bahakra	Double Tile	6,780	40.4	1.5:1	17.7	1:8,000	5.7	0.015
Augmentation	Double Tile	31,000	44.0	1.5:1	13.2	1:5,000	3.7	0.025
Jawaharlal Nehru Lift Canal	Double Tile	3,200	66.4	1.5:1	8.6	1:5,000	4.7	0.017

Table 6. Design Characteristics of Lined Canals in India.

Canal	Type of Lining	Discharge (Cusecs)	Bed Width (ft)	Side Slope H:V	Depth (ft)	Bed Slope	Velocity (ft)	Manning's 'n'
Main (Reach Below Long Lake)	Concrete	9.700	50	1.5:1	20.7	1:10,000	5.77	0.0146
Delta-Mendota	Concrete	4,600	48	1.5:1	16.6	1:20,000	3.81	0.0138
Main (Trial Lake Reach)	Concrete	13,200	20	1.5:1	21.0	1:1,640	12.21	0.0152
Eastlow	Concrete	4,500	20	1.5:1	18.9	1:10,000	4.92	0.0144
Frianktkern	Concrete	5,000	36	1.25:1	17.2	1:10,000	5.06	0.0143
Roza Main	Concrete	2,200	14	1.25:1	11.2	1:2,500	7.02	0.0145
	Concrete	1,300	12	1.25:1	9.1	1:2,564	6.14	0.0143
Madera	Concrete	1,000	10	1.25:1	9.0	1:3,333	5.25	0.0142
Gateway	Concrete	700	10	1.5:1	6.9	1:2,857	4.99	0.0141
Charles Hansen	Concrete	1,500	12	1.25:1	7.2	1:769	9.98	0.0142
Madera	Concrete	823	8	1.25:1	7.1	1:1,428	6.91	0.0141
Chirapur	Concrete	8,825	16.5	1.5:1	13.0	1:4,000	6.00	0.0140*

* Design Value of 'n'

Lining of Haveli canal built in 1938 without compaction of subgrade failed immediately after its first operation and had to be rebuilt after compacting the subgrade.

Undisturbed soils are often satisfactory for a foundation for lining without further treatment. However, natural in-place soils of low density (light soils) should be thoroughly compacted or removed and replaced with suitable material. Because of the expansion qualities when wet, clays are usually a hazard to hard surface linings and they shall be avoided.

Treatment of Expansive Clay Subgrades

a) If it is necessary to place a concrete or other rigid type of lining on expansive clay, these are several ways of reducing or controlling the probable damage. Clays vary so much in characteristics that the pressure required to prevent expansion may be less than 1 lbs/sq.in. in some types and as much as 150 lbs/sq. in. in others. If the clay encountered can be controlled by loading the surface with non-expansive compacted soil, lining can be placed on this loaded subgrade and satisfactory service obtained.

b) Similarly, if the expansive clay is a thin layer in an otherwise suitable subgrade, it has been found fairly effective to overexcavate the canal and replace the clay with gravel. Excavation to a depth of at least 2 ft. has so far been practiced but the depth and type of clay will influence the amount of excavation required.

c) Where over excavation is prohibitive alignment changes to possibly better soils may be the best solution.

Treatment of Gypsum Soils in Subgrade

Gypsum soil is another hazard to hard-surface linings. Water in contact with gypsum will dissolve salts in the soils, in time creating cavities which may result in canal breaches and serious damage. A totally waterproof lining with a buried membrane would prevent most failures, but action by rain water may also cause trouble. Successful solutions include making the lining waterproof by applying a cement-plaster coating over the existing concrete lining or placing a compacted layer of selected clay material under the concrete lining. Various drainage systems are also used to rapidly remove water that gets under the lining.

Drainage of Canal Roads in Lined Canals

There can be certain situation where a flood embankment has to be built along one of the banks of a lined canal. The canal road in such cases with flood embankment on one side and the safety dowel on the other side gets flooded during rain storms. There have been cases when such flooding resulted in sink holes in the canal bank which conveyed huge volumes of water towards the canal prism resulting in colossal damage to lining, specially when the canal happens to be empty (during initial construction or annual closures). Such damages were numerous during construction of Chashma Right Bank Canal-Stage-II. In order to guard against such damages Canal-Road Drainage arrangements shown in Figure 2 had to be provided. This arrangement disposes the rain water discharges accumulated on the canal road back to canal since they can not be discharged out through the flood embankment.

Subgrade Sterilization

Weeds may be a potential hazard not only to earth or membrane linings, but also to asphaltic linings. Weeds may penetrate the latter and, when dead, leave openings through which water can leak. Treatment of the subgrade with a soil sterilant is advisable when such linings are to be placed in areas already weed infested or in old canals where such weeds are tules, cat tails, or willows are growing. Boron compounds, principally borax and boric acid, are favoured for use in conjunction with chlorates in sterilant treatments because the borates tend to leach more slowly. The U.S. Bureau of Reclamation recommended a water solution of polyborchlorate applied by spraying directly on the subgrade prior to placing the lining. Adequate sterilization is normally achieved by using an equivalent of 270 grams of powdered polyborchlorate per square meter of subgrade.

Coefficient of Roughness

The value of coefficient of roughness or Manning's 'n' to be adopted in the Manning's Equation varies according to the type of lining and the finish obtained during construction. Various values given by different authorities based on text books and actual experience have already been reproduced in Table-3. The proper selection of 'n' value is a very sensitive and controversial issue and has to be selected very carefully based on the experience of the designer. For concrete lining, in the beginning of operation the well finished concrete surface is very smooth and 'n' comes near to 0.013 but with the passage of time, the surface gets rough due to sticking of clay etc. and growth of fungus and vegetation increases the 'n' value to 0.018 and in some cases it goes upto 0.02.

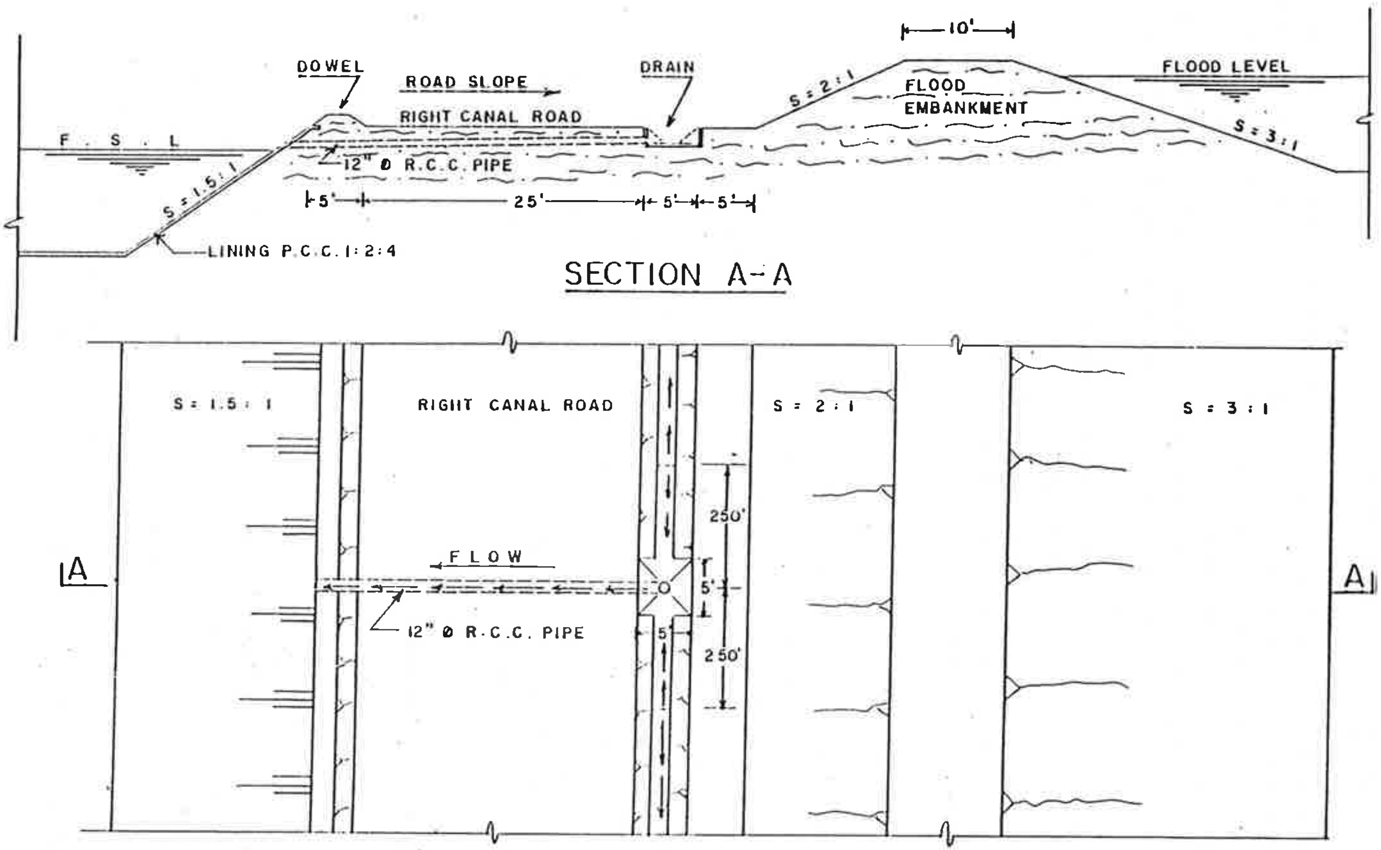

Figure 2. Proposal Showing Right Canal Road Drainage from Catch Water Drain to the Canal through R.C.C. Pipe.

During the design of Haveli canal in 1938 a very low value of 'n' (0.0146) was adopted but actual roughness being higher the channel attained a higher water depth which resulted in overtopping and eventual failure of lining. For bigger conveyance channels it is always safe to adopt a conservative value of 'n'. However, for distribution channels if a liberal value is adopted then during initial operation periods, water depth attained may be lower which may pose command problems. So selection of 'n' value has to be very judicious, by keeping in view the present as well as future conditions obtainable in the channels.

Embankments

Compaction of Embankment in Fill

For most hard surface linings the canal embankment must be compacted at least to the height of the lining. The Top width of the compacted embankment, (T) in Figure 3, varies with the size and location of the canal, type of lining, and other pertinent factors but is usually 2 to 4 ft. for canals have a maximum discharge capacity of 100 cusecs and 6 to 8 ft. for larger canals.

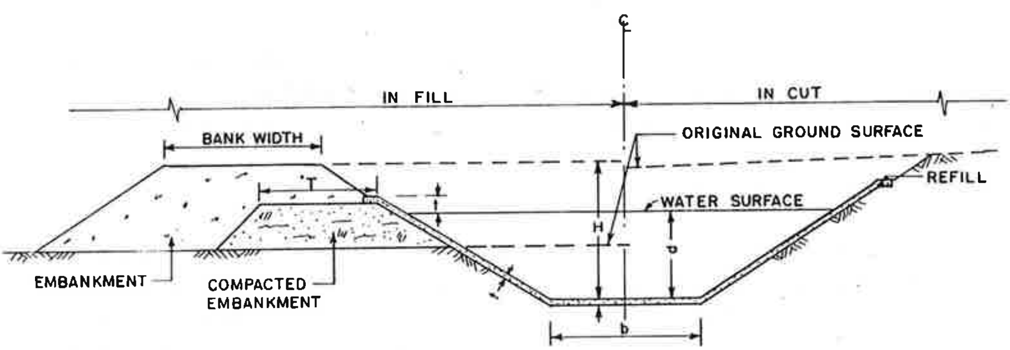

Figure 3. Typical Cross Section of a Hard Surface Lined Canal.

Loose material is placed over and outside the compacted embankment to provide space for operation roads and additional stability. However, now in Pakistan the practice is that the entire embankment accommodating the canal roads is compacted in avoid re-compaction of loose fill at a latter stage when it may be decided to metal the canal roads.

Specifications for Compaction

Unsuitable material should be stripped from beneath compacted embankments. Specifications for compacted embankments should require that after the necessary stripping of top soil, the entire surface of the subgrade for compacted embankment be ploughed thoroughly to a depth of not less than 6 inches, moistened and compacted. The material used in the embankment should have a specified moisture content and be compacted to a specified density in layers not more than 4 inches thick after compaction. The dry density of the soil fraction in the compacted material should not be less than 95 percent of the laboratory maximum density as determined by the Proctor method.

Rough Method for Determining Optimum Moisture Content

If Proctor test equipment is not available on small work sites, the optimum moisture content can be approximately determined by adding water until the material can be formed manually into a compact ball. No water should be squeezed out and the material should maintain its dense structure after opening the fist.

Compaction Standard for Loose Soils in Cut etc.

The compaction of loose soils in cut sections, or of soil replacing unsuitable subgrade materials, or soil for backfill, should meet the same requirement for density as indicated under the heading of specifications for compaction.

Lined Canals in Laminated Soils

In certain areas where the local soils are formed of sediment deposits brought down from hills by natural torrents the alluvium formed is not uniformly textured but is composed of different layers deposited during different flood cycles. The soils thus formed are heterogeneous and comprise laminations of clays, clayey loams, clayey silts with thin layers of fine sand sandwiched in between at different depths. Such soils were encountered during the construction of CRBC-II in certain reaches. Fine sand lenses at different depths were noticed from certain drainage syphons excavations which remained open without back-filling for a period of two years due to concentration of the contractor on other works. Wind storms, birds and burrowing animals distinctly identified these soft layers by digging holes and ravelling of sand from there while the clayey soils stood firmly below and above these layers in almost vertical cuts. When the lining was completed in such reaches hydrostatic pressures were noticed due to presence of a water ditch constructed by the contractor some distance away from the canal banks. The ditch fed water to the sandy layers which was conveyed towards the prism and developed wet soil pressure on the lining and resulted in horizontal cracks which had to be sealed and in certain reaches some damaged panels had to be relaid. The position is explained in Figure 3-A. One of the remedial measures suggested was to over excavate the canal by 8 ft. on both sides and re-compact the excavated material to break the laminations before lining but the cost was prohibitive and was a difficult operation during on-going contracts. It was eventually decided to avoid a water channel close to the canal Right of Way (R.O.W) and continue filling the canal prism as it was completed to counteract the external hydrostatic pressures. It was also thought that with the passage of time the lands on the right side of flood embankment will heavily silt up and the problem of seepage from the sandy layers might be automatically solved.

Subgrade Drainage

Danger to Lining with Rising Groundwater

Generally when the hard surface lining is provided in the canals the groundwater is well below the bottom of lining. However, with the continued irrigation applications and lack of proper farm drainage the groundwater rises and may attain levels above the bottom of lining. In such cases drains must be provided underneath or alongside the canal to relieve any hydrostatic pressure which might cause uplift or bursting of the lining when the canal is emptied during annual maintenance closure or an accidental breach in the canal.

Artificial Drainage Arrangements

There are several type of artificial drainage installations which are as described hereunder:-

i) Provision of Tile Drains along Toe of Slope

Four or six inch tiles are placed in gravel filled trenches along one or both toes of inside slopes. These longitudinal drains are either connected to transverse cross drains which discharge the water below the canal or to pump pits or extend through the lining and connected to outlet boxes on the floor of the canal. The outlet boxes are equipped with one way flap valves which relieve any external pressure that is greater than the water pressure on the upper surface of canal base, but prevent backflow. A typical Tile drainage arrangement is shown in Figure 4.

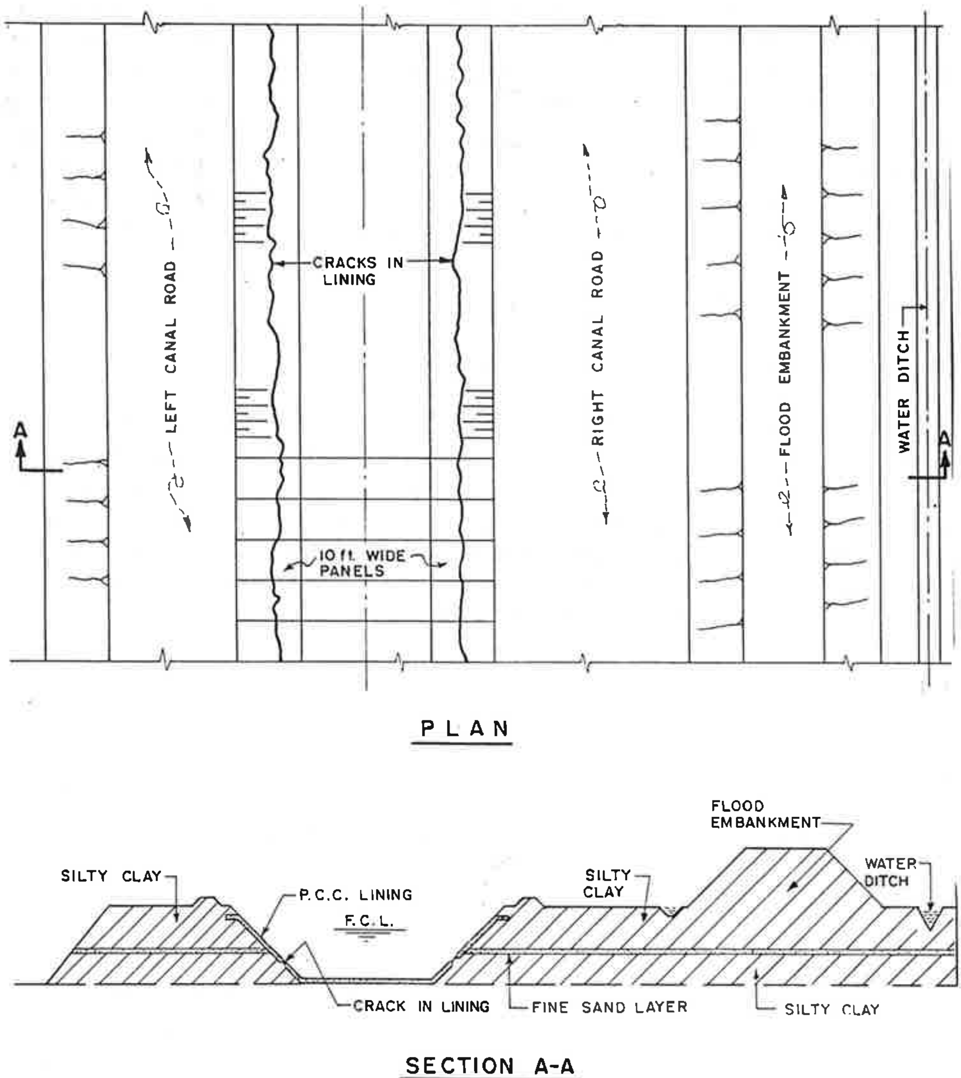

Figure 3-A. **Plan and Section of CRBC-II Showing Laminated Embankment, Seepage from Sandy Layers and Resulting Cracks/Damage to Lining.**

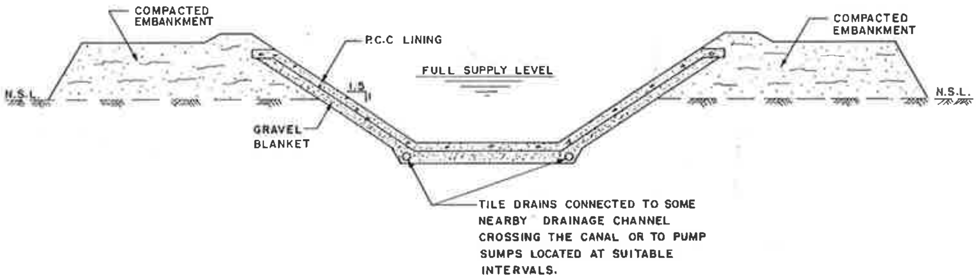

Figure 4. Typical Tile Drains for Drainage of Subgrade Behind Lining for Releasing Hydrostatic Pressure.

ii) Provision of One Way Flap Valves in Canal Invert

The second type consists of a permeable gravel blanket of selected material or sand and gravel pockets, drained in the canal at frequent intervals (10 to 20 ft.) by flap valves in the canal invert. A typical flap valve for use without tile pipe and in a fine gravel and sand subgrade is shown in Figure 5. Both the tile pipe system and the unconnected flap valve type must be encased in an envelope which will prevent piping of subgrade material into the pipe or through the valve.

iii) Provision of One Way Flap Valves in Lining Side Slope

When the permeability of the subgrade soil is low i.e. between 3 and 50 ft. per year, drainage arrangements for the subgrade may be required. Figure 6, shows a simple type of drainage outlet from a sand filter behind the brick lining. When the water level in the canal drops, because of sudden upstream closures or other reasons (a breach in the canal), the outlet will drain the excess water present in the adjacent soil and relieve the pressure behind the lining.

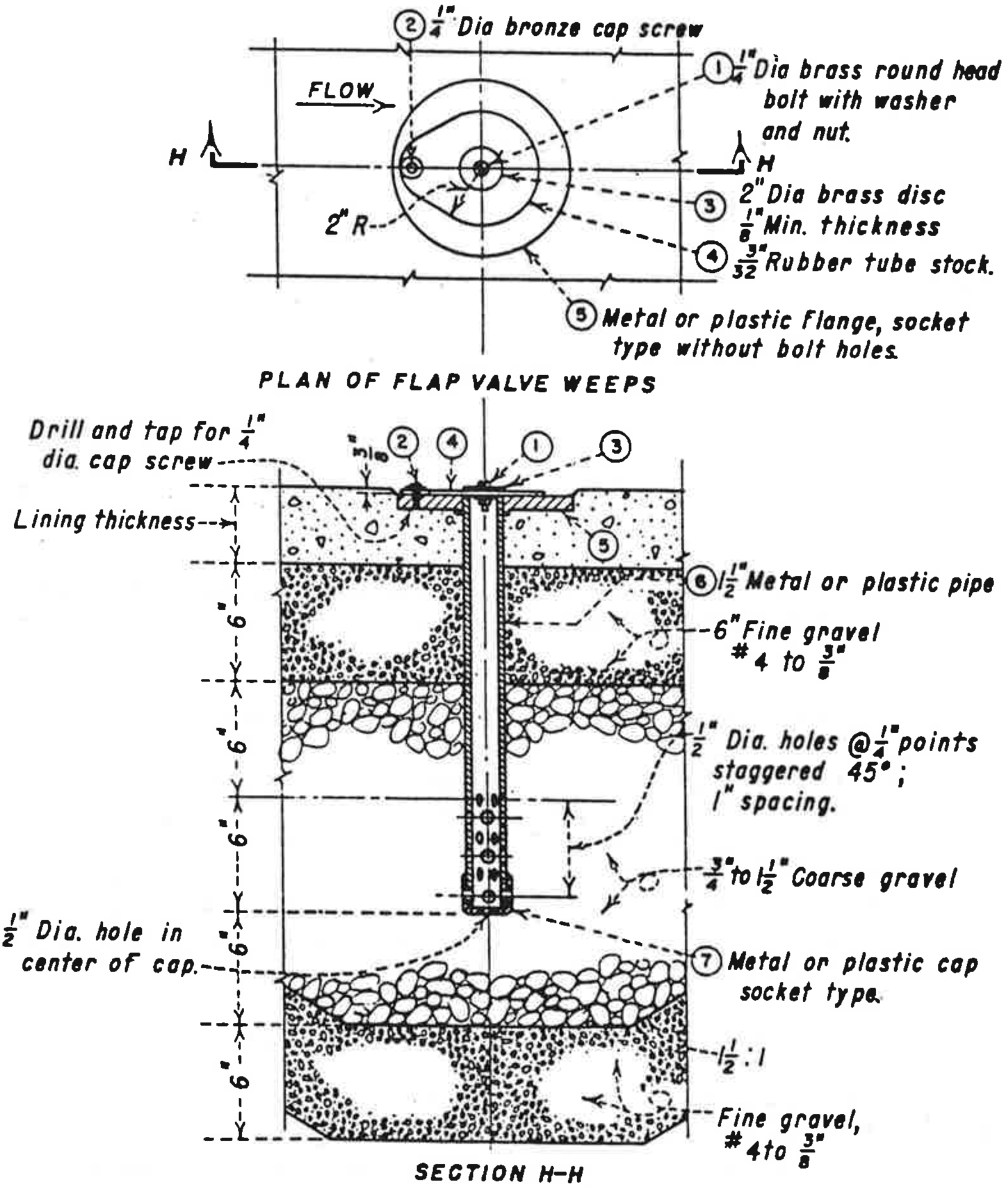

Figure 5. Flap Value Installation for a Canal Underdrain.

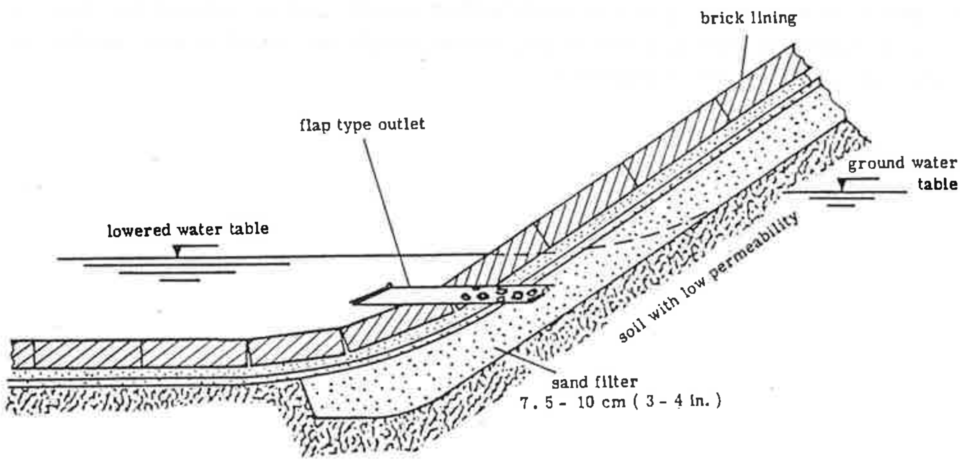

Figure 6. Drainage Arrangement for Brick Lining in Soils with Poor Permeability.

iv) Provision of Vertical Gravel Filled Drains

On B.S-I Link and certain other channels like CRBC-I a 2-3 inch thick blanket (subgrade) of 1:30 cement sand mortar was provided under the lining and this was connected to 9-inch dia. vertical boreholes filled with gravel or pit sand provided at 50 ft. interval on both sides as shown in Figure 7. The vertical boreholes were taken down to pervious strata or watertable below for disposal of drainage water collected at the back of lining. Such holes did not prove to be very effective. On the other hand it is argued that these were responsible for quick rise of groundwater along the lined canals.

Design Water Velocities

The velocity of flow in a channel is the principal measure of transport, for both water and sediment. Low velocities tend to induce sedimentation whereas higher velocities reduce the risk of sedimentation but create the possibility of lifting the lining should be velocity head be converted into pressure head through a crack. To avoid the possibility of lifting of the lining, the maximum water velocity for hard linings should not exceed 8 ft./sec. A design check using a Manning's 'n' of 0.003

less than the design "n" used for the lining, is also required to make certain that the depth of flow does not approach critical depth closely enough to develop standing waves at sections where the bottom might be raised above theoretical grade due to construction tolerance.

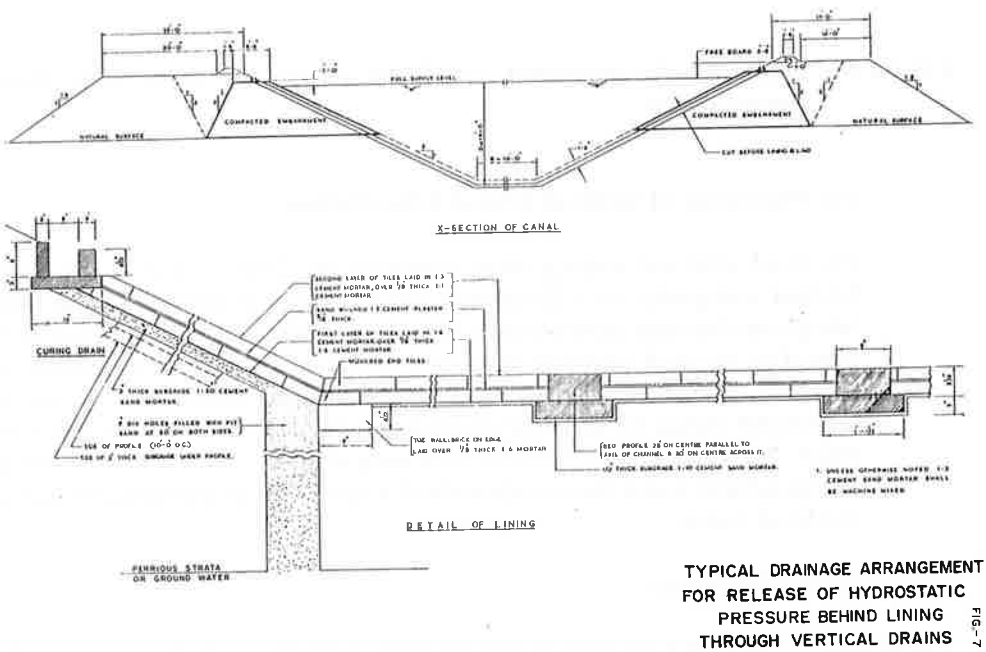

Figure 7. Typical Drainage Arrangement for Release of Hydrostatic Pressure Behind Lining Through Vertical Drains.

Prevention of Silt Deposits in Canals

Bed load and fine sand can be prevented from entering a canal, but no suspended silt. In unfavourable conditions suspended silt may settle in the canal network where its removal would be costly. Removal of sediments from lined canals is extremely difficult and involves risks of damage to lining if attempted through mechanical means. The minimum velocity which prevents silting is the critical velocity and deeper a canal becomes, the higher is the velocity necessary to prevent silting. Figure 8 shows the critical velocity curve developed by Kennedy for canals in the Punjab Province (now in Pakistan). To prevent sediment deposition in lined channels, the best shapes of conveyance, in order of efficiency, are the rectangular and trapezoidal section in which B>D, where B is the bed width and D is the central flow depth.

Thickness of Lining

No general rule can be stated for establishing the thickness of concrete lining which is not a structural number. For small canals un-reinforced concrete lining of 1½ inch thickness have been satisfactory. For large canals, the cases where foundation or subgrade conditions are unfavourable, or where high velocities are inevitable, thicknesses of 2-inch to 5-inch have been used. According to a survey of concrete linings in Portugal thickness ranged from 2½ inches to 4 inches depending on the size of canal and other conditions. Figure 9 shows the recommended thickness of some hard-surface linings in relation to canal capacity. It is also recommended that the thickness of the concrete lining may range from 3 to 8 inches depending on the quality of the concrete.

According to same authorities absolute watertightness needs a thickness of about 9 inches for lining but the economics do not permit such costly provisions and a compromise has to be made to reduce the losses to a minimum. In the Pakistan Command Water Management Project, concrete lining thickness of 3 inches with 1:2:4 volumetric mix (strength 3,000 lbs/sq in) has been used for all canal sections, discharge ranging from 6 to 600 cusecs.

For concrete lining under-construction with the "Khushab Scarp-Canal Rehabilitation and Lining Component Project" concrete lining thickness of 2½ inch is being used for all canal sections, discharge ranging from 13 to 191 cusecs.

The just completed "Chashma Right Bank Irrigation Project, Stage-II" has a concrete lining thickness of 4 inch for all canal sections, with discharge ranging from 3100 to 3600 cusecs.

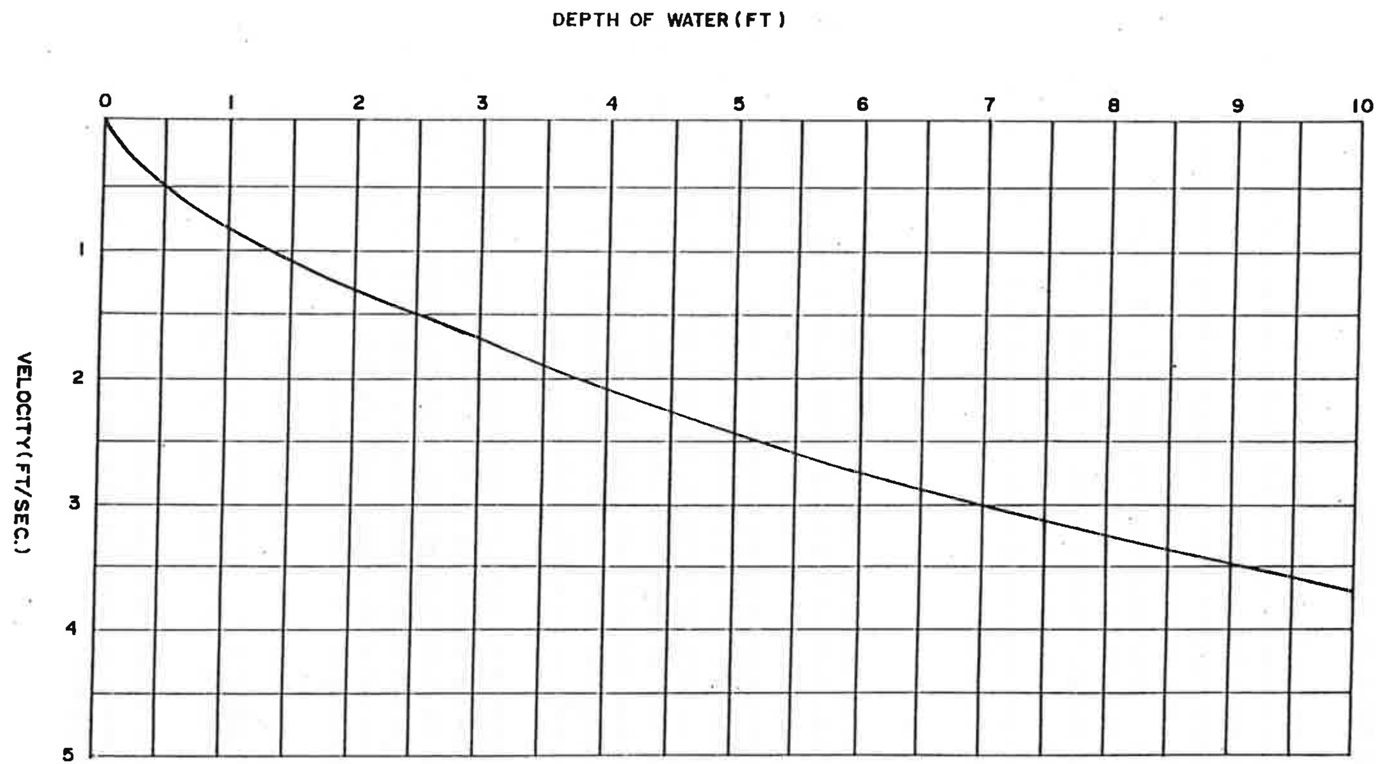

Figure 8. Non-Silting Critical Velocity Curve by Kennedy for Canals in Punjab.

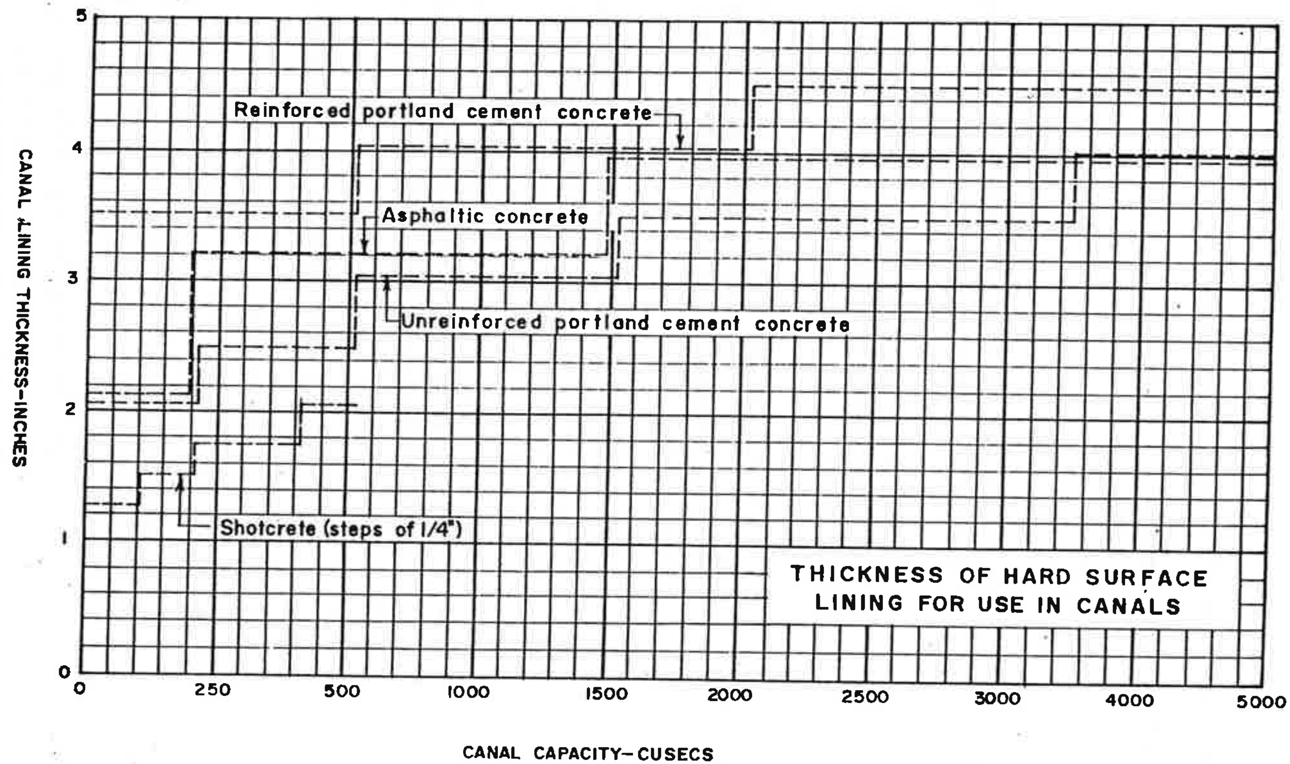

Figure 9. Determination of Thickness of Hard surface Lining.

Joints in Lining

Joints in lining can be of the following four types:-

i) Expansion joints
ii) Contraction Joints
iii) Construction Joints
iv) Construction Grooves

- Expansion joints are not ordinarily required in a concrete lining, except where structures intersect the canal.

- Longitudinal contraction joints at bottom of slope concrete with the previously placed concrete in the bed will be in the shape of a butt joint, but without any sealing compound.

- Transverse contraction joints are provided to control transverse cracking which results from shrinkage during volume changes caused by drops in temperature or moisture loss, also moisture loss accompanying curing.

- Construction joints are necessary where lining operations are discontinued at the end of the day or for other reasons and resumed after considerable time interval.

- Longitudinal joints are used in the bed concrete to control irregular longitudinal cracking, where the perimeter of the lining is 30 feet or more. Where desired, the canal prism will be divided at the bed slab by the longitudinal joint.

- No longitudinal joint will be provided for the side slope lining.

- Some common types of joints and grooves are shown on Figure 10. Types (a), (b) and (c) have successfully been used in various concrete canal linings. Type (a) is a dummy groove recommended by the USBR. joints (d) and (e) are highly efficient with regard to watertightness. Joint (f) is suitable for thin lining. The sill can be placed ahead and continuous construction is possible if a means of cutting the slab at the joint is provided. Type (g) is not suited to modern paving machinery but for hand placement. In the Joint Type (f), the vertical saw cut creates a weakened plane. These control joints will act as construction joints. This type has been successfully used for 4 inch thick concrete lining at Chashma Right Bank Irrigation Project, Stage-II.

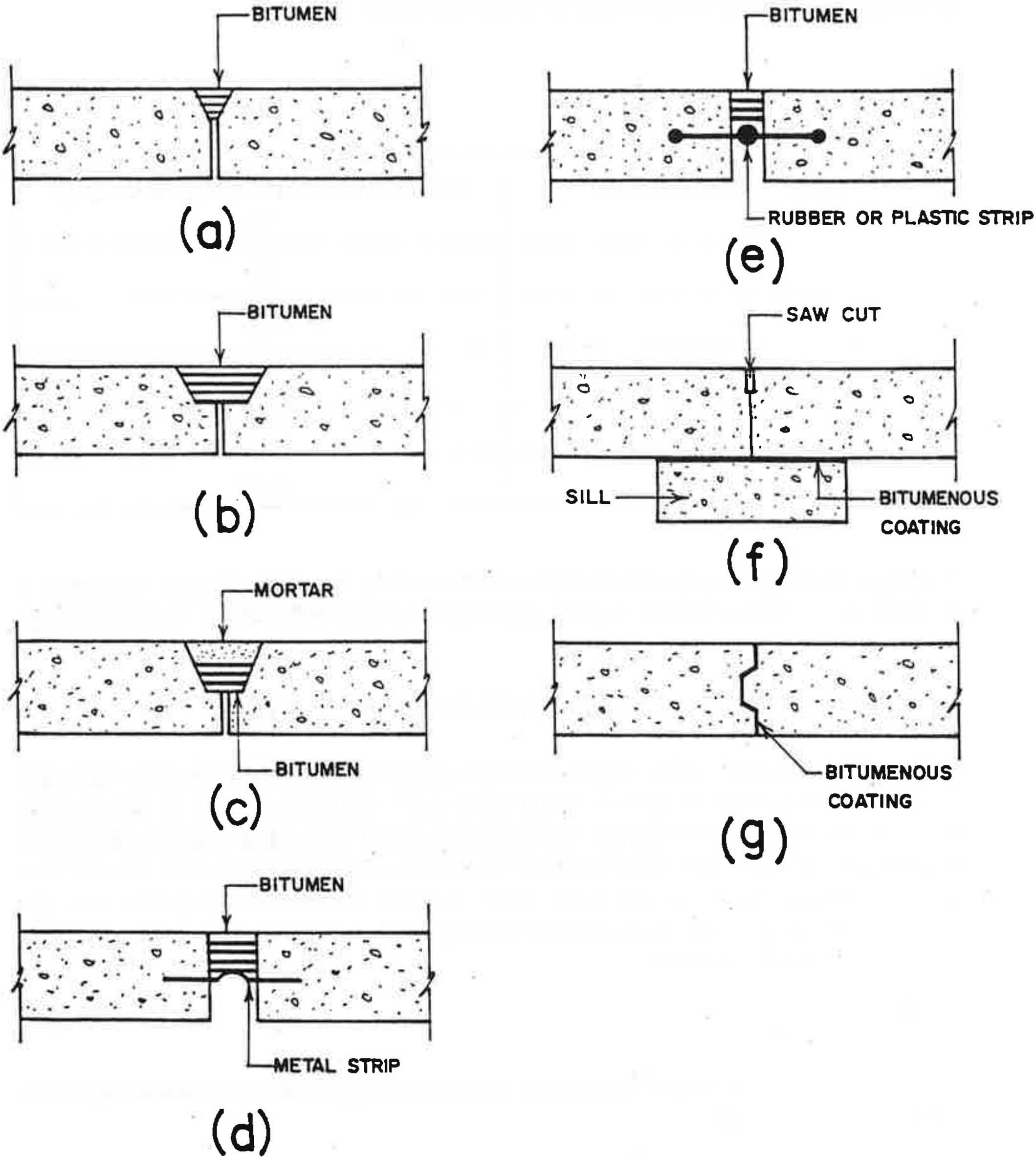

Figure 10. Typical Joints for Concrete Canal Lining.

The recommended spacing of transverse joints type (f) varies from 10 to 15 feet, depending on the size of channel and thickness of lining. The recommended spacings for various thicknesses of concrete lining are;

LINING JOINTS SPACING

LINING THICKNESS (in)	RECOMMENDED JOINT SPACING (ft)
2	10
2½	10
3	12-15
3½	12-15
4	12-15

However, from practical consideration and screeding capability of local contractor's working with manual labour, a joint spacings or panel width of 10 ft. is desirable.

ROLE OF DESIGN IN THE SUCCESS OF LINING

Unlike unlined canals, which have their own problems the design of lined channels is highly sophisticated or rather complicated. If the designer ignores or fails to take cognizance of any of the factors enumerated above under the heading of factors effecting the design, the resulting channel may be problematic if not a failure. The following major lined canals have been built in Pakistan during the last six decades and a brief narration will be made against each giving the reasons for the success or failure of lining.

Haveli Canal

This canal was built in 1937-38 linking Trimmu Barrage with Sidhnai Barrage with following design Data:

- Discharge at Head = 5,224 cusecs
- Bed Width = 84 feet
- Depth = 12 feet

- Side slope = 1:1
- Type of Lining = Double Tile brick with reinforcement
- Longitudinal Slope = 1 in 10,500
- Manning's 'n' = 0.0146

The lining failed after initial operation because:-

i) Side slope of 1:1 was too steep against the natural angle of repose of soil in saturated condition.

ii) A low value of 'n' was assumed. Actual friction resistance was higher and resulted in greater depth and overtopping and consequential failure of lining. Actual observed value of 'n' was 0.02.

iii) No compaction of embankments was carried out. So the loose soils settled on soaking and the lined collapsed.

iv) Insufficient freeboard of only 1 foot was provided from the lining.

v) With rise of groundwater along Haveli canal and specially after construction of the parallel Trimmu-Sidhnai Link the hydrostatic pressure during canal closures and breaches in the canal lifted the lining in the bed and sides.

vi) Provision of reinforcement in the lining also proved to be detrimental since it did not permit cracking to release pressures but resulted in lifting of panels.

Thal Canal

Thal Main Line Upper taking off from the left flank of Jinnah Barrage (Kala Bagh Barrage) was constructed in early forties with the following Design Data:

- Discharge at Head = 7,500 cusecs
- Bed Width = 71 feet
- Side slope = 1.25:1
- Full Supply Depth = 17.8 feet
- Type of Lining = 4-inch thick P.C.C. (1:3:6)

The lining failed because of the following factors:

i) It worked well for the first 16 years but with gradual rise of groundwater above the bed and in the absence of proper surface drainage and drainage of subgrade panels started collapsing, during annual closures.

ii) The side slope of 1.25 horizontal to 1 vertical was steeper than the angle of internal friction of the saturated soil.

Bambanwala-Ravi-Bedian Dipalpur Link Canal

This canal after emerging from the Ravi syphon had the following hydraulic features:-

i)	Discharge	=	4,863 cusecs
ii)	Bed Width	=	52-56 ft.
iii)	Av.Depth	=	16-14 feet
iv)	Valve 'n'	=	0.018
v)	Water Surface slope	=	1 in 8,000 to 1 in 13,400
vi)	Side slope	=	1.25 H to 1 V. for some part
		=	1.5 H to 1 V. for the remaining
vii)	Type of Lining	=	Single Brick Tile underlaid by 3 inch thick cement sand plaster.

The condition of lining during operation of last 40 years is satisfactory although the lining has buldged out at several places due to hydrostatic pressure. The canal is in general higher than the level of the surrounding lands. The lining has remained generally undamaged mainly due to the existing groundwater deeper than the bed level of the canal.

Balloki-Sulemanki Link-1

This Link canal was built in the mid-fifties with the following design data:-

i)	Discharge at Head	= 15,000 cusecs
ii)	Designed Bed Width	= 112 ft.
iii)	F.S. Depth	= 18 ft.
iv)	Side slope	= 2 H to 1V
v)	Manning's 'n' (assumed)	= 0,017
vi)	Longitudinal Slope	= 1 in 8,000
vii)	Freeboard	= 1 ft.

First 73 R.D's of the Link is unlined and reach R.D. 73 to 266 is lined with double-layer brick tiles with 1:3 cement sand plaster sandwiched in between.

On operation it was found that assumed value of 'n' was too low and even with the encroachment of entire one foot freeboard the sand could not pass the full discharge. The design was revised to pass a discharge of 12,500 cusecs at a depth of 18 ft and the revise value of 'n' was adjusted at 0.02.

The lining of the link in the deep cut reach from R.D. 73+000 to R.D.106+000 has completely failed because of the following factors:-

i) B.S-II Link was constructed in sixties offtaking from R.D.73+000 of B.S-I Link and was aligned parallel to it at a distance of 350 ft. This caused the groundwater level to rise. The bed level of link in the deep cut reach is 30 to 35 ft below the natural surface. The rise of groundwater played a disastrous role in damaging the lining which is now beyond repair.

ii) The side slope along the bridges was steepened to 1:1 to economies construction but after rise of groundwater this steep slope regard the damage.

Sidhnai-Mailsi-Bahawal Link

S.M.B. Link was constructed in the Sixties as a part of Indus Basin Project. It links Sidhnai Barrage with Mailsi syphon and on to Bahawal canal. The Link is unlined from head to R.D. 76+ and from R.D. 76+ to R.D. 376 it is lined with following design data:

i)	Discharge	=	varies from 10,100 to 4,000 cusecs.
ii)	Longitudinal Slope	=	varies from 1 in 10,700 to 1 in 9,300
iii)	Depth	=	varies from 18.0 ft to 15.6 ft.
iv)	Bed Width	=	varies from 100 ft to 40 ft.
v)	Mean Velocity	=	varies from 4.13 to 3.60 ft/sec.
vi)	Manning's 'n'	=	0.02
vii)	Type of Lining	=	Double Layer brick tiles with 1:3 cement sand plaster at 1/8 inch thick bitumen coating sandwiched in between.

This is the only lined canal in Pakistan of which the condition of lining is very good and intact even after 27 years of operation. The main reasons are:

i) Adoption of proper value of 'n'
ii) Adequate free-board
iii) Better design of lining
iv) Adoption of a flatter side-slope

v) The subgrade material is sandy and can easily dissipate the seepage.
vi) The groundwater is still 20 ft. below the land surface and hence there is no immediate danger to lining.

Akram Wah or 'Lined Channel' in Sindh

This canal was built from 1951 to 1957 with the following design features:

i)	Discharge at Head	=	4,100 cusecs
ii)	Manning's 'n'	=	0.016 for concrete lining and 0.018 for brick lining.
iii)	Type of Lining	=	4 inch thick concrete in bed and 5 inch thick concrete on sides
iv)	Side Slope	=	1:1

The lining in the entire reach of 38 miles is completely damaged and almost totally replaced by stone-pitching and also by bushing.

The reasons for damage to lining are high groundwater with no means for release of hydrostatic pressures and steeper side slope.

FACTORS GOVERNING THE SELECTION OF LINING

Discussion in the foregoing paragraphs leads to the conclusion that following factors have to be considered in detail before selection of a particular type of lining. Scope of this paper does not permit a detailed discussion on these factors which are simply being listed:-

1. Soil Properties
2. Topography
3. Watertable
4. Landuse and Irrigation System
5. Operation and Maintenance
6. Watertightness
7. Durability of the Lining
8. Availability of Construction Materials
9. Availability of Labour and Machinery
10. Cost and Financial Aspects

CONSTRUCTION TECHNIQUES

Numerous construction techniques are employed all over the world for the construction of different types of linings which can not be discussed in this brief paper. However, techniques used in this country for the two popular types of linings i.e. brick/tile and concrete lining shall be discussed in the following sub-paragraphs.

Construction of Cement Concrete Lining

The following methods are used for the construction of cement concrete linings:

- i) Manually placed Lining
- ii) Slipform concrete linings
- iii) Semi-mechanized construction of linings
- iv) Precast concrete slabs linings.

These methods are briefly discussed below:-

Manually Placed Concrete Linings

Placing concrete linings by hand may prove economical when low cost labour is available, or when the reach of canal is too short or cross-section too small to be economical for mechanized placing. In Pakistan concrete linings of all canals has been done manually in panels of 10 to 15 ft. width. Although surface finish by manual placing is good the concrete can not be properly compacted especially in the upper portions of deeper sections of channels when the masons placing the concrete are precariously placed on wooden or steel boards resting on stairs on sides. The resulting hoony-combed concrete at the bottom of lining is not as watertight as obtained by mechanically vibrated screeds or slipforms. However manually placed lining has the advantage that it can permit construction of profile slabs (sleepers) under the joints of adjacent panels which help in reducing leakage at the joints.

Slipform Concrete Linings

In advanced countries like U.S.A. concrete canal linings have been built with longitudinally operated lining equipment, commonly called slipforms. After excavation, compaction and trimming of the subgrade, pouring, shaping compacting and smoothing of the concrete lining is done by use of the slipform. Slipforms are used for almost every size of Irrigation Canal. For small channels, they are usually subgrade guided and for large canals, with lining perimeters exceeding 25 ft, they are usually supported on wheels, crawlers or rail tracks.

Modern concrete lining machines have been developed which have following operation in succession:

a) Subgrade trimmer
b) Slip-form liner working on rails and automatically fed with concrete
c) Jumbo for manual finish of week spots
d) Jumbo for cutting dummy groove contract joints
e) Jumbo for applying membrane curing compound.

For bigger canals bigger machines are designed to meet the local requirements and parameters of the canal. A slipform Machine and Jumbos for half section constructions is shown in Figure-11.

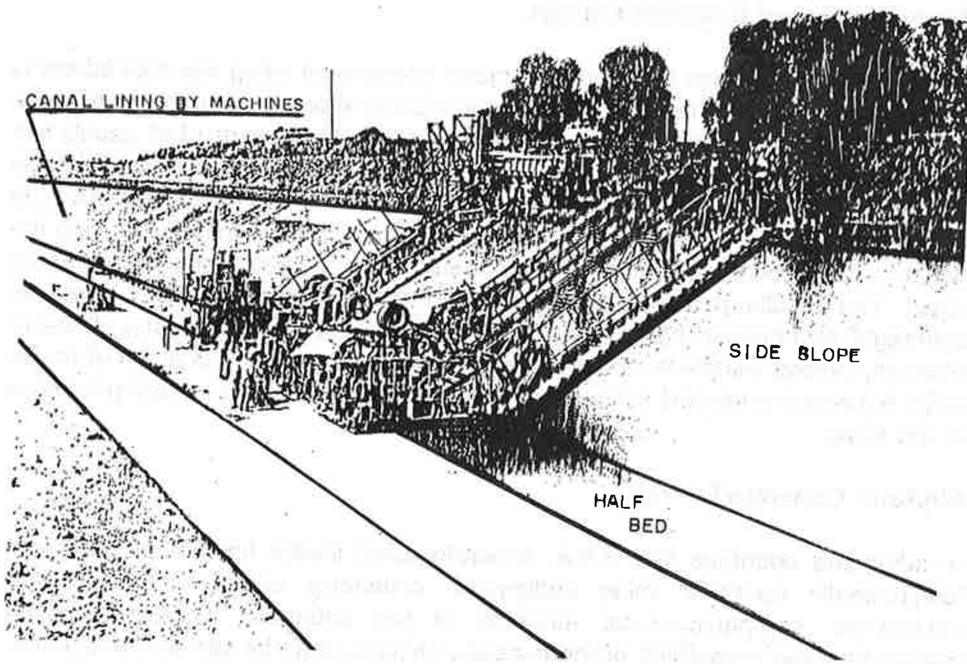

Figure 11. A Photograph Showing Half Section Canal Construction by Lining Machines.

Semi-Mechanized Construction Methods

Where lengths of large canals are too short to warrant the expense of using slipforms or where adequate equipment is not available and labour is cheap, winch drawn screeds operating transversely on the canal slopes as shown in Figure 12 are usually found to be economical. Normally the lining is built in alternate panels and construction joints between panels then function as expansion joints. The form is moved by winches set at the top of the slope.

The concrete is fed to the working platform from the top of slope by means of a chute or by a bottom opening bucket of a mobile crane. The main features in the design of this form are that the vibration must be applied under a head of concrete and the float section must be reasonably from vibration. The form must be weighed in order to keep it in solid contact with the screed guides to control the thickness of lining.

Precast Concrete Slabs Lining

Precast concrete slabs canal lining has been used throughout the world for all sizes of canals, but the trend is declining in countries with expensive labour. Precast slabs are usually made 2 inches thick. The length and breadth may be 2x1 ft. but can be varied to suit canal dimensions and to provide weights that can be conveniently handled by one or two workers. Figure 13 shows the development of a typical design. In this design tongue and groove joints are provided along the edges. The joints should be sealed with mortar or bituminous mastic. Slabs laid with continuous joints sealed with bitumen provide a slight flexible lining that can adjust itself to minor movement of subgrade. In certain locations it may be convenient to cast the bottom sections in place and slabs are placed on sides only. Precast slabs provide better opportunities for quality control and curing in a central casting yard which is difficult in in-situ concrete linings.

Brick Lining

Suitability of Brick Linings

Brick/Tile linings have many of the advantages and disadvantages inherent in linings constructed of precast concrete slabs. Brick linings, however, can be used to advantage in areas where:

i) an abundance of in-expensive hand labour is available;

ii) materials for bricks/tiles are available near the canal sites i.e. earth for moulding bricks should have the prescribed percentage of salts;

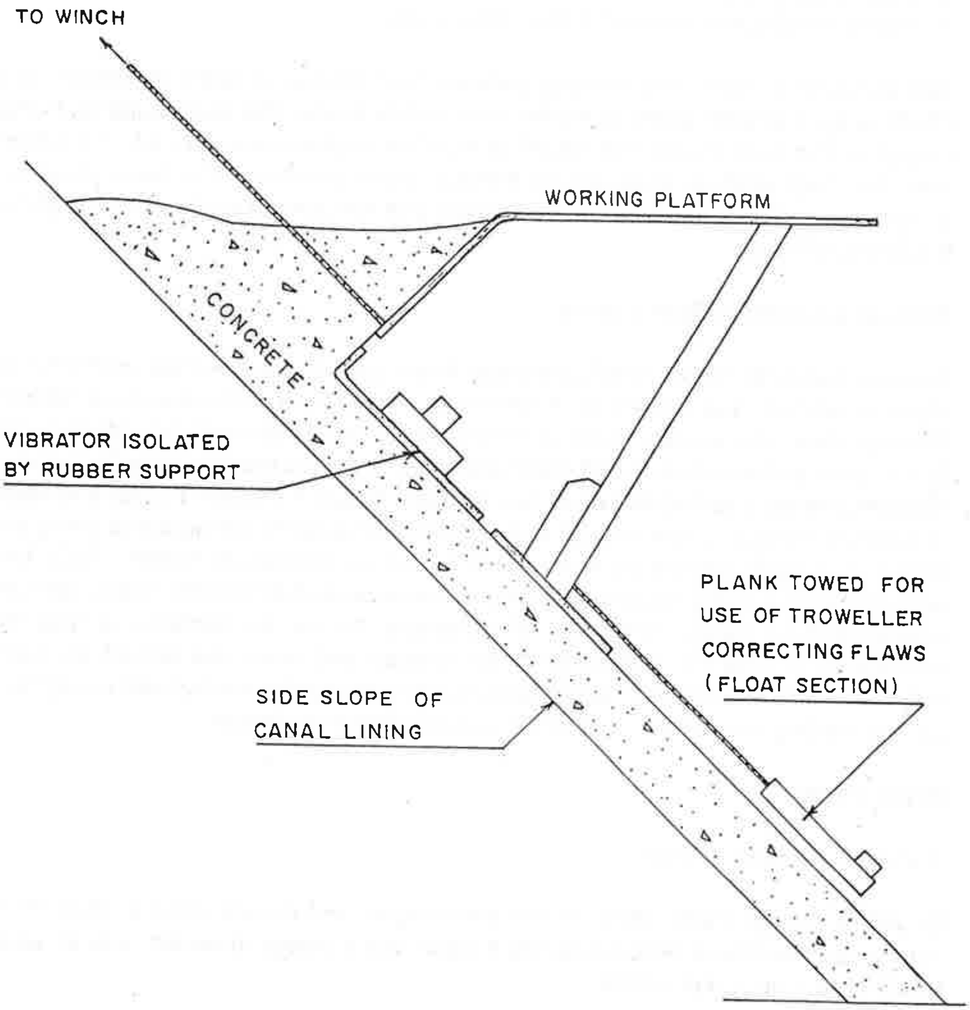

Figure 12. Sketch of a Sliding Screed for Operating Transversely up the Slope of a Canal.

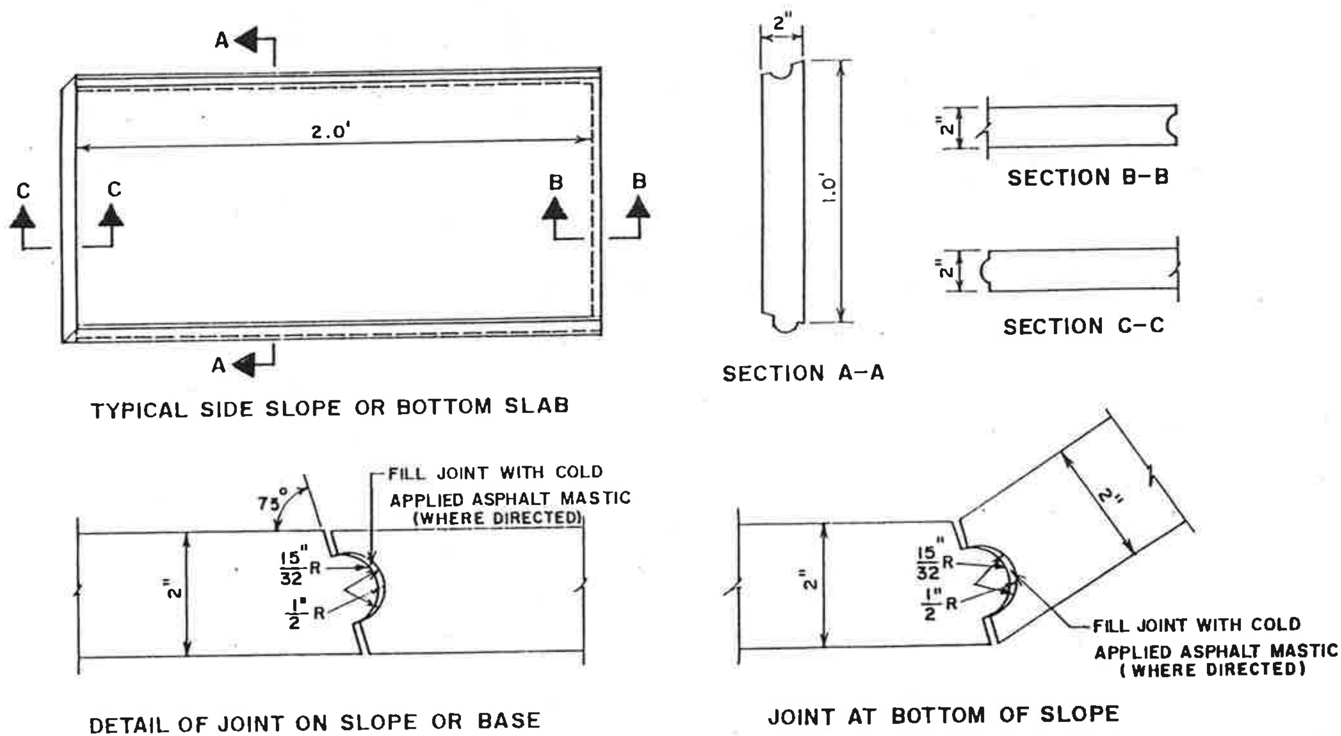

Figure 13. Precast Concrete Slab Unit - Typical Detail.

iii) materials for other suitable types of lining are not available at a competitive price.

Canals Lined with Bricks/Tiles in Pakistan

The following major canals in Pakistan have been built with Brick/Tile linings:-

i) Haveli Main Canal Double layer of 12x5⅞x2 inches tiles laid in cement masonry with 1/2 inch thick 1:3 cement sand plaster sandwiched in between. The masonry was reinforced with 1/4 inch dia. M.S.Bars, laid in the 1:3 cement sand plaster forming a grid of 12x12 inches on sides and 24x24 inches in the bed.

ii) Thal Main Line Lower from R.D. 68+500 to Tail was provided with single-tile lining of the following specifications:

- 1:10 cement sand mortar ½ inch thick as sub-base.
- Overlaid by 1:6 cement sand plaster 1½ inch thick as base.
- Overlaid by 1:3 sandwiched cement sand plaster ⅜ inch thick and overlaid by 2 inch thick single tile laid in 1:3 cement sand mortar over ⅛ inch thick 1:3 cement sand plaster.

iii) The B.R.B.D. Link canal was lined with a single layer of tiles laid in 1:3 cement sand-mortar over 3/8 inch thick 1:3 cement sand plaster and underlaid by 1½ inch thick 1:6 cement sand mortar with a sub-base of 1/2 inch thick 1:10 cement sand mortar.

iv) Balloki-Sulemanki-I Link was lined with double layer tiles just like Haveli canal but without reinforcement.

v) Headrace channels of Chichoki Mallian, Shadiwal and Nandipur Hydel Projects were also lined with double layer tiles of following B.S. Link specifications.

vi) Sidhnai Mailsi-Bahawal Link Canal was lined with double layer tiles 12x6x2 inches with 1/2 inch thick 1:3 cement sand mortar and 1/8 inch thick asphaltic membrane sandwiched in between.

vii) Pehur High Level Canal in NWFP was lined with double layer of brick tiles with 1/2 inch thick 1:3 cement sand plaster sandwiched in between.

viii) Chashma Right Bank Canal Stage I and II have been lined in certain reaches with double layer of tiles and 1/2 inch thick 1:3 cement sand plaster sandwiched in between. Figure 14 shows Typical double and single tile linings used on different Projects.

Limitations of Tile Linings

Clay brick is generally a very porous material. The brick layers, therefore, hardly play any role in preventing seepage losses. The water tightness in brick linings is solely due to cement plaster or asphaltic membrane sandwich. The bricks only form a skeleton to hold the plaster or function as protective cover.

Bricks are manufactured from earth in which the salt content does not exceed 2 percent. The clay content should range between 10 to 20 percent. Extensive tests carried out during the implementation of Indus Basin Project in the sixties had revealed that due to waterlogging and salinity in the irrigated tracts of Punjab, salt content in the soils was no where less than or equal to 2 percent. Consequently the bricks and tiles manufactured from such salt-affected soils when used on lining or structures suffer from the phenomenon of efflorescence i.e. salts come out on the surface after alternate wetting and drying and with the passage of time the brick becomes spongy and looses strength. Additionally trained labour which used to mould bricks has gone to middle east and now proper labour is not available. The tiles manufactured by untrained labour do not give an even surface to lining which requires and higher value of 'n' and the resultant high cost.

ROLE OF CONSTRUCTION TECHNIQUES

Role of construction techniques in lining is pivotal in the success of any type of Lining. Any well planned and intelligently designed project can not fulfil the envisioned objectives unless proper specifications and construction methodologies are followed. The following aspects need special consideration.

Compaction of Embankments and Subgrade

Compaction of canal embankments and subgrades has to be done in layers at optimum moisture content using proper type of machinery. Machinery or rollers used for clayey soils are different from those used for sandy soils. Proper

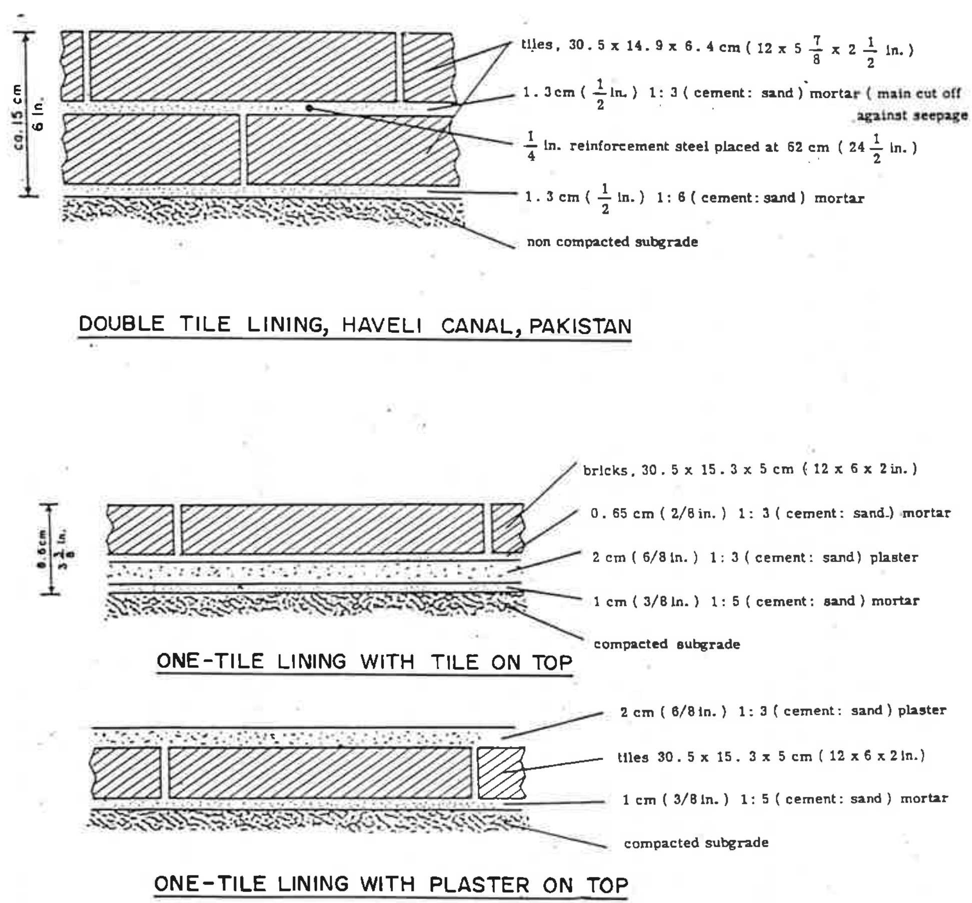

Figure 14. Typical Double and Single - Tile Lining Used on Different Projects.

compaction and concurrent laboratory testing is the key element in any lining project.

Proper Tamping of Concrete and Grouting of Brick/Tile Joints

Concrete in lining should be properly tamped with vibratory screeding platform otherwise the resulting lining would be porous and not watertight. Similarly every joint in the brick is a potential source of leakage and hence the brick/tile masonry of lining should be properly grouted (pointed).

Curing of Lining

Any good type of lining will fail to achieve its desired strength if it is not cured for about a fortnight. Proper curing greatly improves the durability, wear resistance and watertightness of concrete. Tests have shown that concrete which was moist-cared for 14 days had a 28 day strength, about twice that of concrete which was allowed to dry in air. The concrete must be kept continuously saturated to provide adequate curing. This will be done by keeping the exposed surface of concrete continuously moist for 3 to 5 days or by sprayed on curing compound or other pervious cover like burlap. Curing compound, if used, must be of such composition that will remain intact as a sealing coat for at least 28 days.

CONCLUSIONS

1. Lining of Channels need a very thorough knowledge of over a dozen parameters involved in the process.

2. Detailed investigations of the soil characteristics and side stability analysis in the Project area are extremely important.

3. Exploration of sources of materials in the vicinity of the project area are extremely important before selecting the type of lining.

4. Proper construction techniques and methodologies have to be followed for compaction of subgrade, placing of lining and curing etc.

5. Proper operation rules have to be followed for filling and emptying of lined channels.

6. Certain perennial lined channels where lining has failed, pose a serious question about replacing or repairing the lining under prevailing high watertable conditions.

7. Linings have generally failed due to rising of groundwater and lack of proper drainage for the subgrade to release the hydrostatic pressures.

RECOMMENDATIONS

1. Design of channel linings should be done after due consideration of all the factors discussed in the foregoing paragraphs.

2. Selection of the type of lining should be done very carefully keeping in view the availability of materials near the project area, durability and economics of lining. Short life linings should never be provided in permanent/perennial channels.

3. Utmost attention should be paid to compaction of embankments and subgrade at optimum moisture content to 95 percent of maximum Laboratory density determined with Proctor method.

4. Lining should not be attempted in areas where the groundwater has a rising trend.

5. For Larger and Deeper channels proper drainage of subgrade and canal roads of lined channels should be designed and provided. If this is not possible technically or economically lining should not be attempted.

6. In order to provide a perfectly watertight lining which will not be a source of leakage and contribution to groundwater a suggested type of lining could be as below:

    - Precast concrete slab units underlaid with flexible Geomembrane of a suitable type depending on economics and local availability.

    - A typical channel section with precast slabs lining underlaid with flexible membrane is shown in Figure 15.

7. There is no need to provide subgrade drainage for small channels, especially after provision of a geo-membrane under the lining.

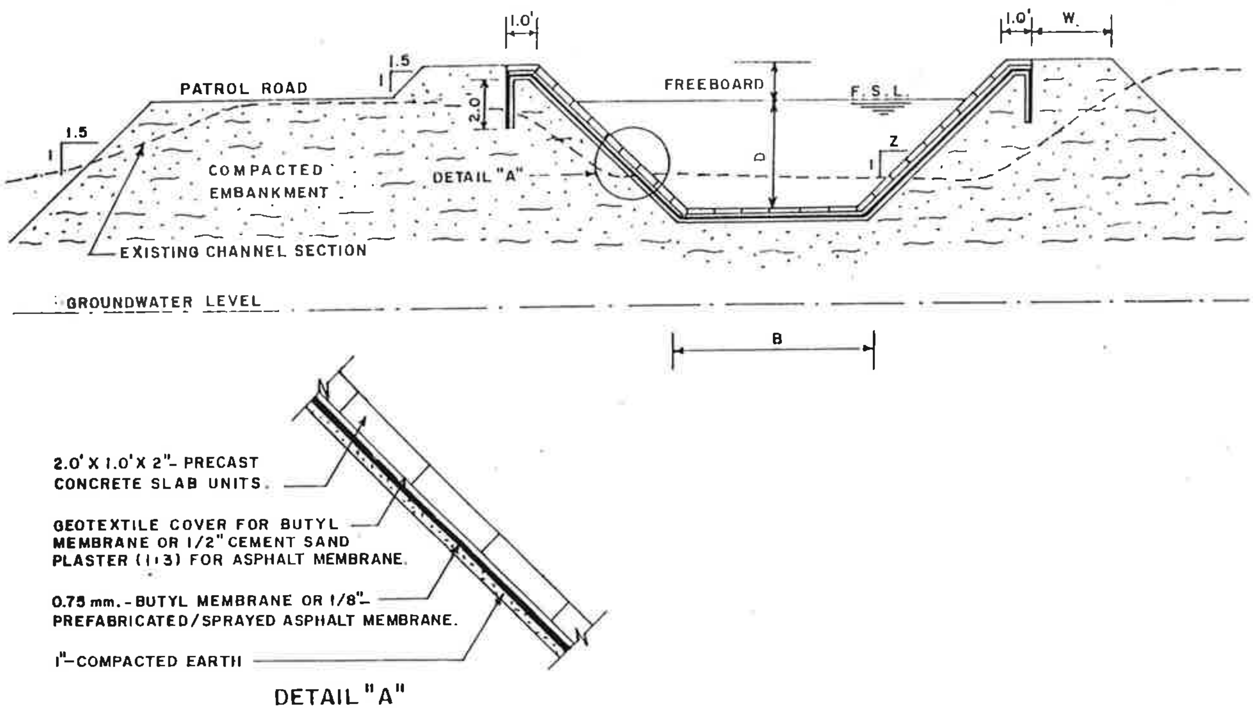

Figure 15. Precast Concrete Slab Units Underlaid with Flexible Membrane - Typical Section.

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STUDIES ON THE PERFORMANCE OF VARIOUS LINING MATERIALS

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ABSTRACT

The irrigation channels are usually pervious resulting in a large wastage of available surface water through seepage. This invariably results in waterlogging and salinity. To overcome these intricate problems, Irrigation Research Institute, Lahore has been conducting research on the performance of various lining materials to reduce seepage losses from irrigation conveyance system. In this paper, the results of different lining materials such as: Brick, Bentonite, Soil Sealant, Polyethylene and Synthetic Rubber are discussed. Brick lining has many site specific field problems. Local bentonite as a lining material has shown rapid deterioration in the field. Soil sealants/emulsions, supplied by the local and foreign agencies, were also tested. These sealants still need a lot of improvements in their sealing properties under varied local conditions. Polyethylene sheets are damaged by weed growth, rodent attack, animal trespassing, etc. Synthetic rubber membranes, under protective covers, gave fairly good results. Normally problems are with their bondage which are being investigated to suggest some reliable remedial measures.

INTRODUCTION

The irrigation canals are usually pervious, resulting in a large wastage of water through seepage. This invariably results in waterlogging and salinity problems, which soon are liable to render the land unfit for cultivation.

It has been estimated that a huge quantity of good quality water is lost by seepage annually creating problems. The loss if saved would add to the national economy and pave a way towards making the country self sufficient in agricultural commodities. One of the ways in which optimum use of water supplies for agriculture can be made is through a reduction in the amount of seepage during transit to farms. This can be accomplished by adopting some lining measures. Here some lining materials, studied at Irrigation Research Institute, are discussed:

Rigid Lining

(a) Flat Brick Lining in 1:3 Cement Sand Mortar

The experimental water channel at Niaz Beg Research Station was made. The section was tapped uniformly to keep a fair compaction. Prior to constructing this specific lining ½ inch thick layer of 1:10 cement sand mortar was spread in the whole section just to provide a smooth surface under the lining sample. First class bricks were laid in 1:3 cement sand mortar.

Initial seepage reduction efficiency as calculated and compared with unlined section was 80.59% which improved upto 84.43% by the time. After that some hairy cracks developed which caused a decrease in efficiency upto 69.25% within one year. Necessary repair touches were done after one and half year and hence efficiency reached upto 88.60%. But then the efficiency decreased gradually i.e. 69% after 3 years, 62% after four and half year, 48.55% after 5 years, and 34.73% after 6 years. The reasons were the damage to lining due to weed growth and rodent attack.

(b) Flat Brick Lining in 1:6 Cement Sand Mortar and Top Provided with ½" Thick 1:3 Cement Sand Plaster

In this case section was tapped for uniform compaction and ½ inch layer of 1:10 cement sand mortar was spread in the whole section just to give the smooth surface under the lining sample. First class bricks in 1:6 cement sand mortar were laid as usual. Necessary curing was done. After that ½ inch thick plastering layer upon the bricks was done to achieve the final section. Observations were started after necessary curing.

The initial seepage reduction efficiency recorded and compared with unlined section was 98.57%. The efficiency started decreasing and it was 76.25% after one year. Appreciably large splits/cracks developed apparently owing to settlement of sub soil, rendered loose by rodent attack. Necessary repairs as per experimental specification was done. Upon repair as usual the efficiency reached approximately to the initial value. Again settlement of bed and sides was faced during the three and half years of testing, showing efficiency decrease upto 19.73% but upon repairing, again the efficiency was improved upto 90.80%. The settlement was a recurring phenomenon as the repair was needed very often.

Compacted Soil/Bentonite Lining

(a) 4.5 Inches Thick Compacted Soil Lining Under 4.5 Inches Thick Soil Cover

Existing channel section was excavated upto 9 inches depth. The soil was then refilled in small thicknesses and compacted at bed and sides to attain a density of 1.5 gm/cc. The whole 4.5 inches thick layer of soil as lining sample was completed. The remaining already excavated soil was provided as cover to achieve final section for testing.

Observations were recorded after attaining saturation. Initially the efficiency of this type of lining was about 61.1 % as compared to unlined section. Seepage reduction efficiency showed little variations upto 2 years. After 2.5 years the efficiency was 54.46% and finally the lowest efficiency was as 31.27% within 3 years of testing.

(b) 4.5 Inches Thick Compacted Soil-Bentonite Mixture (5% Bentonite) Under 4.5 Inches Thick Soil Cover

Bentonite is a type of soil existing in natural condition quite in abundance in Pakistan. Bentonite has the natural property of swelling on wetting and thereafter becoming hard and impervious.

A special soil having 80% fine sand, 10% clay and 10% silt was prepared and locally available bentonite, commercially known as 'HIGEL GRADE' mixed in the ratio of 5% bentonite as one part and 95% of prepared soil as the other part was used for constructing the lining sample. The sample was then compacted in layers to achieve 4.5 inches thick lining. The sample was covered with 4.5 inches thick excavated soil. Observations were started after attaining the saturation of lined section. Initial seepage reduction efficiency was 97.59% as compared to unlined section. The efficiency reduced to 86.05% after 2 years. It was recorded as 79.80% after 3 years, 71.18% after 3.5 years, 66.51% after 4 years and 44.46% after 5 years. Rodent attack, cracks, etc. were the main reasons for this deterioration.

Chemical Soil Sealants for Lining

The soil sealants approach makes use of bituminous or other water miscible emulsion products which when applied to a sub grade of a leaky channel, react chemically to form a solid or semisolid jell type deposits. These by penetration and precipitating in the voids, render the sub grade impervious to water percolation.

Irrigation Research Institute, Lahore has been engaged in evolving and testing of various types of soil sealants for the last three decades. During this period products of a few foreign firms have also been tested under the laboratory, semi field, and field conditions.

A brief resume of the work already done is given below:-

(a) Cationic Asphalt Emulsion

Armour Chemical Company of U.S.A. produced a bitumen-water emulsion under the trade name of Cationic Asphalt Emulsion. The emulsion when tested in a perspex pipe packed with fine to coarse sands in the laboratory showed 40% to 90% seepage reduction. When the same sample was tested in 10 cusec discharge capacity experimental channel at Lahore Branch canal site, the seepage reduction was just 20% to 60%.

Instead of deep penetration and formation of good bitumen- sand mastic, it formed ⅛ inch to ½ inch thick bitumen layer on top of the sandy formation. Initially the treated channel showed reduced percolation rate but thereafter it regained the regional rate owing to the deterioration of the bitumen layer.

(b) Chevron Soil Sealant

California Chemical Company, America produced a wax-water emulsion. The sample was tested in different channels having silty and sandy bed conditions. Under ponding test, the seepage reduction efficiency was 40% as minimum & 95% as maximum immediately after treatment but the efficiency decreased by 16% and 67% after 6 months and 10 months of treatment. In the flowing condition test, the seepage reduction efficiency was found very low. The company produced a number of different formulations which were tested in glass tubes in the laboratory. Promising samples were also tested in field distributaries but the results were not very encouraging. In fact the idea of using wax for forming an impervious layer at some depth below the bed of the channel did not prove very effective.

(c) Soil Sealer 13 (S.S. 13)

Brown Mud Company Torrence, California U.S.A produced an emulsion under the trade name of S.S. 13 using resinous polymers mixed in a carrier of diesel fuel. Its property is to increase the ionic attraction of the soil particles for water and also to increase the thickness of the hygroscopic envelope around each soil particle to eventually retard the flow of water through soil formation.

The material when tested in a big experimental tank, having artificial arrangements for seepage collection, showed 78% seepage reduction just after treatment. The material was also tested in a 20 feet long flume under flowing conditions. It reduced seepage up to 50% at 0.2 feet/sec. flow velocity. The durability of the material was however found to be unsatisfactory on prolonged testing. The material in general could form a thin film only at the surface. The experiment was conducted in the experimental channel of 10 cusec discharge capacity under flowing and ponding conditions and a seepage reduction of 90% (24 hours after treating) was observed which reduced to 30% within a period of one and half year of treatment.

(d) Low Cost Sealants of ESSO Research

ESSO Research Ltd. Abingdon, U.K. also introduced different asphaltic sealants. The formulations were tested at the Irrigation Research Institute, Lahore. Many of the formulations proved satisfactory in penetration and reducing percolation. During laboratory test a ½ to 12 inches penetration and 20% to 98% seepage reduction in fine sand and ½ to 15 inches penetration with 9% to 96% seepage reduction in coarse sand were observed. In some cases the penetration was as much as 6 inches forming a good bitumen sand mastic. Certain specifications usually containing soft grade of bitumen, hydrochloric acid and an emulsifier were found to be promising and were selected for the field trials.

Field tests were run at Pakhoki distributary near Chunian which had a sandy bed with ground water table at 10 feet depth. On the average the sealant reduced seepage by about 48% with persistent recording upto 6 months. After treatment the bed became very stiff and capable to resist erosion. At some places penetration was from 4 to 5 inches deep but in general the sample remained only at the surface making it fairly hard and impervious. These sealants behaved like surface sealants and penetrated only to relatively small thicknesses. Their performance aroused suspicion as at the shallow depths the seal was subjected to erosion, damage by cattle trespassing, growth of weeds, etc.

(e) Soil Sealants Tested Under PARC PROJECT

Local and easily available cheap stuff comprising bitumen 80/100 grade, an emulsifying agent and the laboratory equipment was used for preparing soil sealants.

A number of sealants were tried in the laboratory. Some of these gave promising results at the laboratory level but these still need improvement and detailed investigation.

Flexible Lining

(a) Polyethylene Sheet Lining

Research studies on polyethylene sheet lining were conducted under A.D.P. Research Programme of the Institute and also under U.S. PL-480 funded Project of Lining. A number of specimens of polyethylene sheet have been studied under controlled conditions. Polyethylene sheet of 0.2 mm thickness was installed under 9 to 12 inches thick soil cover in experimental trays at semifield and actual field conditions. Damages to polyethylene sheets due to weed growth and rodent attacks were observed at most of the field channel sites. (see photographs 1&2).

Lining materials are studied at Field Research Station, Niaz Beg, Lahore. The permanent experimental water channel set up for lining studies has been established (see photograph 3).

Seepage reduction of polyethylene lined experimental water channel at Niaz Beg Research Station was 93.38% initially. It was 92.4% after one year. But during one and half year period, it decreased to 67.91% owing to rodent attack, weed growth effects, etc. Upon repairing, efficiency increased upto 80.3%. But then efficiency reduced upto the lowest rate of 37.36% within two years, especially due to rodent attack.

(b) Rubber Membranes

1. Taurus W Foil, A Lining Material

The characteristics of Taurus W Foil, supplied by Taurus Hungarian Rubber, Works, Hungary for testing are detailed below:-

i)	Length	40 meter
ii)	Width	2.5 meter (2 pieces joined by vulcanization)
iii)	Thickness	1.5 mm

iv)	Specific weight	2 Kg/M^2
v)	Colour	Black.
vi)	Basic Material	EPDM, butyl-EPDM, butyl-caoutchouc

Photo 1. Weed roots puncturing the polyethylene sheet, observed after removing the soil cover (Field study).

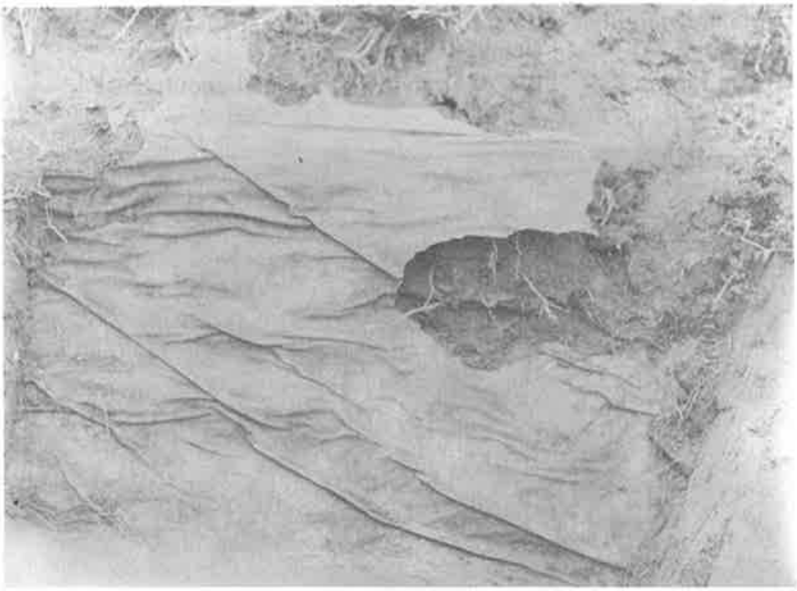

Photo 2. Rodent attack damages to polyethylene sheet, observed after removing the soil cover (Field study).

Photo 3. Permanent experimental set up of water channels for testing various lining materials at Niaz Beg Research Station, Lahore.

To check the performance of "Taurus W Foil" a sample in 100 feet long section of the experimental water channel was installed at Field Research Station, Niaz Beg, Lahore. The prepared section for lining purpose was 12" bed width, 16" depth & 44" surface top width, at 1:1 side slopes.

"Taurus W Foil" sample was shifted at the site and spread on the prepared section. To make a leak tight joining with the concrete pillars at end points, commercial benzene was used to remove the dust. Then the "BUTYL" adhesive bond tape strips were prepared according to the required dimensions and after coating with rubber solution (glue) were let to soak. (see photograph 4).

These adhesive bond strips were later on pasted with the concrete pillars. "Taurus W Foil" was then pasted on the already pasted adhesive tape strips (see photograph 5).

For smooth and fault free sticking, the surfaces joints were pressed with a small iron roller. The "Taurus W Foil" Sheet spread in position prior to soil filling is shown (see photograph 6).

PERFORMANCE AND EFFICIENCY TEST

Ponding tests for percentage seepage reduction efficiency of "Taurus W Foil" rubber sheet were made, with and without 9" thick protective soil cover.

i) Initially the test was carried out with 9" thick soil cover. The seepage reduction efficiency was found to be about 95% and remained constant for almost a year.

ii) Soil cover was removed and then ponding test showed efficiency about 88.34%. Reason was leakage through joints. Upon necessary repair of bondage at joints, the efficiency increased upto 99% and remained constant for next 3 months.

iii) After that the Taurus W Foil was provided with 9" thick silty soil cover. The seepage reduction efficiency on the average was recorded as 92% which remained constant for one year.

iv) The sheet was left exposed to weather to check weathering effects for about next 4 years. No apparent deterioration was observed.

Photo 4. Butyl adhesive strips prepared prior to joining the Taurus rubber sheet with pillars Niaz Beg Research Station, Lahore.

Photo 5. Taurus rubber sheet and Butyl adhesive strips joined with concrete pillars at Niaz Beg Research Station, Lahore.

Photo 6. **Taurus rubber sheet spread in experimental water channel section prior to providing soil cover Naiz Beg Research Station, Lahore.**

v) 9" thick local soil cover was again provided and continuous testing for the last 5 years period shows the seepage reduction efficiency about 95% on the average.

MIZU RUBBER SHEET, A LINING MATERIAL

MIZU Rubber Sheet sample supplied by Sumitomo Corporation of Japan was installed at Field Research Stations Nandipur, Gujranwala & Niaz Beg, Lahore in the presence of Japanese company experts. Basic characteristics of the sheet are given below:

i)	Length	100 meter
ii)	Width	8.0 meter
iii)	Thickness	1.2 mm
iv)	Specific weight	1.8 Kg/M^2
v)	Colour	Black.
vi)	Basic Material	EPDM

vii)	Quality	Synthetic rubber with polyester fibre as reinforcement

EXPERIMENTS AT FIELD RESEARCH STATION NANDIPUR

At Field Research Station, Nandipur, district Gujranwala, an experimental channel of 200 feet length was prepared. Trenches for side anchoring, with dimensions one foot depth & one foot width were also dug out at a distance of one foot on either side.

Testing the Sheet in Exposed Conditions

It was planned to instal the MIZU Rubber Sheet in exposed condition i.e. without soil cover or brick protection to check weathering effects and durability. Profile walls were constructed at both ends of the channel using 1:3 Cement Sand (C/S) brick masonry.

The sheet was then spread in the channel resting in the section and in anchor trenches on both banks (see photograph 7). Brick masonry/pitching was done above the MIZU Rubber Sheet in the anchor trenches.

Photo 7. Mizu rubber sheet spread in experimental channel and anchor trenches at Nandipur Research Station, Gujranwala.

Effects of Cattle Trespassing

The Sumitomo Corporation, Japan experts claimed that the product is capable of withstanding the normal traffic of local livestock like buffaloes, cows, goats, etc. A flock of buffaloes was let loose in the experimental lined channel to walk on the MIZU sheet. The following observations were recorded:

a) With the walk of normal animals, no apparent damage was seen at the bed of the channel(see photograph 8).

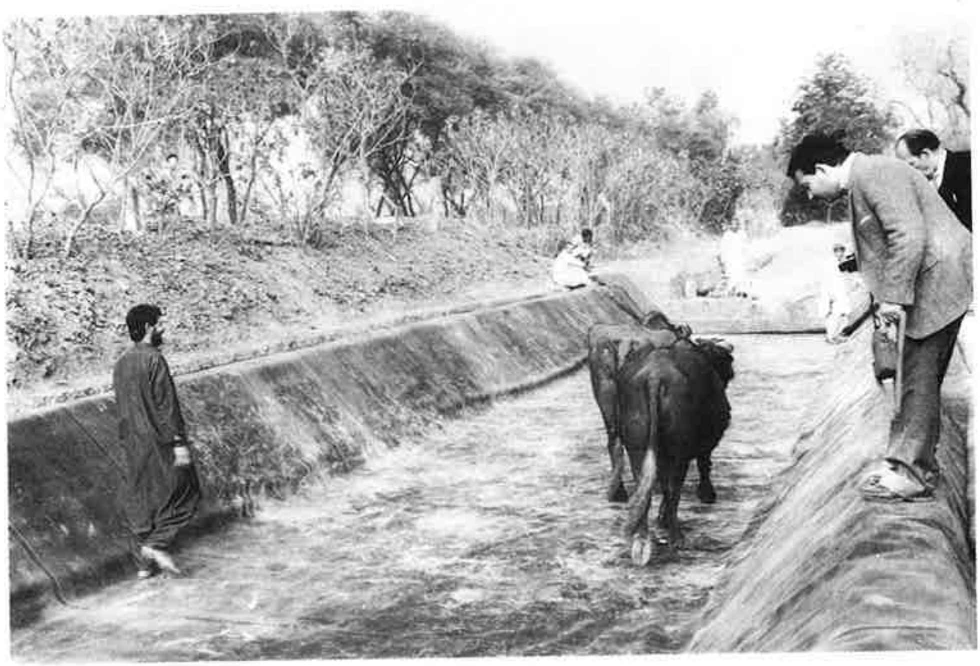

Photo 8. Buffaloes walking on the Mizu rubber sheet lined section to observe the damaging effects of cattle trespassing at Nandipur Research Station, Gujranwala.

b) A buffalo walked out by climbing up the side of the channel even then no damage was seen. Hoof prints clearly indicates no damage to the sheet. (see photograph 9).

Photo 9. A view of the buffalo hoof print - indicating no damage to Mizu rubber sheet at Nandipur Research Station, Gujranwala.

EXPERIMENTS AT FIELD RESEARCH STATION NIAZ BEG

Testing the Sheet in Exposed Conditions

At Field Research Station Niaz Beg, Lahore, a section of channel 100 ft. long having leak tight gates embedded in concrete pillars at both ends was selected. The section represents a small irrigation experimental channel. Dimensions of the section were 12" bed width, 16" depth, 23" sides and 44" top width. Anchor trenches on both banks were also dug out. MIZU sheet was spread in the section and anchor trenches(see photograph 10). Precaution was taken that the sheet should neither be in loose nor in tight position. The soil was refilled in the anchor trenches above the sheet and compacted. Brick masonry was provided on bank top upto trenches on either sides for good anchorage.

Photo 10. Mizu rubber sheet installed in exposed condition in water channel section at Niaz Beg Research Station, Lahore.

The Sumitomo Corporation, Japan has improved the bonding technique on the basis of the past experience. In this case instead of bonding the sheet with end pillars, an extra, about five feet, MIZU sheet piece was bonded with the parent lined sheet at a distance of about three feet away from the end pillar (see photograph 11). This additional bonded piece was raised subsequently and soil filled behind the sheet up to end pillar on both sides of the lined section and then water was ponded to measure the rate of seepage.

Photo 11. A view of providing extra sheet piece at end points in lined section to avoid bond problem at Niaz Beg Research Station, Lahore.

MIZU Rubber Sheet under Brick Cover

Keeping in view local field conditions, it was planned to set up test by providing brick cover upon the sheet so that it may resist the field problems. A section selected for this test was dug upto 5" depth at bed and side. A half inch thick layer of 1:10 C/S was provided in the section to give smooth surface. The MIZU sheet was spread and protected with edge brick lining using 1:3 C/S mortar on sides and bed (see photograph 12). Then experiments for seepage measurements were carried out.

Photo 12. Mizu rubber sheet installed under brick on edge in progress at Niaz Beg Research Station, Lahore.

MIZU Rubber Sheet under Soil Cover

A prepared section selected for the test was dug upto 1′ depth at bed and sides which ultimately measured 28" depth, 22" bed, 39" side, and 78" top width. 1′x1′ wide anchor trenches at one foot away from the top bank on both sides were also dug. The section was cleaned and then the sheet measuring 15 feet wide was spread in the section and the side trenches. Initially the soil was filled in the anchor trench and compacted. Then soil was refilled in the section above the sheet and compacted to provide one foot thick soil cover. Then experiments for seepage measurements were carried out.

PERFORMANCE & EFFICIENCY TEST

In order to pond water in the lined section the additional bonded sheet piece was raised at end points and then soil was filled behind them. The data collected, calculated and tabulated is as under:

	Specification	Seepage Reduction efficiency(% age)			
		Initial	½ Yr.	1 Yr.	1.5 Yr.
1.	MIZU sheet without soil cover(Exposed)	99.59	99.29	99.35	99.36
2.	MIZU sheet under brick on edge cover	94.60	97.79	99.44	99.02
3.	MIZU sheet under soil cover	96.42	-	-	-

RECOMMENDATIONS FOR DIFFERENT LINING MATERIALS

Rigid Lining

i) Efforts should be made to develop very high quality rigid lining materials which may require minimum maintenance problems.

Bentonite Lining

i) Locally available bentonite should be thoroughly investigated for lining purposes.

ii) Sealing property of local bentonite should be improved by mixing it with some suitable chemicals.

iii) Bentonite lining layer must be protected with the soil cover.

Soil Sealant Lining

i) Sealing and penetration property of soil sealants should be improved.

ii) Such emulsions/sealants should be developed as may resist uplift or back pressure.

iii) Further research to perfect the sealants for all grades of sand is necessary.

Polyethylene Sheet Lining

i) A detailed study on damaging effects of weed growth on polyethylene sheet lining may be continued, particularly under controlled conditions, for making more reliable conclusions and recommendations.

ii) Such a high quality special type/grade polyethylene sheet should be developed as may resist damaging effect of weed growth, rodent attack, deterioration in sun light, etc.

iii) In certain areas the damaging effect of weed growth to polyethylene sheet lining is very severe. Use of ordinary polyethylene should be avoided, and if it is used, then some protection against weed penetration should be provided to the lining.

iv) Some effective weedicides may be used to destroy the weed growth in polyethylene sheet lined channels.

v) Rodent attack or animal trespassing may damage the polyethylene/plastic lining and the damaged lining is more prone to weed growth damages, so proper measures should be taken to control rodent attack and animal trespassing to prolong the life of polyethylene lining.

Rubber Membrane Lining

i) Bonding materials & bonding techniques for rubber membrane lining should be improved.

ii) Proper protective cover should be studied for rubber membrane lining.

iii) The thickness of rubber membrane, if possible should be reduced without affecting its durability.

iv) Reinforced rubber membranes are more reliable than simple rubber membranes, so the reinforced type should be preferred for lining purpose.

v) Long term investigations should be made on different types of rubber membranes, under varied local conditions, to make reliable conclusions and recommendations.

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CANAL LINING PERFORMANCE PARAMETERS IN THE CHASHMA RIGHT BANK CANAL STAGE-I IRRIGATION SYSTEM

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ABSTRACT

An on-going 3-year study is being conducted by the International Irrigation Management Institute at the Chashma Right Bank Canal Irrigation System in the Northwest Frontier Province of Pakistan. Simulation and performance evaluation studies of the system have yielded considerable information on the hydraulic behaviour of the main canal. Performance parameters related to both the lined and unlined reaches of the system's Stage I are analyzed, compared and discussed. Primary and secondary data on seepage, roughness coefficient, velocity, canal capacity and physical conditions and maintenance are utilized in order to asses the merits and demerits of lining in the context of present operating conditions. The document draws attention to the fact that during the initial years of system operation seepage losses had relatively high values in the unlined and relatively low in the lined section; however, at present, comparable values have been documented for both the sections. Actual roughness of the brick and concrete lined sections is higher than the design value of .016. Estimation of this parameter, done through a hydraulic model, indicates a range of .018 to .022. This finding has obvious implications as reduced canal capacity will constrain every day operations in the future. The paper concludes by pointing out that the experience of CHASHMA Right Bank Canal provides useful information about the technical and operational aspects of canal lining which could be considered at the project planning and design stage of future projects.

INTRODUCTION

Although canal lining is a common practice throughout the world and the technical know-how has been well established for many years, its worth in some cases is still a debatable subject. In the context of developing countries, canal lining programs are always questioned on the grounds of relatively high costs and less than desirable workmanship in the lining which brings into question the cost effectiveness or economic viability of such a technology. Water saving has been the most cited objective of canal lining, while recent studies (Charles, A., 1992 and Purshottam, J., 1988) have raised questions about the amount of real savings and on the sustainability of the low losses achieved in the early years of lining. A further argument brought against lining refers to the negative impact that it can have on the recharge of groundwater in those areas where unlined canals are an important component of recharge to aquifers.

Notwithstanding, canal lining is considered as a legitimate tool to conserve water by reducing seepage losses; in some cases it can provide an opportunity to utilize the canals for additional storage purposes, or is used to upgrade the hydraulic conditions of the canal for improvement of system operation. Another objective of canal lining, often considered in India and Pakistan, is that it allows an increase in the command area by adopting flatter slopes, since 20 to 60% decrease in roughness is possible due to lining. However, sustaining the maximum canal capacity (by keeping the roughness and slope as per design) becomes a critical issue in light of prevailing design, construction and operational conditions in those countries.

The irrigation system of the Indus Basin was developed 50 to 100 years ago. It consists of alluvial channels of different capacity, some of the main canals having capacities more than 12000 cfs. The system basically covers the Lower Indus Basin and has worked without major problems and with minimum maintenance for some decades; natural gradient and soil types of the basin were appropriate for the adopted design and helped the system to achieve the hydraulic balance. But during the last thirty years, problems of sedimentation and shortage of water started developing, especially at distributary tails due to increases in silt intake and cropping intensities. To solve this problem the Punjab Irrigation Department (PID) decided to rehabilitate a major part of the system by partial lining. At the same time lining was adopted in new projects for the Upper Indus Basin due to soil conditions, in order to increase the command area and to support the crop based irrigation operations. In this background, the International Waterlogging and Salinity Research Institute (IWASRI) in collaboration with the Hydraulic Research Institute Wallingford, UK, have decided to organize a Workshop on "Canal Lining and Seepage" in order to bring together senior engineers, administrators and experts from Pakistan and selected countries to focus on the broad question of canal lining and seepage reduction, assess their perceptions and concerns and, through this process, evolve a research agenda that can assist the GOP in reaching sound decisions on the canal lining program being envisioned.

The paper that follows relates to a component of the on-going 3-year research efforts by the International Irrigation Management Institute (IIMI) on its project "Crop-based Irrigation Operations in the North West Frontier Province of Pakistan". The study is being conducted on the Chashma Right Bank Canal (CRBC) Stage I Irrigation System.

Performance parameters related to lining such as seepage, roughness coefficient, canal capacity, velocity, and physical conditions of the canal have been quantified and compared against design values. Since a sizeable reach of the CRBC canal is unlined, the above mentioned parameters are also compared across the lined and unlined sections, wherever possible. The impact of the results on canal performance are analyzed and discussed, and some recommendations for the future are given.

SYSTEM DESCRIPTION

The Chashma Right Bank Canal Project is a major perennial surface irrigation system that, once completed, will cover a gross command area (GCA) of about 690,000 acres (280,000 ha) of land along the right bank of the Indus River in central Pakistan, stretching between the Chashma and Taunsa barrages.

The source of water for the project is the Indus River by means of the Chashma barrage which was commissioned in 1982. The Canal is 152 miles (258 km) long with a culturable command area (CCA) of 569,767 acres (230,675 ha) that spans two provinces: namely the North West Frontier and the Punjab, in a 60 to 40 percent proportion, respectively.

Construction of Stage-I has been completed and became operational in early 1987, it includes the old Paharpur Irrigation System which has been remodelled for increased capacity and is now being fed by the CRBC through link channels. The Main Canal's full capacity of 4800 cfs (138 cumecs), to be distributed through 50 distributaries will be fully utilized upon completion of Stage-II (in advance stage of construction, with termination scheduled for 1993) and Stage-III (construction scheduled to begin in 1993/94 while completion is expected in the year 2000).

The command area of CRBC presents special topographical features which account for the present design. The project area can be divided into two distinct units:

(i) an eastward sloping piedmont plain on the west; and

(ii) an alluvial flood plain of the Indus river, flat lying on the east.

To cover the maximum command area, the main canal was designed as a contour channel, running on the highest possible contour, with quite flat longitudinal slopes for most of its length and feeding distributary channels on its left side only. According to the PC-1 document (1991), the soils of Stage-I are of heterogeneous nature; sandy silt in RD 0 to RD 135+000, a gravel section from RD 135+000 to RD 145+000, fine sand and dune sand in RD 145+000 to RD 210+000 and sandy silty clay in RD 210+000 to RD 260+000. The main canal runs in the reclaimed bed of River Indus for the first 19 miles and then after flowing for 6.5 miles through old cultivated lands traverses through a 14 miles stretch of sandy area with sand dunes.

Another peculiar feature of the area is the flood run-off from the hill torrents which starts at the Koh-i-Sulemanki range and finds its way down to the River Indus, thus the need for many draïnage structures crossing the main canal.

The unlined head reach, RD 0 to RD 120+000, of the canal is in high fill, with the full supply level 30 ft higher than the natural ground surface in some of the reaches; this section was kept unlined due to the high water table conditions in the reach. The lined section is mostly in cut, with the full supply level only a few feet higher than the natural ground surface. According to the design documents lining was adopted primarily to reduce the co-efficient of roughness and secondly to provide the bank strengthening in view of the soil conditions.

As to the lined section, a double-layer brick lining with no asphalt section has been adopted from RD 135+000 to RD 210+000 and from RD 244+000 to RD 257+000. A four inch thick concrete lined section is in place for the remaining of the stage I channel. As a cost reduction measure, compaction of embankment was restricted to the prism under the dowel and behind the lining in Stage-I. For the Stage-II, however, full compaction was provided in view of the experience in Stage-I. The outside slopes of the fill embankment and exposed cut sections of the main canal in Stage-I have been proved to be susceptible to rain erosion causing serious loss of fill material and entry of the eroded material into the canal prism. Table 1 below summarizes specific information about the design features of the lined and unlined portions of CRBC Stage-I.

STUDY APPROACH

Objectives

The study pursued the following objectives:

i) to identify key parameters related to the estimation of physical performance of a lined canal.

ii) to assess the benefits of lining by comparing the performance of the lined versus the unlined sections of CRBC Stage-I.

iii) to compare designed and measured (or calculated) parameters related to lining in order to determine their sustainability.

Table I. Design Parameters of the Lined Section of C.R.B.C.

Reduced Distance (ft)	SLOPE	BED WIDTH (ft)	DEPTH (ft)	VELOCITY (ft/sec)	CANAL CAPACITY (cusecs)	SIDE SLOPE
0 to 99000	1:8093	174	8.35	3.21	4768	1/2:1
99000 to 114712	1:8093	174	8	3.18	4464	1/2:1
114712 to 120000	1:7954	174	7.75	3.06	4227	1/2:1
120000 to 130900	1:14000	45	16	3.82	4227	1.5:1
130900 to 170000	1:14000	44	16	3.81	4156	1.5:1
170000 to 201198	1:14000	42	16	3.79	4009	1.5:1
201198 to 224000	1:14000	36	16	3.67	3984	2:1
224066 to 237000	1:14000	35	16	3.63	3959	2:1
237320 to 244000	1:14000	33	16	3.67	3825	2:1
245630 to 253000	1:14000	45	16	3.63	3821	2:1
253000 to 260000	1:14000	31	16	3.63	3609	2:1

Methodology

To address the above mentioned objectives, a pragmatic but analytical approach was adopted. First, the available field data (both from primary and secondary sources) related to the present situation were analyzed. It was clear during that preliminary analysis that the operation of the main canal has a significant effect on its hydraulic behaviour and must be quantified properly in order to compute the parameters.

Therefore, as a second step and in order to replicate the field scenario comprehensively and accurately, a mathematical simulation model SIC (Baume, J.P. et al., 1993) was used. The model provides the opportunity to reproduce, through a mathematical-based approach, the physical and operational conditions of a canal. It can quantify the effects of each parameter exclusively, without disrupting the actual day-to-day operation of the canal.

The information utilized in this study consists of:

- water and canal performance data collected by IIMI during two years of field activities.

- hydraulic data collected by WAPDA agencies: Alluvial Channel Observation Project (ACOP) and the CRBC operations division.

- data provided by design office and other related documents (like PC-1) of Stage-I.

- information collected by the canal construction consultant firm, NESPAK, in their System Performance Monitoring Report of December 1988.

It should be pointed out that the study pertains to CRBC Stage-I only. Inferences made for the other components of the CRBC system, based on these results, need to be treated with care.

Parameters Studied

A set of parameters was selected to cover different aspects related to the merits and demerits of lining. Although some of these parameters are interrelated, individually they still reflect canal performance. Those selected were the following:

. seepage losses
. roughness coefficient
. canal capacity and freeboard
. velocity
. physical conditions and maintenance
. impact on management

In the section that follows, each one of the parameters will be discussed keeping in mind the objectives set forth above.

EVALUATION OF PHYSICAL PERFORMANCE PARAMETERS

Seepage Losses

The most commonly cited purpose for canal lining is to reduce the conveyance and seepage losses. Theoretical values (sometimes obtained under controlled laboratory conditions) for seepage losses are normally used at the project planning stage. In recent years, efforts have been made (particularly in Indian Punjab) to measure the actual losses of new and old lined canals. However, a common problem in this comparison remains the unavailability of pre-lining seepage data. Therefore, it is still a valid question persists as to what extent lining is useful for reducing seepage losses. CRBC provides the opportunity to evaluate the behaviour of seepage losses in newly commissioned lined and unlined canal sections under the same physical and environmental conditions, which can then be compared with the design assumptions. In the following section, losses from both lined and unlined sections are discussed.

Initially, a high seepage rate was expected from the unlined portion due to permeable soil conditions and the canal prism being in "fill". Sure enough, in the first month of canal operation, the seepage rate from the unlined section yielded values of more than 25 cfs/MSF (cubic feet per second per million square feet). Water appeared in borrow pits on both sides of the canal within a day and started affecting already cultivated areas. The Government of Pakistan through WAPDA was forced to take immediate actions and remedial activities like *Killa Bushing* and silt enhancement (introduction of silt from outside). A tile drainage program was also launched to control the water table in the upper reaches of the main canal; this program was afterwards extended to cover the entire Stage-I and is likely to be continued for Stage-II.

Furthermore, flow measurements taken in January, February and March 1987 showed that more than 50 percent of the water was disappearing in the first nineteen miles (29 kilometers) of the unlined section, upstream of the cross regulator. The above effort brought the losses into the permissible range of 8 cfs/MSF within a year (see Figure 1-a). This decrease in seepage occurred basically through control in the inside of the canal by means of berm formation (killa bushing effect) and by filling up the pores of the permeable layer on the canal bed and banks with fine silt and clay. Seepage from the unlined section downstream of the cross-regulator decreased rather slowly because the lighter silt particles were transported beyond, while the upstream reaches were favored with the deposition of the heavy silt load. Subsequent measurements taken in 1990-91 (taken once in a month) showed that the canal losses from the unlined section were in the range of 3-8 cfs/MSF.

On the other hand, very low losses were reported from the lined section in the beginning of canal operations. At the end of 1988, NESPAK published the canal losses based on measured seepage rates for Stage-I (NESPAK, 1988). These quantities for unlined and lined reaches presented in Table-II below are still used by the different agencies when estimating seepage losses in the system.

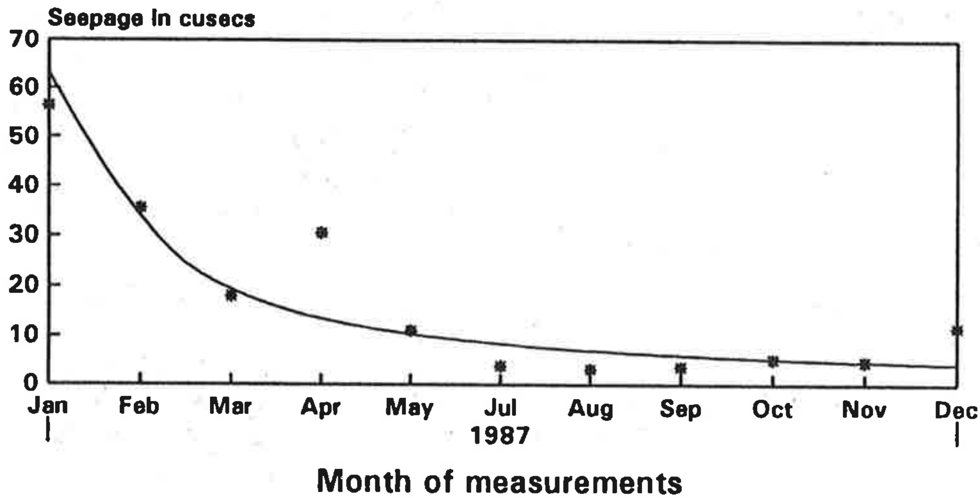

Figure 1a. Total Seepage from Unlined Section during First Year of Operation (1987).

Table II. Seepage Rate and Total Losses for 1987-88 Reported by NESPAK.

Reduced Distance (feet)	Wetted Perimeter (MSF)	Seepage Rate Range (cfs/MSF)	Total* Losses (cfs)
Barrage to 97,500 (unlined)	23.0	3.0 - 20	69.00
97,500 to 120,000 (unlined)	4.5	4.5 - 25	20.25
120,000 to 845,000 (lined)	37.5	2.0 -4	75.00
Total	65.0		164.25

* seepage rates were measured for the lined and the unlined section of Stage-I and then, based upon those values, canal losses for all three stages are computed.

Measurements taken by ACOP in 1990-91 revealed that the losses for the lined section were higher than the losses obtained for the same section in 1987-88

(Figure 1-b). Some of the measurements for lined section have been in the range of 5-6 cfs/MSF.

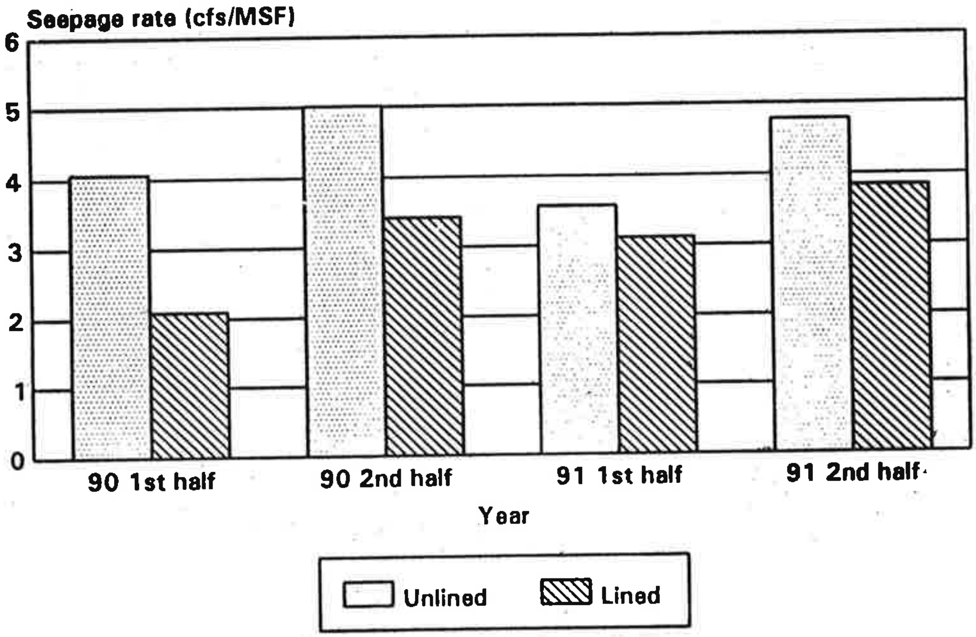

Figure 1b. Seepage Rate for CRBC Stage-I Year 1990, 1991.

From the average values shown in Figure 1-b the following information is derived:

i) seepage from the lined section has substantially increased during the six years of operation,

ii) losses from the unlined and lined section are practically in the same range, particularly in 1991, and

iii) the average losses in the second half of the year have been higher than those for the first half due to higher discharges in the main canal during those latter months.

Further analysis was undertaken regarding the relationship between water depth and seepage in both unlined and lined sections. In the former, the correlation of seepage with water depth can be traced to the process of berm formation. Figure 1-c shows the seepage-depth relationship taken for 1990-91. Also, it was observed in 1993 that the seepage increased tremendously when the inflow was higher than

3000 cfs; this means that the berm formation caused a reduction in the percolation from the banks below the normal water level, while the bank strata above remained highly permeable.

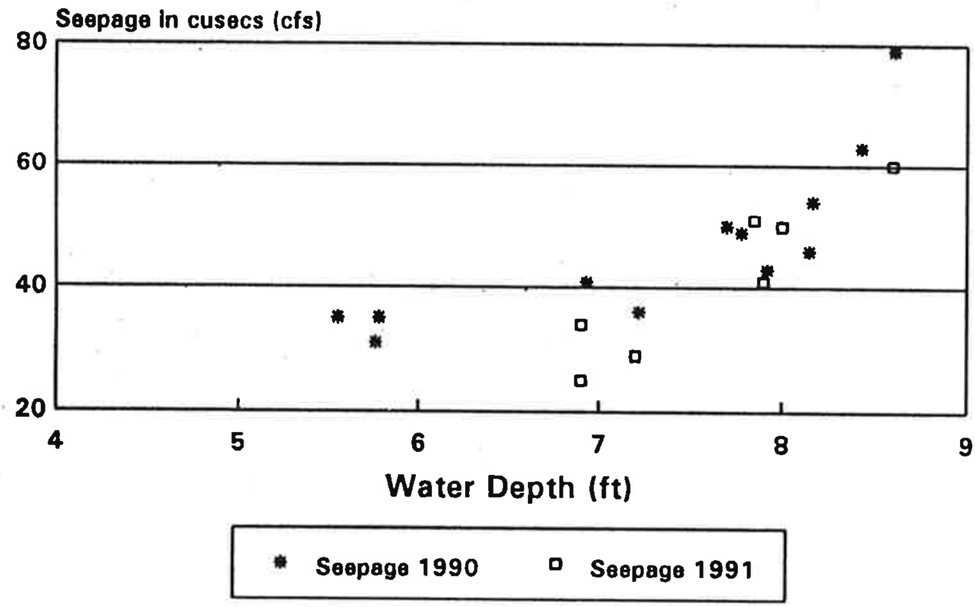

Figure 1c. Seepage vs. Depth for Unlined Section RD 5 to 51 (1991).

The seepage-depth relationship for the concrete section is shown in Figure 1-d. The depth variation in this reach was not much, but there seems to be a linear trend. The cluster of points in the middle indicates an increase in seepage with time, since they represent three years.

Possible reasons for the higher losses are lining imperfections and damage to lining caused during operations. A significant increase in canal losses from lined canals, within a couple of years of operations, has also been observed at other locations in Pakistan and India (Purshottam, J., 1988 and ACOP, 1988-1992).

Behaviour of Roughness Coefficient

As indicated earlier, project planners for the Chashma Right Bank Canal have adopted many measures to make the project financially beneficial. The objective was achieved by designing the main canal on the highest contour with a flat slope of 1 in 14000 feet and a small roughness coefficient for Manning's equation of n=0.016. The twenty four miles-long unlined section has been designed on Lacey's equations with a value of f=0.96 (equivalent to n= 0.021). The average bed to depth ratio was 20:1 for the unlined section and 2.4:1 for the lined section. The average designed bed slope was 1 in 8000 feet for the unlined section.

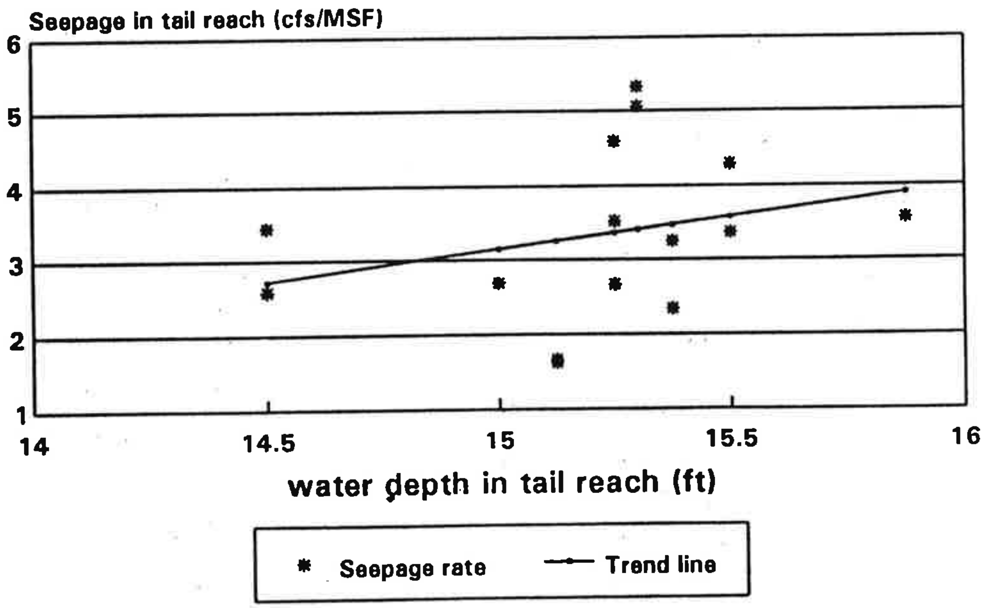

Figure 1d. Seepage rate vs water depth in Concrete Section of Stage 1 (1990-91).

Computing a realistic roughness coefficient is not straightforward from observed field data of velocity, water surface slope and hydraulic radius due to the influence of operational and other interfering factors. The present operations cause heavy backwater affects upstream of all control-structures, which influences the energy slope. Furthermore, physical changes taking place in the canal cross-sections (hydraulic depth, side slopes, etc) also affect the value. The SIC model was used to realistically estimate the roughness coefficient by eliminating the operational effects. The following procedure was adopted:

i) Only those cases were simulated when the inflow in the main canal was more than 50% of the maximum design discharge (i.e. 2400 cusecs or more).

ii) The steady state component of the model was applied to simulate the hydraulic, physical and operational conditions of the canal using field data.

iii) For those reaches where the effect of backwater did not exist, the value of 'n' was directly computed using the 'Manning formula' and then compared with the model output.

iv) Average 'n' values estimated in steps ii and iii were verified by simulating a field scenario and by comparing computed and observed water levels.

For the estimation of roughness, two complete field scenarios were simulated: inflows of 3700 cfs in 1990 and 2516 cfs in 1991. For each year, the topography of the respective year, measured offtake discharges, seepage losses and gate openings for cross-regulators were used. The observed water surface level was achieved by adjusting the 'n' value (through hit and trial method) while conserving the same water volume in different reaches. Hence, with all parameters known, the roughness coefficient 'n' was computed for five reaches of Stage-I. Table III below gives those values of 'n'.

Table III Computed roughness coefficient using: (a) energy slope and Manning's equation; and (b) hydraulic model.

Distance along the canal in 1000 feet	1990		1991	
	Manning Eq. for Energy Slope & actual Velocity	Hydraulic Model	Manning Eq. for Energy Slope & actual Velocity	Hydraulic Model
(Unlined)				
0 - 51	.016	.017	.016	.018
51 - 98	.024	.021	.026	.022
98 - 120		.022	.024	.022
Lined				
120 - 130	.024	.019	.023	.019
130 - 170	.0185	.018	.0185	.019
170 - 210	.0205	.018	.021	.019
210 - 237		.021		.022
237 - 257		.022		.022

The roughness coefficient for the unlined section, because of its steep slope, is less than the values normally used for the alluvial channels of the Indus Basin. At the beginning of the lined section (RD 120+000 - 130+000) the 'n' value is quite high due to the transition from the unlined to the lined section which causes a heading up (backwater effect) of the water, thereby increasing the resistance to flow.

To verify the computed 'n' values, they were again used in the simulation of a third scenario pertaining to the actual field conditions in the third week of June 1993 (2800 cfs inflow). For the measured values of discharge and cross sections, the water levels were calculated using the roughness coefficients. Results show a good fit between the observed and predicted water surface levels (Figure 2), which confirms that the estimated roughness values were correct.

To compute the difference in water levels that occurs when using the design and actual roughness values, the above scenario was repeated utilizing the design value of n=0.016. The predicted water levels in this case were much lower than the observed levels as shown in Figure 2.

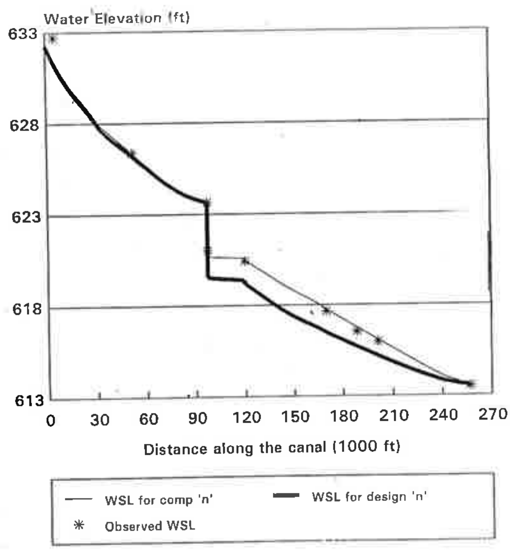

Figure 2. Water profile at 2800 cfs inflow comparison of design and computed 'n'.

The results suggest that the existing roughness of the lined section is in the range of .018 to .022. The increase in roughness at the tail of Stage-I is partly due to heavy sedimentation, but the value of .018 & .019 in the head reaches of lined section suggest that the actual rugosity of brick and concrete lining is more than the original assumptions.

Canal Capacity and Freeboard

Lined canals can experience a reduction in the originally designed maximum canal capacity due to either an increase in the roughness coefficient, a decrease in cross sectional area, unsuitable design of structures, or improper operation. The associated decrease in the freeboard can adversely effect other parameters like seepage, velocity, integrity of the banks, etc.

Field observations show that CRBC normally functions with less than the recommended freeboard in some of the lined reaches. The data indicates that when the inflow exceeds 3000 cfs, the water level is already above the full supply level (i.e. 4800 cfs) at both the tail of Stage-I and at the beginning of the lined section. The present operational practices and the hydraulic parameters contribute to this situation.

To desegregate the effects of operations from the achievable canal capacity, the simulation model was applied. Water levels were predicted for the full supply discharge using the design and actual (computed in the previous section) values of roughness and considering optimum operational conditions.

The predicted and design water levels and left berm of the canal (dowel for unlined section, top of the lining for lined section) are shown in Figure 3. Results indicate that there is no freeboard or canal capacity problem in the unlined section while the lined section faces serious free board problems. The predicted water levels at the full supply are two feet higher than the design levels (Figure 3) which means that some reaches would not be able to carry the full supply discharge. There is a slight difference between the design water level and the predicted level for the design parameters (with actual topography), which is due to changes in canal cross sections.

These results indicate that the freeboard is an important parameter for checking the physical performance of a system. A reduction in freeboard can occur due to many reasons, which can be understood with a proper monitoring of the system.

Velocity

Velocity is a critical parameter to transport the silt loaded water. The alluvial channels of the Indus Basin were recommended to run always at higher than 70% of the design discharge to avoid siltation. It is also recommended that the spatial variation in the velocity should not be much different from the discharge variation along the canal to avoid the siltation and scouring caused by the imbalance of stresses along the canal prism.

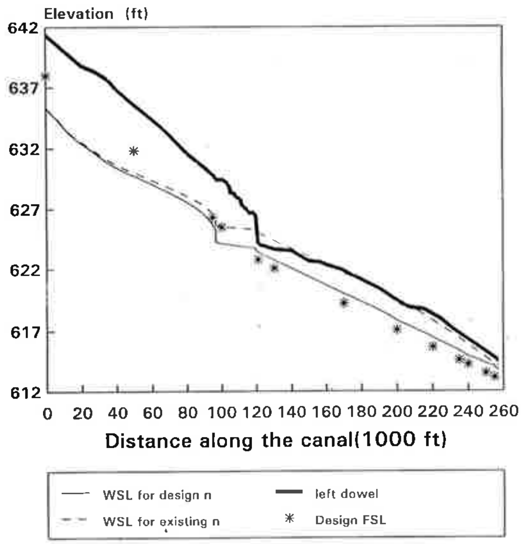

Figure 3. Water surface levels at FSL (4800 cfs) unlined - lined section of CRBC-Stage I.

In CRBC Stage-I, the temporal and spatial variation of velocity were quite high. Velocities recorded in 1990 showed a variation from 3.0 to 0.7 ft/sec along the canal for the same inflow. The variation in the tail reach was 0.9 to 2.7 ft/sec during the year. Figure 4-a shows measured velocities in the main canal for the minimum and maximum inflow.

The hydraulic model was used to estimate the real decrease in the velocity by standardizing the effects of current operations. The model simulated the actual field conditions at an average discharge using the computed roughness coefficient discussed in previous section. The same scenario was repeated using the design parameters. Figure 4-b shows the predicted velocity for both scenarios along with the measured velocity. There is a good fit between the predicted and the measured velocity in different reaches but there is a difference between the two sets of predicted velocities which indicate that the effects of roughness changes are quite prominent. It can be inferred from these results that uniform velocities cannot be achieved in the canal under present physical and operational conditions.

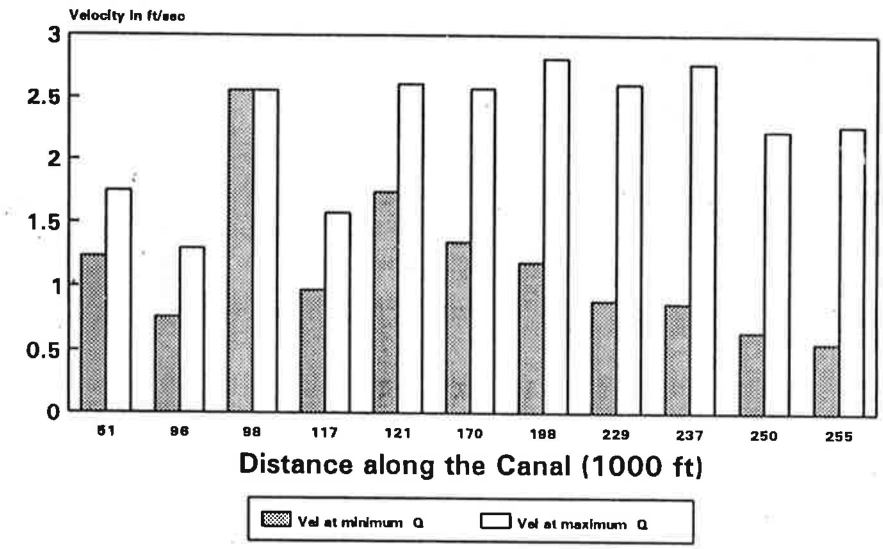

Figure 4a. Measured Velocities along CRBC for max. (3700 cfs) and min (1400 cfs inflow.

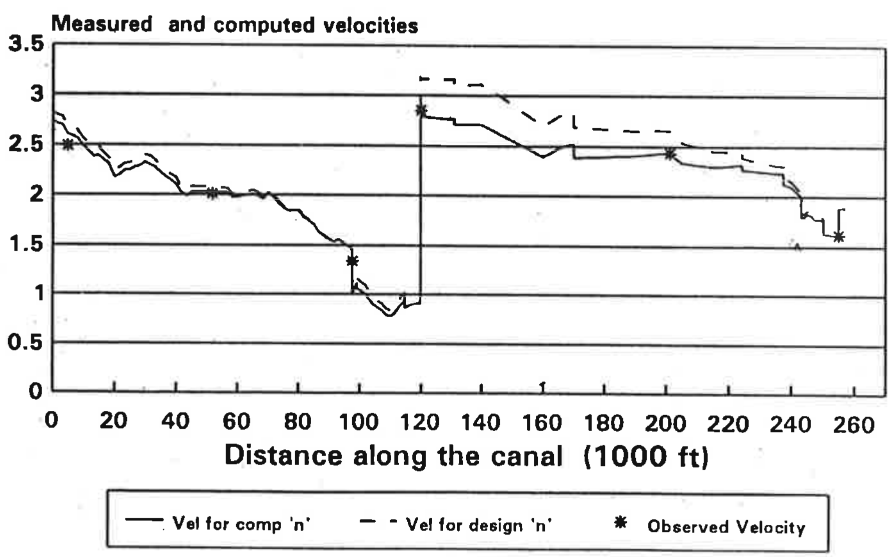

Figure 4b. Velocity profile at 3000 cfs inflow comparison of design and existing 'n'.

From the velocity hydrogram (Figure 4-b), those reaches can be identified which have more likelihood of sedimentation (already happening in the field). A trend of sedimentation in these reaches emphasis the need to estimate and maintain an appropriate operational velocity required to carry the silt load through the main canal.

Physical Conditions and Maintenance

The present challenges to the physical integrity of the lined section are: (a) damage to lining; and (b) sedimentation. These problems are occurring at a localized level but are prominent enough to be considered at this stage. Lining imperfections detected so far are related to deterioration of the brick surfaces, dislocation of bricks, bulging of concrete slabs, and opening of expansion joints.

Sedimentation has been a bigger problem. More than three feet of silt deposition in the tail reach of Stage-I and 0.3-0.5 ft. high sand dunes were observed along the major part of the lined section during 1992 and 1993. Figure 5-a shows sand dunes in the reach where the effects of water ponding are negligible. Figure 5-b indicates heavy sedimentation due to very low velocities in the tail reach.

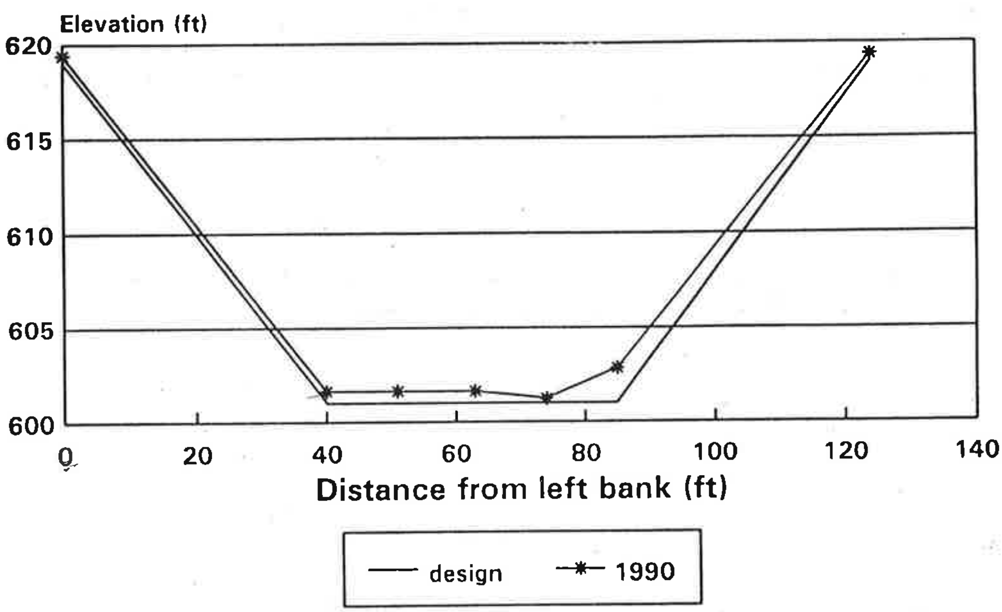

Figure 5a. Concrete section in mid reach RD 200,000 sand bars on bed and silt on banks.

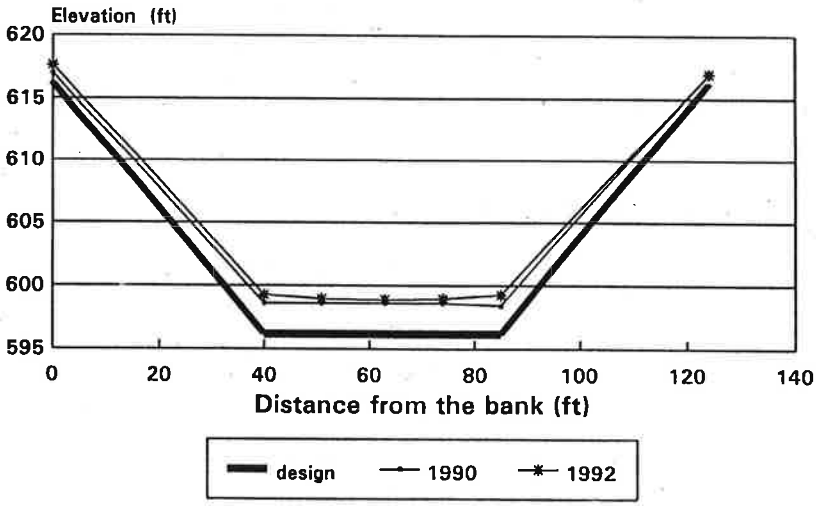

Figure 5b. Concrete section at the tail RD 245,000, 3 feet silt on canal bed in 1992.

The design and existing bed for a typical unlined section is shown in Figure 5-c. Although the rise in bed level due to sedimentation is about 9 feet in five years, the design bed level has not been achieved yet. Once this happens, the incoming silt will become a more serious problem. WAPDA is already considering the construction of silt diversion structures, or other remedies.

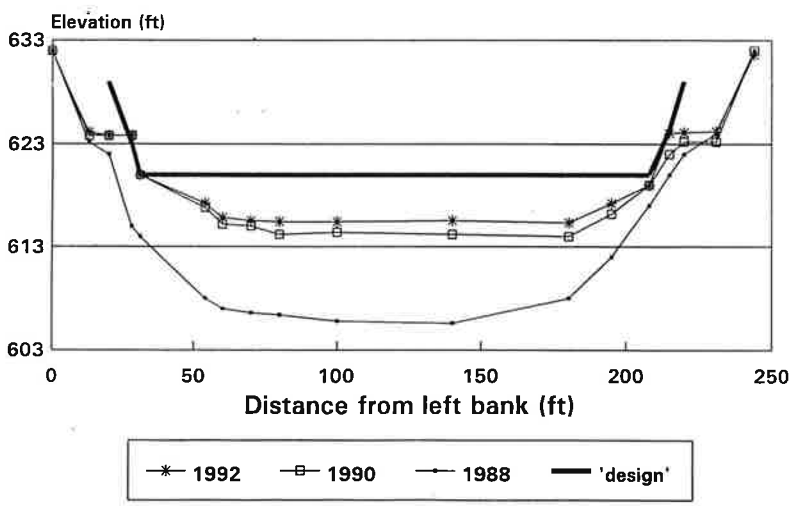

Figure 5c. A typical unlined section RD 80,000 achieving design sec. by silt deposition.

After three years experience with the canal (87/88 to 90/91) WAPDA estimated that the maximum annual total O&M cost for Stage-I would be around 8 million rupees (PC-1, 1991); however, the total O&M budget for the last two years (90/91 and 91/92) exceeded by far this limit (see Table IV, below).

Table IV. CRBC Stage-I - O&M Total Costs.

YEAR	Total O & M Expenditures (Rs. million)
1987-88	12.754
1988-89	8.272
1989-90	13.560
1990-91	20.149
1991-92	16.082

Furthermore, records for 1992-1993 show that only partial maintenance (desilting and repair to damaged lining) could be carried out during the normal 4-week annual closure. This indicates that yearly maintenance requirements are accumulating and measures should be taken to solve this problem.

Impact on Management

Managers of the main canal have indicated that the lining has definitely facilitated management and O&M activities. The conveyance efficiency of the lined section is better and more predictable. Average velocity of the lined section is higher than the unlined section. Also, the lined section achieves steady-state hydraulic conditions relatively fast. On O&M for example, during canal closure the lined section dries up in a few days, while some sections of the unlined canal never become dry. Lining has provided room for better control due to less human interventions, better protection against breaches and easier bank maintenance. Another advantage is comparatively smaller over pass structures (especially for hill torrents) which are not only originally less expensive but also more enduring and easy to maintain.

CONCLUSIONS

1. The CRBC irrigation project was able to increase the command area by approximately 10,000 acres through lining of its main canal. In addition, other benefits were derived from the lining like allowing by-passes provided for hill torrents, canal crossings and control structures to be smaller and hence more economical, more efficient and easier to manage.

2. Seepage losses from both unlined and lined sections are in the same range for inflows less than 3000 cfs. For higher discharges, seepage increases rapidly in the unlined section. This has imposed a limitation for the operating authority, which has not been able to operate the canal at the maximum possible inflow.

3. Actual roughnesses of the brick and concrete lined sections are higher than the design value of .016. Estimation of this parameter, using a hydraulic simulation model, indicates a range of .018 to .022 for CRBC. As a result, there has been a change in the maximum carrying capacity of the canal and it is now impossible to maintain the required freeboard.

4. Critical silt carrying velocities and required water surface slopes should be established and maintained for the main canal in order to reduce associated maintenance costs. Silt deposition at the tail of Stage-I cannot be handled without having an appropriate velocity in this reach.

5. Serious management efforts are required to achieve the operational targets set forth in the design document due to physical limitations of the system. Stage-II will become fully operational this year; and therefore, now is the proper time to move from the present "transient" perception of the operations to well defined operating rules.

6. The O&M requirements of CRBC's main canal have been, so far, significant. Desiltation and repair work will be required every single year to achieve proper performance of the main canal.

7. The Chashma Right Bank Canal provides useful information about the technical and operational aspects of canal lining which can be considered at the project planning and design stage of future projects (including CRBC-Stage-III). Lessons learned from CRBC can be summarized as follows:

    i) Operational rules to be implemented for a new irrigation scheme must be considered at the design stage and should be enforced afterwards.

ii) It is rarely possible for an irrigation system to function as per design parameters. The operational stability of a canal depends upon the hydraulic balance achieved during the first few years of operation. Therefore, flexibility must be provided to accommodate those future variations.

iii) The water savings accrued from lining during the planning stage of an irrigation system is usually very optimistic; this factor should not be the only consideration in deciding whether lining is appropriate or not.

8. The study strongly suggests that the canal lining programs being considered by the GOP should be properly justified based on more realistic estimates of the benefits to be derived from lining. At the planning stage alleged impact of the lining including maintenance costs must be contemplated for longer time periods and for alternate sets of boundary conditions. The Authors agree that more field research is required to establish the conditions under which lining should be recommended within the Indus Basin. Identification of appropriate parameters for lined sections should also be the target of forthcoming research.

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ROLE OF MAINTENANCE: EXPERIENCE FROM PAKISTAN

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ABSTRACT

Pakistan has the largest contiguous gravity irrigation system in the world. It provides employment to 70 percent of the population. This irrigation system is now almost a century old. The sustainability of irrigated agriculture in Pakistan is threatened by waterlogging and salinity. There is emerging problem of secondary salinity as a result of excessive use of moderate quality of ground water. There is an ever increasing demand for good quality water and that can only be supplied through conservation of existing water resources and the modernization of the system. This paper describes the types of canal lining used in Pakistan and their associated maintenance problems. The existing guidelines for the maintenance of lined canals and the maintenance problems from the first lined canal in Pakistan, to the most recent one are also discussed. The maintenance costs are directly related to the quality of the construction and the soundness of the design techniques used. The knowledge, behavior and the commitments of the maintenance staff also have a strong bearing on the performance and the ease of maintenance. There is need for good planning and good design criteria, improved construction supervision and the strict construction quality control to reduce the subsequent maintenance costs. Lining as a means of modernizing the system can be a viable solution, but its adaptation in a sediment laden water environment is a question that remains to be answered.

INTRODUCTION

Pakistan has one of the largest contiguous irrigation systems in the world and the irrigated agriculture activity dominates its economic scenario since nearly 60 percent of the Gross National Product (GNP), mainly food and fibre, is generated through this sector. About 70 percent of the country's population earns its livelihood through agriculture. The available water supplies for irrigation are limited and cannot be increased without modernization of the canal system, which requires a huge amount of capital. The only way that irrigation supplies can be increased, is through conservation of the existing water resources by improving management to reduce the water losses. The most commonly accepted means of reducing canal seepage loss is the lining of the irrigation canals. A few canal systems such as the Thal, Haveli and some link canals were lined at the time of original construction.

In order to improve the deteriorated condition of the irrigation systems, Government of Pakistan has embarked upon a large scale program of rehabilitation of existing irrigation systems. Under this program, a significant number of irrigation canals have been lined completely or partially and others are being planned.

This paper reviews the experiences with maintenance of lined canals in Pakistan and also discusses the possible causes of failure of linings and their remedies.

MAINTENANCE OBJECTIVES

The primary objectives in maintenance of both lined and unlined irrigation canals in Pakistan are:

* to keep the system in top operating condition at all times through proper maintenance.

* to obtain the longest life and greatest use of the facilities of the system by providing good maintenance and timely replacements.

* to achieve the foregoing objectives at the lowest possible cost through a proper maintenance programme.

THE IMPORTANCE OF MAINTENANCE FOR AN IRRIGATION SYSTEM

The importance of maintenance for the success of any irrigation system cannot be underestimated. Preventive maintenance, not only pays dividends in the economical operation of a smooth working system, but also means the uninterrupted delivery of water to the command areas.

All structures and facilities are subject to deterioration in varying degrees with the passage of time. Constant vigilance is necessary to identify and correct the potentially unsafe and unsatisfactory conditions as they develop. Cracks in the lining, general erosion, settlement of embankment or structure, encroachment of freeboard, scour, seepage and severe damage at animal crossings near to the villages can result in a major failure of the system if not corrected or repaired without delay. Breaches can be an expensive failure, not only due to the cost of the repairs, but also for the loss or damage to the crops of the farmers directly affected as well as those living downstream, who could be deprived of water.

Many problems that develop may not be of such a serious nature as to cause failure. But the problem of silt accumulation and lack of inadequate drainage of banks and side slopes is the most serious and widespread occurrence. These problems must be given due and timely attention. Experience has shown that if they are not tackled in time, these problems frequently result in a reduction in the life of lining and more costly repairs over the years.

The use of proper materials for repair or replacement is also very important. This includes:

* adequate attention to the proper replacement of earthfill including site preparation, moisture control, compaction and other placement features

* proper proportions and/or constituents in masonry mortar, wetting bricks, site preparations and, even the bricks themselves

* suitable aggregates and other constituents of the concrete.

The concerned officials (engineers and sub engineers) should always be on the lookout for new materials or products and their adoption, as well as better ways to use the existing materials or improvements in construction techniques.

MAINTENANCE CATEGORIES

The maintenance of all types of irrigation canals in Pakistan is usually divided in four categories, which are:

* regular routine maintenance
* seasonal repairs
* annual repairs
* emergency repairs

Routine Maintenance

Routine maintenance refers to the day to day work items that must be accomplished to keep a system operating well. These are, basically, preventive maintenance functions that are undertaken on a continuous basis to prevent the problems to become larger and more expensive. It is the first line of defence and proves to be extremely cost effective when carried out in a competent and professional manner. Routine maintenance generally includes the following functions:

1) filling rat holes, raincuts and rain holes when observed.

2) promptly removing trees that have fallen into the canal.

3) repairing cracks in walls or replacing backfill material where water flows behind a structure.

4) replacing missing stones or bricks in the lining as soon as possible to prevent additional material from being washed away.

5) cleaning weeds and other floating trash from in front of the structures and from the lining surface.

Seasonal Repairs

The seasonal maintenance is the light maintenance work, part of which has to be accomplished during canal closure. This work can be undertaken by permanent employees or casual labor hired for this purpose. Seasonal work is limited in extent because of the short time period available during closure and the availability of staff and casual labor. This work generally includes:

1) repairing and resetting of outlets.
2) repairing damaged panels of lining.
3) removing all obstructions from the bed and the sides.
4) completing temporary repairs.

Annual Repairs

The annual maintenance work is the heavy work that is generally contracted out to private contractors or the Machinery Division of the Irrigation Department. The annual maintenance program involves the extraordinary or extensive program of replacing the damaged portions of lining and embankment slopes. It also includes the occasional large desilting works and a comprehensive raincut repair program when required. This is beyond the capability of a sub division and is decided upon by the higher offices.

Emergency Repairs

Emergency repair refers to the repair of serious damages or failure which, unless prompt action is taken, may entail even more catastrophic problems concerning canals and farmlands. These damages are not always predictable with respect to time of occurrence or to their scale. Catastrophic damages of irrigation systems may result from any of, or combination, of the following causes:

* floods or heavy rainfall.
* careless operation of irrigation facilities.
* human actions such as stealing water by blocking canals, cutting canal banks, destroying gates etc.
* destruction of the freeboard, or portion of lining or embankment by animals.

DESCRIPTION OF EXISTING CONDITIONS OF LINED CANALS

The following information briefly describes the condition of some of the lined canals starting, from the first lined canal (1937) to the one most recently lined (1988). Figure 1 shows location of the lined canals selected for the review. Technical data of these canals is summarized in Table 1. The condition of existing lining along with the problems of maintenance and the maintenance practices related to these canals are as follows:

Experience from Haveli Canal

This canal offtakes from Trimmu Barrage constructed at the confluence of the Jhelum and Chenab Rivers. The canal was built during the years 1937-38 and has a head design discharge of 5224 cfs. It serves mainly as a link canal carrying water to feed the Sidhnai Canal System offtaking from the River Ravi at Sidhnai Headworks. Its total length is 45 miles and is brick lined. During the first opening of the canal, it was impossible to run it to full supply because the Manning's roughness value was found to be 0.02 not the designed value of 0.016. This resulted in the whole of the free board being encroached and the subgrade becoming saturated. This subsequently caused the settlement of the soil, created segregation and hollows behind the lining. Soil water pressure caused bulging of the lining at many sites and the adjoining lands became waterlogged and salinity affected indicating that the lining was ineffective as an impervious membrane.

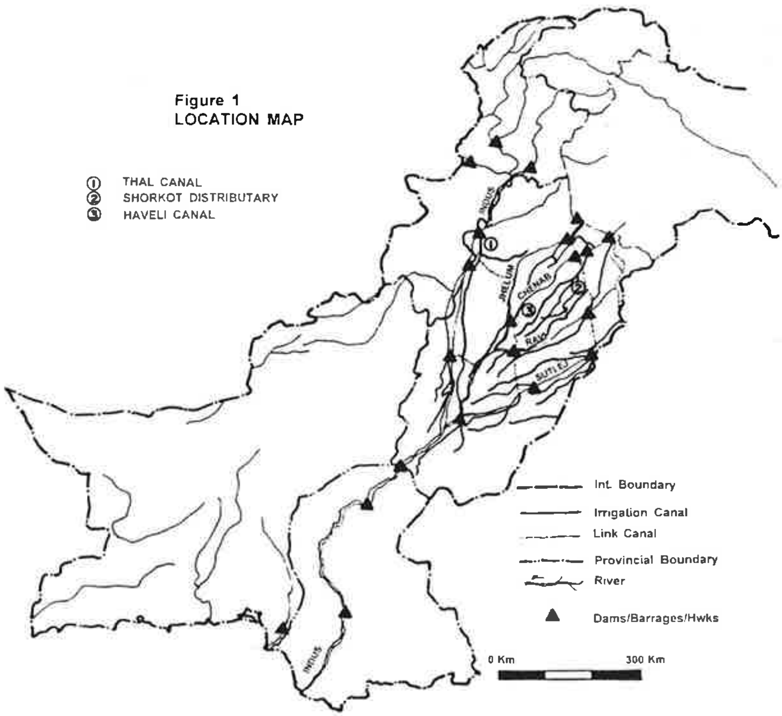

Figure 1. Location Map.

Table 1. Technical Data of Selected Lined Canals

FEATURE	HAVELI	THAL	SHAHKOT
Year built	1937	1944-50	1988
Design Q (cfs)	5224	7500	33
Main canal (miles)	45	225	44
Type of lining	Double Brick tiles	Concrete/ Brick tiles	Concrete
Bed width (ft)	84	71	4.8
Depth (ft)	12	17.8	2.8
Side slopes	1:1.25	1:1.5	1:1
Maintenance needs	Frequent	Frequent/badly damaged	Few

The greater damage, however, to lining of this canal was caused by constructing the unlined Trimmu Sidhnai (TS) Link Canal parallel to Haveli Canal, at a distance of only 350 feet. This resulted in constant seepage from TS Link to Haveli Canal, causing lifting of the bed of the Haveli Canal at many places. The portion of the lining above water line became salinized due to capillary action.

The maintenance problems therefore encountered were; lifted panels, salt effected bricks and settled portions of the lining. Subsequent poor maintenance has led to high seepage rates and, after a period of 53 years rendered lining as useless. The lining of this canal requires extensive repairs but even then, the durability of those repairs would be questionable.

Experience from Thal Canal

The Thal canal offtakes from Jinnah Barrage, which was constructed on the River Indus in 1942. The upper part of Thal canal is called the "Main Line Upper" and the lower part is named the "Main Line Lower". The design capacity at head is 7500 cfs and the supply irrigates an area of 1.89 million acres. In the original project, it was decided to provide canal lining in the Main Canal and the Branches to conserve water and reduce seepage loss, since the canal system passes through desert permeable soils.

The Main Line Upper is approximately 31 miles long and was constructed in 1944. Lining starts from RD 10+ 800 and the remaining part, until its tail at RD 157+660, is concrete lined. In constructing the canal, the lining was designed to pass 6000 cfs (now revised to 7500 cfs) and the structures were designed for an ultimate discharge of 10,000 cfs, to cater for the future remodelling needs.

The Main Line Lower offtakes from the tail regulator of Main Line Upper and is approximately 100 miles long (tail RD 502+560) and was constructed in 1950. It is lined from head to tail and has a design capacity of 4524 cfs at head. The canal is brick lined upto RD 5+800, concrete to RD 40+000, earthen tiles to RD 51+000, concrete to RD 68+500 and then with finally with earthen tiles in the tail stretch. Its main tail offtakes, Munda and Indus Branch are also tile lined.

In general, the tile lining behaved reasonably well and only required a few patch repairs in the bed, due to the abrasive action of the rolling sediment load. The concrete lining on the other hand developed cracks, both in the bed and sides, and frequent problems of panel bulging were reported, requiring replacement every year during the annual closure of the canal. It is normal practice that, during the annual closure, the bed of canal is cleared of all obstructions such as broken bricks, sediment mounds and tree branches. It is generally agreed that the tile lining performed very well during the first 8 to 10 years of the operation of the canal.

For the Main Line Upper, major maintenance problems were reported in the reach RD 30 + 000 to RD 70 + 000. This was due to breaches in the years 1974, 1976, and 1978. Concrete lining was adopted for the first time on this canal and to economize, a lean mix ratio of 1:3:6 was used. With the passage of time, the mortar from the surface of the concrete pealed off and the coarse aggregate was exposed. One of the contributing factors to this was that the proper curing time was deficient, due to general scarcity of water in the Thal area at the time of canal construction. Extreme temperatures in the area may also have been partially responsible for cracks in concrete lining. In the cut reaches, the disposal of rain water was inadequate and, where provided, was not maintained properly. Also in the cut area the canal prism is mostly surrounded by a clayey strata, which under saturated condition causes the banks to slip on the water side at the time of canal drawdown. The damaged concrete panels were repaired with stone pitching and this process is still continued.

Experience from Shahkot Distributary

This distributary offtakes from the tail of Mianwali Branch System of the LCC Main Canal. It was constructed in 1925 but partial lining was undertaken in 1988 under the Command Water Management Project (CWMP,IDA). Its length is approximately 44 miles (tail RD 143 + 515) and the lining starts from RD 40. The lining is comprised of concrete slabs joined together at the site with a cement mortar. At the time of project formulation, the objectives laid down were as follows:

* to provide improved command at the heads of outlets
* to provide better irrigation facilities to farmers
* to minimize conveyance losses
* to improve equity conditions
* to increase irrigation intensity by utilizing the saved water after lining

After operating for a period of nearly 4 years, the distributary was checked during the annual closure in 1993 by the International Irrigation Management Institute (IIMI) field staff. The lining was found to be intact, but it was observed that there were depositions of sediment inside the concrete in such a way that an earthen section has formed at many places, especially towards the tail. The reaction of the tail farmers was that after lining, they have suffered badly and they were better off when the canal was unlined. This may be due to overestimation of saving in seepage losses in lining of the canal.

The maintenance requirements have practically remained the same as for an unlined canal, but no systematic monitoring is being undertaken to establish whether the objectives of lining have been achieved or not.

DIFFICULTIES AND PROBLEMS IN MAINTENANCE OF LINED CANALS

The term maintenance is sometimes used vaguely, and loosely, in many irrigation projects to denote both the operation and maintenance of the canal systems. The magnitude of the problems encountered in the maintenance of canal systems is so vast and varied in nature that they need to be identified in different subgroups. They can broadly be classified into the following categories:

(i) operational difficulties of the canal system

(ii) misuse and mismanagement of the canal waters by the farmers

(iii) deficiencies in the hydraulic and structural design

(iv) defective constructions

(v) inadequate staff and inadequate funding available for maintenance of canals

Operational Difficulties

Many assumptions are made at the planning stage in the design and operation of various components of the canal system. Average duties adopted in the design of the canal sections fall short of the peak demands in the fields. In addition, actual conveyance losses widely differ from those accounted for in the design of canals.

Misuse of Water

A serious problem in the maintenance and operation of canals is the misuse of the water through malpractices by the farmers. This includes breaching of canal banks, tampering with the offtake structures (outlets), and obstructing or damaging the drop structures.

Design Deficiencies

The most important aspect in the maintenance of a canal system is the design setups, both hydraulic and structural. No design method is perfect and no structure, due to economic constraints, is designed to serve its total life as trouble free. Little work is done on the relative performance of different alternative design approaches, and the adequacy of the design setup is rarely observed in the field. The practice is to repair the damages in a routine way whenever they occur again and again. Shakir and Chishti (1993) reviewed the various methods for the design of irrigation canals in Pakistan and concluded that in most cases, the effect of an important parameter, like sediment transport, is neglected. They suggested that the omission of sediment transport from the basic design is the key factor in causing problems in the irrigation canals. Shakir and Chishti observed that much of the maintenance work could have been reduced, if a proper method of design had been adopted.

Defective Construction

Another problem in operation and maintenance of irrigation canals is the defective construction of the lining. Improper compaction of the subgrade, use of inferior quality material for construction, theft of cement and ineffective supervision during construction, can all result in an early failure of the lining and often demand significant repairs. In addition to the increased maintenance cost, it creates problems for effective delivery of water to the downstream reaches, and sometimes demonstrations/protests by affected farmers have to be faced by the maintenance staff.

Inadequate Staff Numbers and Funding for Maintenance

The existing staffing pattern is one Division, comprising one Executive Engineer, 3 Assistant Engineers (Sub Divisional Officers) and 9 sub engineers to oversee maintenance and operation of the canal system serving an irrigable areas of 400,000 to 500,000 hectares (1.0 million to 1.2 million acres). On the average, a patrolling staff member (beldar) looks after 9 km length of the canal. This level of the existing staff is hardly able to operate the system properly and to attend the maintenance needs promptly.

The maintenance funding available at present is also quite inadequate. The present rate of Rupees 3 (0.1 US Dollars) per acre (Rs 15000 per canal mile) is insufficient, even to attend purely temporary repairs, without considering the heavy or permanent repairs.

EXPERIENCE GAINED AND LESSONS LEARNT

From the experience of operation and maintenance problems of lined canals in Pakistan, the following main points have emerged.

- ☞ compaction of the subgrade before lining is the key to the success of a stable lined section, as many reaches of lined canals in Pakistan have failed, due to improper attention to this.
- ☞ in high water table reaches, concrete lining has a better overall performance than the brick/tile lining and has less maintenance requirements.
- ☞ if embankments are not properly consolidated, this results in early failure of the lining.
- ☞ inadequate drainage results in frequent failure of linings. Therefore, proper drainage and adequate free board are necessary. Pressure release valves alone are not adequate. A proper blanket of filter under the lining should be provided, wherever necessary.
- ☞ the maintenance and operation of irrigation canals is becoming a specialized job and for this a separate cadre of operation and maintenance staff needs to be established.
- ☞ cattle ghat sites or buffalo wallows should be constructed near villages, in case of lined canals, to guard against damage by the farmers and the animals.
- ☞ a greater number of bridges/crossings should be provided to facilitate the traffic of nearby villages, otherwise, possible damage by animals and tractors can occur, especially in case of shallow canals.
- ☞ plantation on berms of canals should be discouraged, as this is injurious to linings.

Above all the sound design and quality construction are the key to the reduced maintenance requirements.

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THE ROLE OF MAINTENANCE IN EXTENDING LINING SERVICE LIFE

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ABSTRACT

The paper briefly describes th^ outcome of field and laboratory work undertaken by HR Wallingford in collaboration with a number of national organizations and agencies concerned with canal lining problems. The aim of the work has been, and is, to provide increased knowledge about the likely service life of lining, to investigate the effect of defects on lining performance and to determine the benefits to be gained from relatively low cost maintenance works.

INTRODUCTION

Increased demand for limited water resources from competing sectors of the economy has been a driving force behind extensive canal lining programmes throughout the world. As water use by the agricultural sector is now widely perceived to be inefficient, pressure to utilize the available water resources more effectively elsewhere can only increase. It is therefore vital that irrigation system improvement programmes are demonstrably effective in raising, and sustaining, water use efficiencies. There is no doubt that linings when new, or when maintained in good condition, can be effective in significantly reducing seepage from earth canals. It is considerably less certain how effectively they will be performing the same function when they begin to age. It is commonly assumed that hard surface linings will have an effective service life of 25 years or more. In conditions where quality control of construction cannot be assured, and maintenance is sporadic, there is evidence from many countries that the effective service life of conventional linings can be very much shorter than assumed, sometimes of the order of a few years only. It does not necessarily take major damage to a lining to radically reduce its efficiency. A lining may appear structurally sound when its primary function, that of reducing seepage, may be severely impaired or actually nullified. Field observations and measurements have shown that failed joints and cracking, particularly on smaller canals, can develop within a relatively short period to the point where the lining becomes ineffective. Comparatively low-cost maintenance of canal linings can help to safeguard the high capital investments involved in lining. There is some evidence that this is a singularly cost-effective measure. However for the average irrigation system, factors such as the sheer length of the canals, tight limitations on the maintenance budget, and a narrow window of opportunity for maintenance during the annual closure period, mean that maintenance work must be closely targeted to those places where it will yield the best returns. In order to do so, irrigation agencies need to regularly monitor the relative and absolute functioning of system components so as to detect areas of under-performance. In fact, such a level of management knowledge is more generally needed for any initiative to improve control and use of water.

LINING FAILURES

In order to set into context the work which is the subject matter of the present paper, it was considered useful to identify the types of failure to which hard surface linings are prone, and then to highlight those situations in which low cost maintenance work to reduce lining seepage loss is most appropriate. A lasting repair obviously depends on successful diagnosis of the problem.

Failure types:

1) settlement owing to improper design, or to inadequate construction procedures

2) movement under earth pressure for example, swelling of expansive soil or over-steep canal side slopes

3) movement under excess external hydraulic pressure at times when the canal water level is low relative to the ground water table and/or:

4) settlement around the joints caused by joint failure and washout of fine soil material under hydraulic back pressure

5) deterioration of lining material by abrasion or aggressive canal/groundwater

6) aging of joint material, or joint failure caused by growth of underlying vegetation

7) shrinkage cracking

In addition, major problems are experienced in cold arid/semi arid climates due to:

8) frost heave

Failures of types (1) and (2) may obviously involve expensive remedial measures or rehabilitation.

Failures caused by high back pressures (3) and (4) might be avoided by changing operational practice so as to reduce the rate of drawdown. However, in other cases drainage works might be required to relieve soil water pressure. Replacement of materials on a large scale may be involved in the type of deterioration included in (5), and frost-induced failures (8) require design changes and major reconstruction.

Failures of types (6) and (7) are those in which it is less clear that the lining has failed and where a relatively limited maintenance intervention could be most cost effective.

In these cases the structural condition of the lining remains fairly sound but it has failed to a greater or lesser degree in one of its other service conditions, namely the ability to retain water.

A hard surface lining is a water-retaining structure. National codes of practice for water retaining structures are more stringent than structural/building codes owing to the need to limit stresses and deflections. However, canal linings are often constructed with less control over materials and methods than other structures which are more immediately visible and in which the consequences of failure are more dramatic in terms of loss of human life. Cracks and joint failures in bridges tend to get early attention whereas in canal systems they do not.

This paper is concerned with failures of types (6) and (7) which are susceptible to improvement by a limited maintenance effort rather than by large-scale rehabilitation works. They may not generally be perceived as failures since the defective area may appear small relative to the overall wetted surface area. Nonetheless, if the result is a significant reduction in the impermeability of the lining, then they are in fact failures. Work at HR Wallingford and elsewhere (Section 2) to quantify the losses from linings with varying proportions of defects shows that apparently minor defects may have much greater significance than generally appreciated. Small defects can make a lining virtually permeable.

QUANTIFYING SEEPAGE LOSS FROM LININGS

Designers customarily use published or standard figures for seepage losses from lined and unlined canals when considering the potential benefits of lining in terms of water saving. Figures in the literature for example FAO (1977), may show a range of values for unit losses from a given type of lining, but they fail to supply other relevant information, for example the **age of the lining**. Whether or not a lining is effective over its full design lifetime - and there is evidence that it will often become ineffective much sooner - it is clear that the measured seepage loss will depend on how old the lining was at the time of measurement. The types of failure being considered here do not take place instantaneously but over a period of time. Tests made immediately after construction would show a more optimistic picture than if undertaken in later years.

The pattern of decline in the performance of lined canals may be expected to be somewhat different from the aging of earth canals. There is a normally a cyclical variation in the rate of seepage from unlined canals. It will depend on the transported sediment load and the time elapsed since the last cleaning. Although fine transported sediment may to some degree assist in sealing up cracks in lining it can hardly arrest a process of general decline.

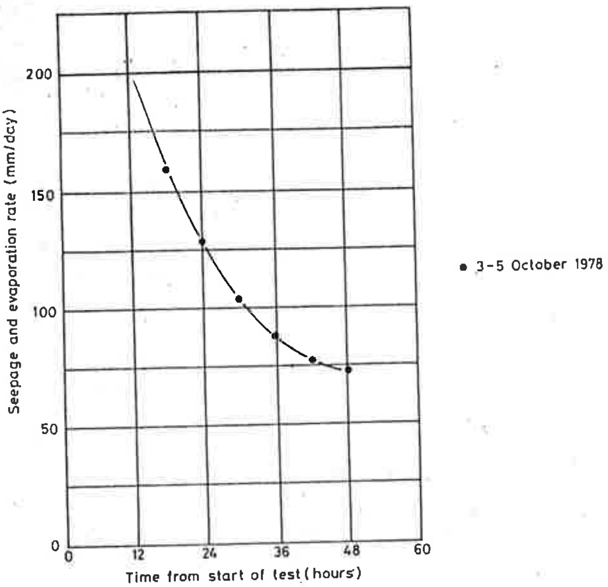
Another relevant piece of information which is not quoted in tables giving standardized values for losses is the **depth to the groundwater table.** Groundwater level, particularly when high, will affect the unit rate of loss.

HR Wallingford began to look at questions connected with canal linings from 1980 onwards. Holmes and Weller conducted ponding tests on small lined and unlined channels in Kaudullah, Sri Lanka, in 1980-1981 in a programme of research with the local Irrigation Department. Previous tests had produced very variable results from various lined lengths, all of them high. The soil had a clay fraction of about 8%. Lining was of cast-in-place concrete constructed by manual methods.

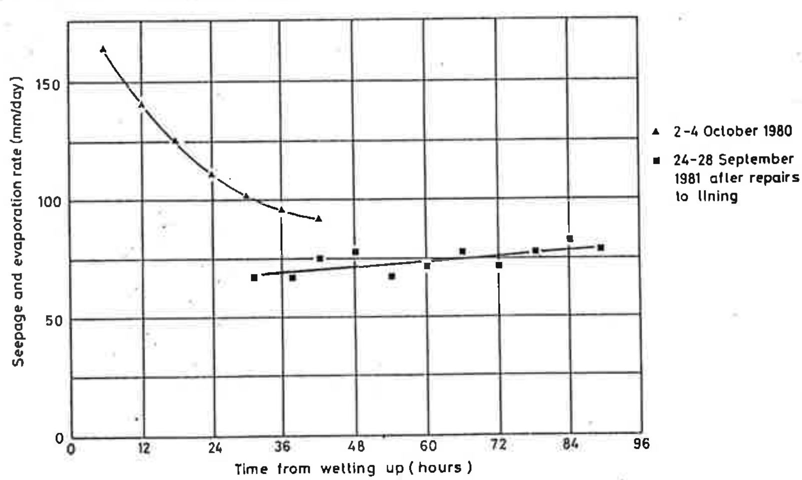
Ponding tests revealed high rates of loss from both lined and unlined canals. Losses from the lined channel were around 0.09 m^3/m^2 of lining per day after 48 hours. For the unlined channel the loss rate after 72 hours was 0.072 m^3/m^2/day in similar soils (Figure 1). For purposes of comparison, figures for losses quoted by FAO are 0.03 m^3/m^2/day for cast-in place concrete linings in reasonable condition and 0.08 m^3/m^2 per day for compacted soil linings.

Investigation showed that during construction the lining had been placed in a series of pours. Cracking had occurred along the construction joints both transverse to the canal axis and along the junction between the bed and sides.

The cracks, though obvious, appeared very minor in nature. In fact, it was not until the lining had been thoroughly cleared of deposited silt that the significance of the cracking was appreciated. Rapid repair to the cracks resulted in a reduction of seepage to around 0.75 m^3/m^2/day, still high but a significant improvement (Figure 1).



Ponding test on unlined Branch Channel 1



Ponding tests on concrete lined Branch Channel 1A

Figure 1. Irrigation Channel Ponding Tests (Kaudullah).

Following measurements on concrete linings by Dhillon and Singh of the Irrigation and Power Research Institute (IPRI) in the Indian Punjab, which showed losses increasing with age of lining up to 0.1 m^3/m^2/day at 13 years, HR undertook a cooperative research programme with IPRI. Goldsmith and Makin (1988) measured seepage losses by ponding test in 24 bricklined water courses. The results of the work have been presented in the opening session, so a short summary only will be included here.

The rates of loss measured from channels of the same cross section were highly variable, with a wide standard deviation, a finding which agrees with results of tests from around the world. Grouping the channels by age (Figure 2) showed that soon after construction the linings were effective in reducing seepage.

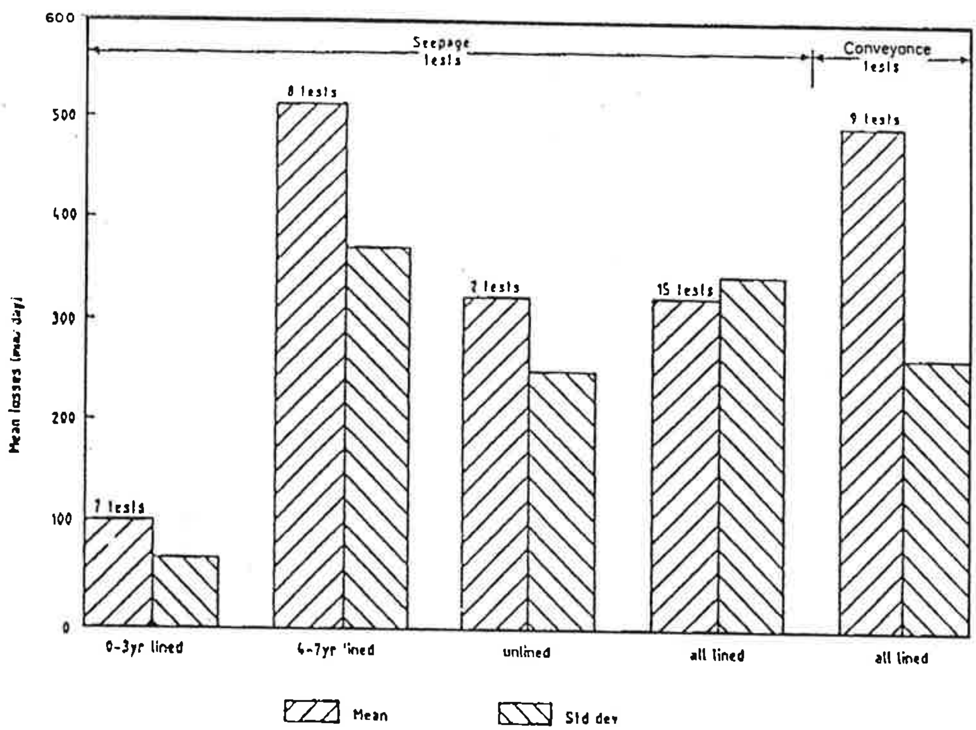


Figure 2. Summary of Ponding and Conveyance Test Results.

Channels which were older than 4 years on average suffered losses equivalent to, or in some cases higher than, unlined channels. The numbers of older lined channels performing similarly to relatively new ones were outweighed by those in the poorest condition. Cracking was clearly evident in many cases. The excess seepage occurring in the worst cases may be explained by the fact that the bed slope of the lined canals had been decreased to gain extra command at the tail of the system. It may also be that farmers, begrudging the loss of land occupied by the earth shoulders to the canal, attempted to cultivate right up to the channel walls, thereby reducing the stability of the section. It should also be noted that the total seepage loss was reduced to a unit rate based on the channel wetted surface area. Total loss, allowing for the improved conveyance capacity of a lined section over an unlined one, could have been therefore less, though not substantially, than the unlined case. Improvements in operation are sometimes anticipated from canal lining. In the same area a programme of distributary lining was reported to have produced a better supply according to farmers at the tail end.

In 1989, Hashem Ali (1990) of the Water Research Centre (WRC), Cairo, undertook a series of laboratory tests at HR Wallingford to quantify the effect on the rate of seepage of incrementally increasing the proportion of defective area in a model of lined canal (Figure 3).

Figure 3. Model Facility.

The physical model represented a canal in a soil of high permeability (sand) with an underlying impermeable layer at depth. The level of the groundwater in the model could be varied by means of an adjustable weir. The setup was designed to examine the problem in a controlled environment where the affecting variables could be selectively altered, a situation which can rarely, if ever, be achieved in the field.

To provide benchmark conditions the rate of loss for an unlined channel was first measured. For experimental purposes an impervious lining was simulated with a rubber sheet. Defects were simulated by piercing the lining along its length either in the bed or in the sides, and the seepage outflow for a given groundwater level was measured at steady state conditions. The percentage of the lining area subject to defects was gradually increased. The principal results (Figure 4,5) were that:

* seepage increased with increased head above groundwater table.

* small percentages of defects in terms of lining surface area produced high rates of seepage. Defects equivalent to less than 0.02% of area resulted in seepage loss equal to the unlined case when the water table was drawn down significantly below the canal invert.

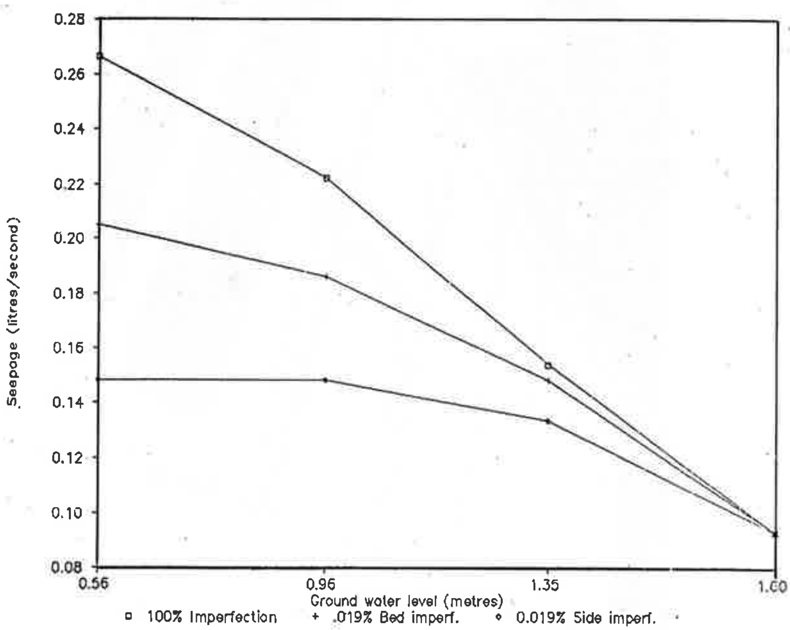


Figure 4. Seepage from Canal for Unlined and 0.019% Bed and Side Imperfection.

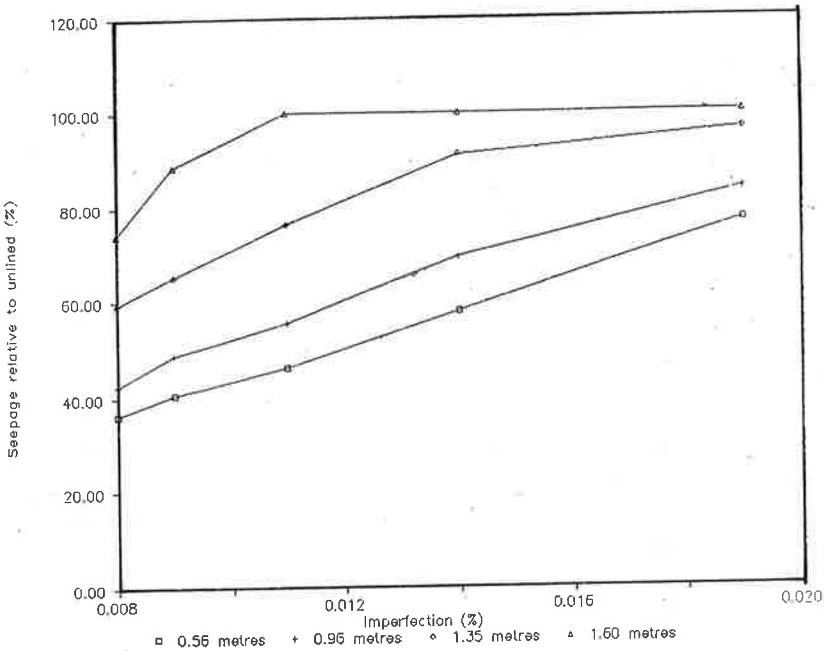


Figure 5. Seepage from Canal for Various Water Table Levels.

Ali also compared the relative effects of defects in the sides and invert of the canal and showed that the latter were more critical (Figure 4).

As previously stated, it needs to be pointed out that the surface area of a lined canal would be less than for the equivalent unlined canal so the direct comparison between lined and unlined cases needs adjustment. It should also be noted that the defects were distributed evenly across the lining surface area, either bottom or sides. Randomly distributed defects, can be expected in prototype canals, with some areas worse than others. However, the test results strongly suggest that it does not require major damage to a lining for its performance to deteriorate sharply. These results were subsequently replicated by Ali in a series of tests at the Delta Barrage laboratory, WRC, Cairo (Ali, 1990).

Between 1989 and 1991, HR Wallingford working with the Water Distribution and Irrigation Systems Research Institute (WDISRI), WRC, Cairo, conducted a number of ponding tests on small canals in the Mansouriya area near Cairo. One canal had been concrete lined about ten years previously. The ground water table was high in all cases, at or around the canal invert level. Two adjacent lengths of the same canal were chosen for comparison.

After testing the first lined length, the canal was dried out and cleaned down. Extensive damage was found to have occurred to the lining on one bank resulting from traffic loading on an adjacent road. The lining was rehabilitated by a small local contractor using unskilled manual labour. Quality of materials and workmanship was monitored to provide an indication of the standard of workmanship typical of such small works, though no attempt was made to control the quality of the work. The rehabilitated length was then retested.

A new length of lining was constructed on an adjacent unlined length of the canal using the same methods. It too was tested after construction.

The results were compared. The rehabilitated length showed considerable reduction in seepage over the original condition. Furthermore it gave comparable results to the newly lined length (Figures 6, 7 and 8). These tests are intended to provide a baseline for regular monitoring over time to assess the rate of decline in performance. If deterioration is apparent, limited maintenance can be applied before retesting the lining.

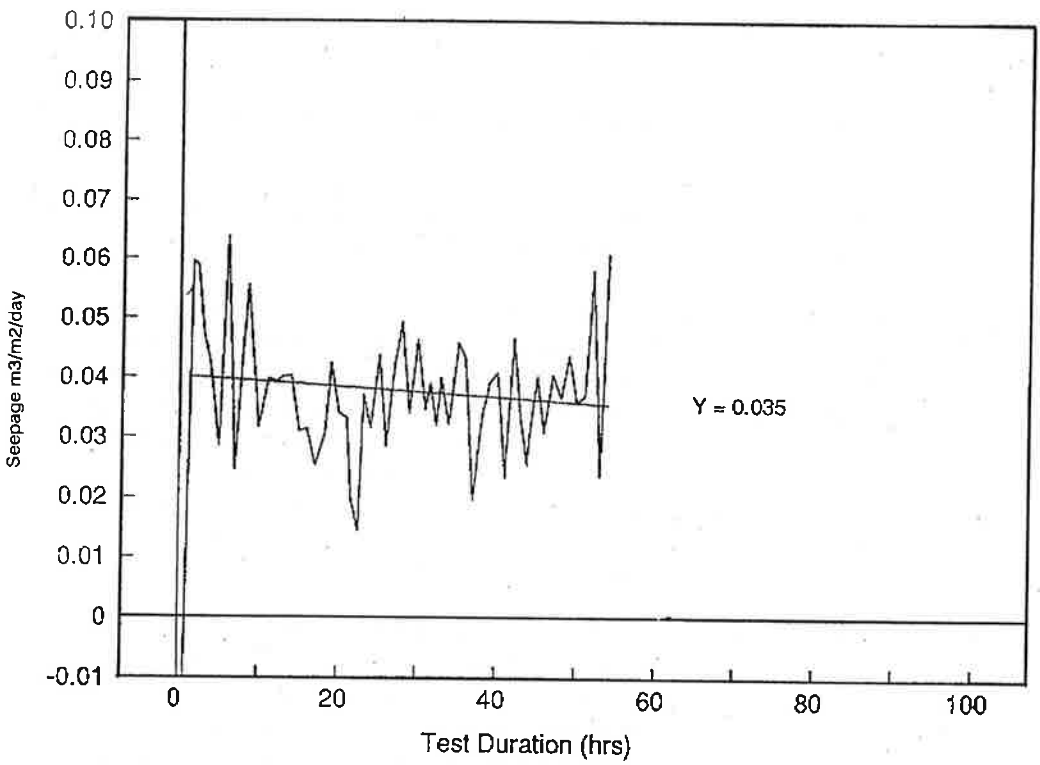


Figure 6. Beni Magdoul Ponding Test 21-23 July 1991.

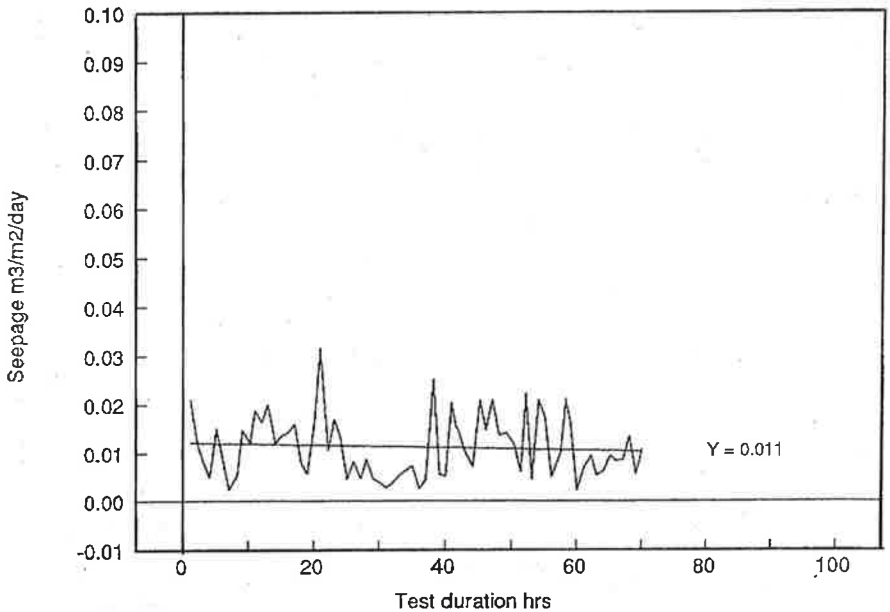


Figure 7. Beni Magdoul Ponding Test 3-6 May 1992.

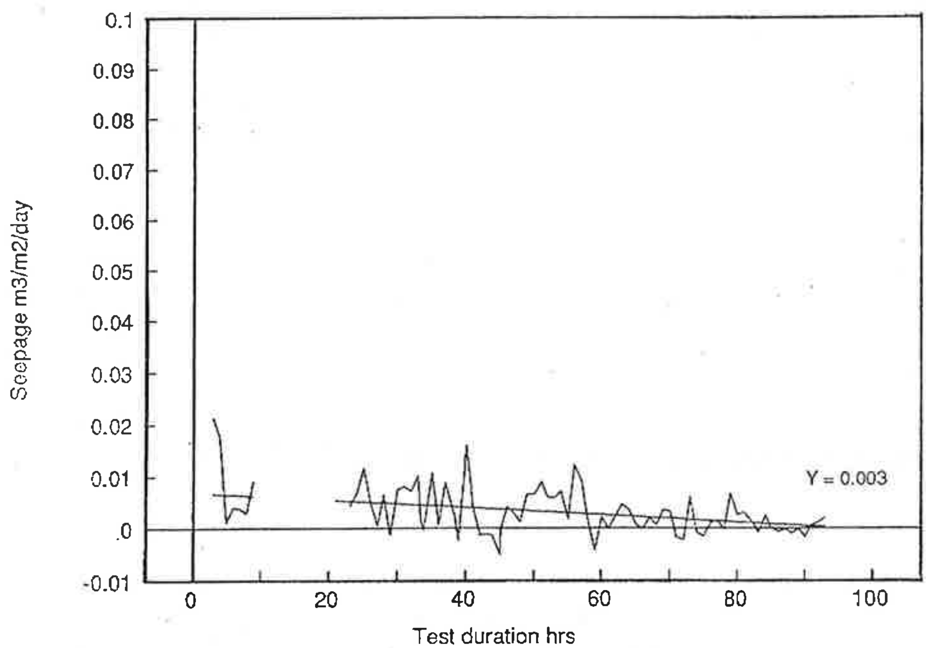


Figure 8. Beni Magdoul Ponding Test 6-10 June 1992.

DISCUSSION

It is clear that no single statement concerning the performance of lining over time can sufficiently represent the wide diversity of performance which has been observed in the world. For example, Zhau (1993), reporting on the results of a large number of canal ponding tests conducted in Shanxi Province, PR China, to investigate the performance of hard surface linings over time, concluded that the life of linings was highly variable. He found some linings for which seepage increased approximately linearly with time, some which leaked at an accelerating rate over time and some which maintained consistently good performance. Limited maintenance works have been done on selected linings in the Province and have reportedly been effective in reducing seepage over three years on average. Based on prevailing costing he found that such limited maintenance works would pay for themselves in terms of value of water saved within a year and they were therefore cost effective.

The costs and circumstances are specific to that particular area of China. Nonetheless, similar information could be built up for other countries and regions to assist in promoting cost-effective maintenance programmes and increasing water use efficiency.

One of the fundamental reasons for the great variability of results must lie in the realm of construction. Quality control of construction is dealt with in other papers presented in the Workshop. It is worth noting, however, that where quality control is difficult to enforce in major works constructed by large contractors, it is considerably more difficult on works at tertiary level constructed by small contractors. It is therefore important to consider how sensitive the work will be to low quality in construction and maintenance.

Of the various engineering materials involved in lining, soil gets the least attention. Untrained labour may be involved in foundation preparation, fill selection, handling and placement. Yet the consequences of improper procedures can be crucial to lining performance.

CONCLUSIONS AND NEEDS FOR INVESTIGATION

Performance

A large number of variables affect the performance of lining. The most obvious ones are the type of lining and the nature of the underlying soil. In addition, a shape factor (the size and proportions of a canal section) is involved. Age of lining, depth to water table, transported silt load. The methods used in the initial construction and the quality of the materials and workmanship obviously exert a very strong effect. Much of the published data in the world fails to record information other than the first two of these.

The World Bank commissioned a study of the performance of road pavements designed to varying standards. The aim was to identify likely life and the timing and cost of maintenance/rehabilitation works. No equivalent information is available for linings.

There is a need for general performance studies of lining with more relevant information to guide the designer, such as depth to water table, lining age and some kind of lining condition indicator at the time of the test. Existing data need to be supplemented to create a data bank. Increasing scarcity of water resources means that system performance will need regular monitoring to improve water management. Data on lining performance could be included as part of the same process.

Work at Wallingford and elsewhere showed that the life of linings could be considerably shorter than designed, sometimes a few years only. The proportion of defective area which caused the lining to seep at the same rate as an unlined channel was less than 0.1%.

Diagnostic studies to investigate and quantify the performance of lined lengths which are still structurally 'sound' but which are subject to cracking/joint failures could provide the basis for limited, but cost-effective, maintenance interventions.

Post-works monitoring would be required. Firm data on the benefits and the consequences of failing to do maintenance would support any request for improved maintenance funding.

Joints

Satisfactorily performing joint designs need to be identified along with methods to combat the growth of underlying vegetation.

Alternative linings

Existing work to test and evaluate alternative indigenously-produced lining materials with emphasis on cost and maintenance requirements needs to be continued. In India, spray-applied sealing coatings aimed at restoring the impermeability are being evaluated.

Quality control

Training of site staff and technicians in appropriate techniques. Production or dissemination of a basic manual setting out 'how to do it' procedures could be of assistance.

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ALTERNATIVE MATERIALS AND CONSTRUCTION TECHNIQUES FOR LINING TERTIARY LEVEL IRRIGATION CANALS

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ABSTRACT

Irrigation schemes require enormous lengths of tertiary canal; 30 to 50 km per 1000 ha irrigated being common. Where projects are based on scarce water sources, and/or the value of cropping is high or the soils are permeable, it may well be economic to line tertiary as well as more major canals. Whilst the cost per unit length of lining tertiary canals is small, the overall cost to the project, due to the length required, will be significant. It is therefore worthwhile considering the most appropriate and cost effective lining material and method of construction. The paper draws on recent experience in Pakistan, Egypt and other Mediterranean countries to compare different construction methods and materials for lining tertiary canals. Concrete is the most common lining material. In many countries in-situ placement of concrete lining using hand labour is still common and provides local employment. Alternative high technology concrete slipform pavers are however also available. In Mediterranean countries it is more common to precast tertiary canals in short sections; either in small scale precasting yards or in larger mechanized yards serving a region. Alternatives to concrete such as glass reinforced cement and plastic, asphalt/bitumen, flexible membranes and masonry are also considered both in terms of cost and durability.

INTRODUCTION

In the context of this paper, tertiary canals are taken to refer to canals at the tail end of the irrigation system which serve an irrigation block directly. Enormous lengths of tertiary canal are required on all irrigation projects; About 30 to 50 km being required to feed each 1000 hectares of land irrigated. Hence, though the cost per unit length of lining these canals may be small, the overall cost to the project is significant; typically around 15 to 25% of the overall cost of the irrigation system.

The planning of tertiary canal lining needs to be considered separately from that of the larger canals. This is because of their size, proximity to the agricultural areas they serve and the assignment of the responsibility for maintenance of such canals. The difference in scale between tertiary and larger canals often means that different technologies are appropriate for each. The proximity of the canals to the agricultural area and the fact that it is at the offtakes from these canals that the farmers interface with the irrigation system as a whole means that the canals have to be planned to withstand the rough treatment likely to be encountered from the farmers, their families, animals and agricultural machinery. Similarly on many projects, whilst responsibility for operation and maintenance of the larger canals remains with a government authority, responsibility for the tertiary canals is often devolved to the farmers as individuals or through water users associations.

On many irrigation projects it is not considered economic to line the tertiary canals, even when the larger canals are lined. Projects where it may be economic to line tertiary canals as well as the larger ones will exhibit one or more of the following conditions:

- water is a scarce resource
- the value of cropping is high
- soils are very permeable.

ALTERNATIVE CONSTRUCTION METHODS

When assessing the type of lining to be used for a tertiary canal, the obvious considerations are the effectiveness in controlling seepage and cost. Other factors discussed below which will affect the choice of lining are:

Durability:

Use of local resources: This is particularly important if the project is competing for scarce foreign exchange.

Maintenance: If the farmers are expected to maintain the canals themselves, is the choice of lining technology appropriate such that the farmers will have the necessary skills and resources to maintain them.

Jointing: One of the most common causes of failure of canal linings is the jointing system. Any lining material must have an effective jointing system which should be as durable as the lining material (this is rarely the case).

Flexibility: Tertiary canals are frequently constructed on embankments running through irrigated areas in order that they achieve gravity command over the fields. Settlement of the embankments is a common reason for the failure of such canals, and hence the ability of a lining technology to accommodate some settlement can have a significant affect on its life expectancy.

For the purposes of comparing the various types of canal lining, this paper refers to a "standard" tertiary canal section. This section has a bed slope of 0.0008, a capacity of 30 lps, a depth of flow of 200 mm and 75 mm freeboard. All prices are quoted in US Dollars at 1990 values.

The following tertiary canal lining technologies are discussed in turn below:

-Concrete:

* hand constructed in-situ
* precast:

. ground level
. elevated canalettes

*slipformed

-Concrete and masonary

-Asphaltic concrete

-Brick tiling

-Soil/cement

-Glass reinforced cement

-Glass reinforced plastic

-Plastic membranes

-Clay puddling

Hand Constructed In-situ Concrete

This is by far the most common system of canal lining in use, trapezoidal shaped channels (Figure 1) are constructed using predominantly labour intensive methods often supplemented with a small mixer machine. The technology is simple, well understood and the labour intensive approach provides secondary benefits by employing local semi skilled and unskilled labour.

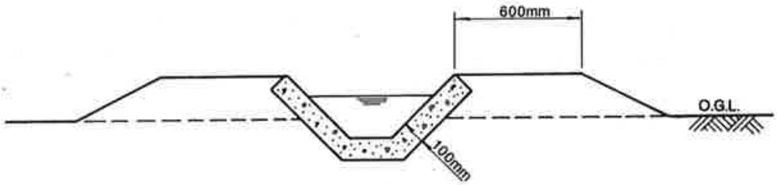

Figure 1. In-situ Concrete Tertiary Canal.

Very durable canals can be produced and, if properly constructed and maintained, have been reported to last 40 to 50 years (Kraatz, 1971). Indeed, the authors have seen 30 year old canals in the highlands of Pakistan still in excellent condition. Unfortunately, it is also common to see channels of a year or two old which have already failed. Such cases highlight the need for particular attention to be paid to the preparation of the earthworks, the thickness and quality of the concrete and the joints.

From examination of many trapezoidal concrete channels we conclude that for hand constructed tertiary canals, the lining should be a nominal 100 mm thick. Given the tolerances of the earthworks finish usually achievable with this type of work, the lining will have a tolerance of ± 25 mm and hence the minimum thickness of the lining will be around 75 mm; the minimum acceptable. Good quality concrete is also vital, this being a function of good materials, mix design, mixing, transport, placing, compaction, finishing and curing. It is not recommended that these small channels are reinforced, the difficulty of placing the reinforcement and the cost outweigh the advantages in strength.

At 100 mm thick the concrete is entirely dependent on a solid earthworks platform for its support. Hence quality control of the construction of the earthen embankments is of critical importance. The overall section of the embankment, including adequate berms, must be constructed and compacted in layers and the shape of the canal then excavated from within the embankment. The size of the berms should also be sufficient to provide support to the upper edge of the canal, with some allowance for erosion, but should not be wide enough to encourage farmers to drive vehicles or wheeled carts adjacent to the canal which will damage the edges. A berm of about 600 mm wide is recommended.

The concrete lining is essentially a rigid structure although some movement can be taken up at the joints. Contraction joints need to be placed at around 3 m spacing with expansion joints every 4th or 5th bay to avoid damage created by the thermal expansion and contraction of the concrete. Where even small amounts of settlement are anticipated, a closer joint spacing is recommended. Traditionally joints have been filled with a sand- bitumen sealant made by mixing road tar and sand. This is almost completely useless. The road tar runs out of the joint in high temperatures and the solvent in the sealant evaporates within a few months leaving a brittle, cracked residue through which grass and weeds are invariable seen protruding. Proprietary rubber bitumen compounds, preferably of the cold applied variety, are reasonable in cost and will provide an easily applied, flexible and moderately durable seal. More expensive compounds such a polysulphides and polyeurethanes are both more difficult to apply and much more expensive and hence are not considered appropriate for tertiary canals.

A typical cost for this type of lining would be around $10 per linear metre for the standard section described above.

In-situ concrete lining of tertiary canals is cheep and has proven very durable provided that the site supervision ensures adequate attention is given to the aspects of construction discussed above. Its usage of local labour and resources make it well suited for remote areas. Local farmers, given appropriate training and resources, can realistically be expected to maintain it.

Precast Concrete at Ground Level

On the West Nubariya Project in Egypt, some 340 km of tertiary canal were to be lined within an irrigated area of 10,000 ha. Here precast concrete box section tertiary canals were originally proposed, which were to be constructed in an on site factory. The main rational for this approach was to ensure adequate quality control of the concrete production. As a by product of the improved quality control and the more rigid box shape achievable using this method, a significant saving in concrete could be achieved (Figure 2).

The box section units were to be manufactured in 1 metre long lengths, cured in controlled conditions in the factory and then moved to the site of the canal on a flat bed truck where they would be unloaded onto a prepared foundation using a crane mounted on the transporting truck. The units were then joined using a mortar fillet and the sides backfilled to provide protection and lateral restraint.

This project was constructed during the 1980s by two Egyptian contractors. Both contractors were unfamiliar with precasting techniques and wanted to avoid the capital outlay of setting up the precasting factory. The first contractor therefore decided to adopt the precasting technique as proposed above but set up mini precasting areas beside each tertiary canal. This to a certain extent nullified one of the main objectives of precasting that of improved quality control as a result of centralised production. The second contractor decided to slipform the tertiary canals to the same section as had been proposed for the precast channels. This latter technique is discussed below.

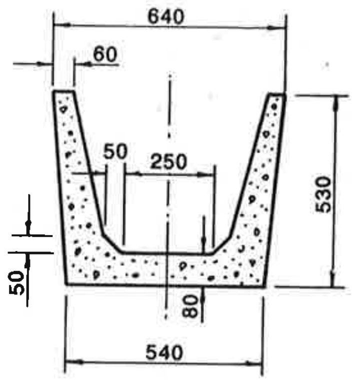

Figure 2. Precast Concrete Tertiary Canal Unit Used in Egypt.

Although the above attempt at large scale precasting was not adopted in practice, we believe that there are significant advantages to using precasting techniques for the large scale production of tertiary canals (it would not be warranted for small schemes). The jointing of the canal units does however require considerable thought to ensure that this does not form a weakness in the system.

Precast Concrete-Elevated Channels

In many countries, particularly around the northern and eastern Mediterranean, precast elevated canalettes are used for tertiary canals. These canalettes are "U" shaped, are manufactured from reinforced concrete and are supported a few feet off the ground by precast concrete piers at either end of each span (Figure 3).

Canalettes have two advantages over in-situ channels; firstly they take up less land and secondly they are easily installed in undulating land which would require considerable volumes of earthworks for conventional channels.

In countries where the infrastructure for producing these channels has developed, for instance Turkey has 16 canalette precasting factories, this system is preferred and used almost to the total exclusion of other systems. In other countries, e.g. the case of Egypt discussed above, precasting is not a well known technology and its development is hampered by the unfamiliarity with precasting systems and contractors and project directors and businessmen not risking capital on constructing the factories required to produce these units.

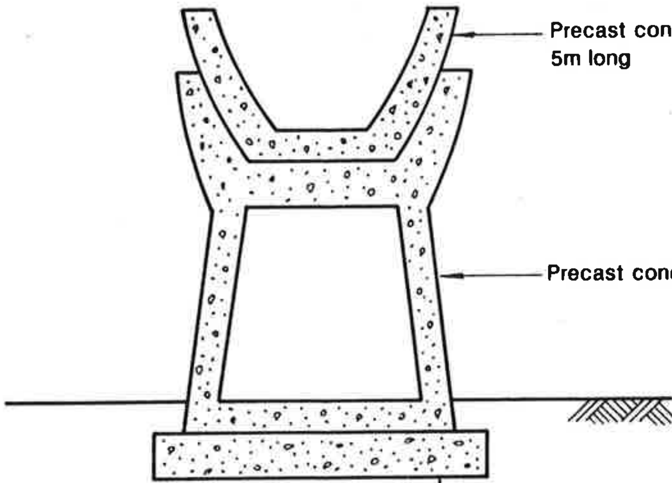

Figure 3. Precast Elevated Canalette

Costs of precast canalettes are similar to cast in-situ channels i.e. about US$ 10 per metre. The saving in materials from the thinner sections required being offset by the investment in the factory and transportation costs.

Slipform Concrete

If the canal system includes long reaches of relatively straight canals without the need for drop structures, slipform lining machines can be used profitably. They are particularly useful in areas where the cost of labour is high and can produce a quality product. Such machines can produce up to 4 km of channel a day. However, to achieve this a high degree of control is required to batch, mix and transport the required volumes of concrete of the required consistency, to trim the section to the required tolerance, to arrange the setting out of the channel, by strings or lasers which control the hydraulics of the machine and to cure the resulting channel.

Contraction joints have to be formed in the lining after the passage of the lining machine and are usually made by cutting a groove in the fresh concrete and filling with a bituminous sealant.

The capital cost of a machine suitable for lining tertiary canals is approximately $150,000. Other capital costs would include the batching plant and truck mixers required to service the machine. Slipform paving will only therefore be suitable for large scale irrigation schemes. It is not possible to estimate the cost per metre of this type of lining, since a high proportion of the costs are fixed, in the capital cost of the machinery.

Rectangular Concrete/Masonry Channels

This form of lining comprises an in-situ unreinforced concrete horizontal base with side walls of masonry or concrete depending the availability aggregate or stone (Figure 4). Base and wall thicknesses are usually greater than for trapezoidal channel, base thicknesses of 100 to 150 mm and side walls of 150 to 300 mm are common, even for small channels. The larger wall thickness being a minimum practical from stone masonry.

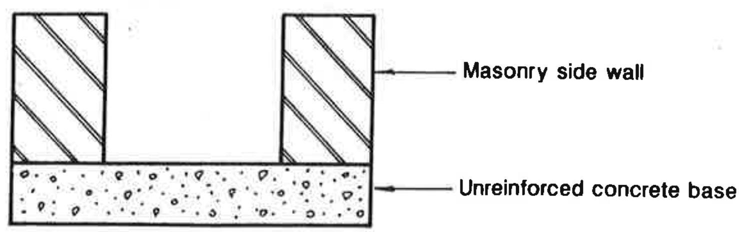

Figure 4. Rectangular Concrete and Masonry Channel.

As a result of the greater material thickness required, the channels are more expensive than trapezoidal concrete channels, US$15 to 20 per metre for the standard channel. However, the channels produced are significantly more durable. Our experience of constructing such channels in the mountains of Pakistan is that they will have a life expectancy an order of magnitude greater than most of the trapezoidal concrete channels. On projects where investment decisions are controlled by economists it is however sometimes difficult to justify the additional expenditure.

As with other types of concrete channel, preparation of foundations is important because of its low resistance to differential settlement. In general, however, it is easier to achieve an acceptable level of quality in construction as it uses the most basic of technologies.

Asphaltic Concrete

Use of asphaltic concrete for channel lining is not widespread in Africa and Asia. It has been in the past in the USA but even there is not used a great deal today.

Asphaltic concrete linings are usually between 50 and 75 mm thick and can be applied either by hand or using a slipform paver. As with cement concrete linings, one of the critical aspects of successful installation is compaction. The serviceable life of these linings is generally between 10 and 20 years (Deacon 1984).

The principal advantages of asphaltic concrete over cement concrete (with which it is most commonly compared) are that it can be placed during winter maintenance periods when it is too cold to place cement concrete and it is not as sensitive to the quality of the aggregate. Comparisons of costs are more difficult given the volatility of the price of oil and, consequently, asphalt. The most common problems with asphaltic concrete are transverse cracking and weed growth; one often accompanied by the other. This is combated by sterilizing the subgrade and repairing cracks promptly to prevent accumulations of silt encouraging weed growth at the waterline. It has also been reported that the top layers of asphalt tend to erode and expose the aggregate. This does not affect the overall serviceability of the lining though it does increase friction losses.

Brick Tiling

To date, this system of lining has been used mainly in India and Pakistan where the brick production is wide-spread. When it was first introduced it comprised two layers of brick tiles sandwiching a cement mortar layer 20 - 25 mm thick. The foundations where generally uncompacted and the sandwich layer lightly reinforced. A more economical system which has found favour more recently is to provide a single layer of tiling over the unreinforced mortar; the tiling providing the erosion protection and the mortar forming the impermeable layer.

Tile linings with the single layer have little internal strength and close attention to the preparation of the subgrade is therefore important. The subgrade needs to be compacted as for concrete linings.

This system of lining employs a great deal of unskilled labour and, with training, local farmers can realistically be expected to take over maintenance activities. The cost of lining the "standard" section compares favourably with masonry and concrete at approximately $12 per linear metre.

Transverse joints, a major weakness with concrete linings, are not required with brick-tiled linings. If properly constructed, this type of lining can last up to 20 years (Kraatz, 1971).

Soil/Cement Linings

Soil/cement linings can be used as a cheaper alternative to concrete where there are well graded sandy gravel soils available locally; preferably with the material from the canal excavation itself. Mixes used are either "dry" or "plastic." For a dry mix, the soil and cement are mixed and placed dry and water is added while compacting. Effective curing is especially important to achieve the required strength. Plastic mixes resemble more closely those used for slipform concrete and can be placed mechanically if desired.

The effectiveness of this type of lining is heavily dependent on the soil type used ideally the soil should be a well graded sandy gravel (Kraatz, 1971).

Cement content is usually between 8% and 12% by weight. It is advisable to carry out tests on trial mixes and on the chemical analyses of the soils for corrosive elements as for conventional cement concrete.

Design considerations, such as jointing and foundation preparations, are much the same for soil/cement linings as for in-situ concrete linings.

Using immediately available materials obviously can make soil/cement linings much cheaper than other types. Life expectancy can be good where the mix is right and good control is exercised.

Glass Reinforced Cement

Glass Reinforced Cement (GRC) is used in the manufacture of prefabricated sections and comprises zirconosilicate glass fibre and cement. The glass fibre gives the units flexural strength so that they can resist stresses such as those induced by differential settlement. The material is used for a wide variety of applications worldwide including sewer and tunnel lining and permanent formwork. In Egypt a trial length of GRC tertiary canal was used on the West Nubariya Project.

The units are made 8mm - 10mm thick; making them much lighter than equivalent steel reinforced prefabricated sections. Sections up to 5m long can be handled by two men. This reduces transportation costs which can be significant. They are jointed using a spigot and socket arrangement, the spigot and sockets are bolted together at the top and the joint is sealed with a flexible adhesive tape. The units can be assembled by unskilled labour.

In Egypt, had the units been mass produced, it was estimated that the costs would have been similar to in-situ or precast concrete. The thinner section does however make the units more susceptible to damage from animals etc.

Glass Reinforced Plastic

Glass Reinforced Plastic (GRP) is used predominantly for manufacturing prefabricated sections such as culverts, pipes and channels though it can also be applied in situ (Kirkby, 1979). Applying it in situ, however, does require highly skilled labour. Prefabricated sections can be made by winding the glass fibre onto a drum together with the resin to form a hollow section which is then cut longitudinally to form two channels. It is impractical to incorporate sharp corners with this system and so channels are either elliptical or circular. Alternately, channels can be made by coating a mould with layers of fibre and resin, in this way box section units can be produced.

The prefabricated sections are light and simple to install. The sections can be joined using a spigot and socket arrangement and sealed with an epoxy resin mortar. The result is a very impermeable channel which is available in a wide range of fashionable colours. It is, however, one of the most expensive systems available with precast units for the "standard section" costing $ 60 per linear metre ex-works and, for developing countries, with virtually all the constituent materials needing to be imported.

Plastic Membranes

Butyl rubber was the first synthetic membrane used for canal lining in the 1950's and remains the most commonly used of the materials available. Others include chlorosulphonated polyethylene (Hypalon) and plasticised polyvinyl chloride (PVC).

The principal advantages of membranes are that they are light weight per unit area, quick to install (up to 44 metres per man day (Kraatz, 1971)) and very impermeable. They can also be installed at lower temperatures than can concrete; allowing work to be carried during winter maintenance periods in colder climates. Material costs on site are between $25 and $30 per linear metre for the standard section.

However, membranes suffer from two distinct disadvantages, which make them unsuitable for tertiary canals. Firstly, most of the materials discussed above degrade in sunlight and secondly they are easily punctured by animals, children etc. These problems can be overcome on large canals by covering the membranes with 30cm of earth, but this is an impractical solution for tertiary canals.

Clay Puddling

Clay puddling is a relatively simple and, if the material is available locally, cheap method of lining of canals. The method of placement relies on compacting the clay to break down its structure and form the impermeable barrier; tests in India give rates of seepage between 0.0 and 0.2 m/day (Deacon, 1984).

Clay lining is, in the most part though, inappropriate for use in tertiary canals. It is vulnerable to "puncturing" by domestic farm animals drinking from the canals. Tertiary canals are also usually subject to regular cycles of wetting and drying as irrigation supplies are rotated. These cycles will induce cracking of the clay and leakage.

ASSESSING AVAILABLE LINING OPTIONS

This paper has discussed the various channel lining options available and how, in general terms, they are appropriate or otherwise for use in tertiary canals. The choice of which system to use is dependent on innumerable local factors including cost, life expectancy required, local resources, including labour and material for construction, maintenance systems and local service requirements.

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SESSION REPORT:
PERFORMANCE OF LINING

Dr. Muhammad Abid Bodla
IWASRI, Lahore, Pakistan.

The session comprised seven papers covering performance assessment of lining appertaining various factors such as, design parameters, construction techniques, lining types, materials and maintenance practices. Main points covered under each presentation are indicated below:

Paper *"Influence of Surface Permeability on Concrete Durability"*
by Meng Zhen Quan

- Factors effecting surface permeability e.g. carbonation, corrosion and freezing and thawing along with their influence on concrete durability discussed.

- Issues: further research required to investigate environmental factors affecting concrete lining.

Paper *"Role of Design and Construction Techniques"*
by S.N.H. Mashhadi

- Aspects such as why and where to line channels are discussed.

- Role of design and factors affecting design and construction considered. Drainage of service roads along lined channels emphasized. Problem involved in construction practices and techniques presented.

- Issues: detailed investigations, selection of proper materials and construction techniques, curing and efficient operation are considered essential ingredients of effective linings. Consideration of watertable conditions and backwater pressure are suggested as vital prerequisites.

Paper *"Study on Performance of Various Lining Materials"* by Dr. Irshad Ahmed

- Evaluation of seepage losses through experimentation on new lining types and materials including geomembranes under local conditions presented.

- Performance testing and evaluation in the field discussed.

- Viewed that silt clearing operations can damage lining.

- Durability of sealing material debated.

- Issues: need to lay down specifications for accepted materials.

Paper *"Canal Lining Performance Parameters in CRBC Stage-I Irrigation System"* by Ms. Zaigham Habib

- Parameters of performance indicators discussed.

- Effect of canal operation management on efficacy of canal lining.

- System is very new and under construction.

- Issues: Results indicate that seepage increased for lined sections and decreased in unlined sections which needs to be debated since system is not fully operational.

Paper *"Role of Maintenance: Experience from Pakistan"* by Dr. Bagh Ali Shahid et. al.

- Cost of maintenance directly relates to design criteria.

- Problems: inadequate drainage, canals passing through cities pose different kind of problems.

- Separate cadre required for maintenance staff for lined channels.

- Issues: disagreement on certain data presented in the paper that relates to value of Manning's roughness coefficient 'n'.

Paper *"The Role of Maintenance in Extending the Life of Lining"* by J.C. Skutch

- Need of early maintenance on certain lining damages and failure indicated.
- Maintenance for aging of material vegetation and cracking.
- Ponding tests to evaluate seepage to quantify damages and maintenance requirements.
- Data bank on lining and Manual preparation is suggested.

Paper *"Alternative Material and Construction Techniques for Lining of Tertiary Level Irrigation Canals"* by D.R. Birch

- Various alternative materials and innovative design and construction practices discussed.
- Need for structures providing social amenities e.g. places for washing clothes and buffalo baths indicated.

GROUP DISCUSSIONS:
DESIGN, MEASUREMENTS, CONSTRUCTION AND MAINTENANCE

GROUP I: DESIGN

Facilitator: **Ian Simmens, Halcrow International, Pakistan.**
Reporter: **Dr. M. Mehboob Alam, IWASRI, Lahore, Pakistan.**

Five different questions were designed to cover various aspects of 'Design and Canal Lining'. Related question and discussions are given below:

Question 1: Critical Parameters Controlling Design:

- Value of roughness coefficient 'n'.
- Reduction of seepage
- Sub-grades.
- Jointing materials
- Watertable levels nature of soils.
- Sediment transport capacity.
- Side slopes
- Conditions for operations and maintenance.
- Impact of size of channel on parameters.

Question 2: Current Design Practices Taken into Accounts for Institutional Factors Supervision Difficulties and Quality Control:

- Use stronger concrete in view of poor performance.
- Increase factor of safety.

- Type of material used for repair and maintenance such as bricks, pre fabrication.
- Spillways if operation is poor.

Question 3: Design Accounts for Future Maintenance Needs Particularly Small Channels Handed over to Farmers:

- Keep it simple.
- Care with joints, cleaning should not damage the section.
- Designing for non-silting velocities.
- Readily available materials.

Question 4: Problems That Remain Unsolved:

- Uplift/back pressure.
- How to guaranty sustainable seepage reduction.
- Joints, Quality assurance.
- Construction during operation.
- Lining in high watertable.
- Training of staff.

Question 5: Lined Channels Requires less Desilting: Choice of 'n'

- Yes: it require less desilting but;
- economical x-section reduced capacity due to silting (Indian experience),
- different experience in various places, more data needed,
- linings increase velocities; choice of 'n', more monitoring needed,
- 'n' depends on size of channels also.

GROUP II: MEASUREMENTS

Facilitator: **Brig. Khurshid Ghias, WAPDA, Lahore, Pakistan.**
Reporter: **Dr. Muhammad Siddique, ISRI (WAPDA), Lahore, Pakistan.**

Main Points

- Pond tests for seepage loss provide good estimates. For large canals, filling of the pond might be a problem. Where conditions permit regulators may be operated to fill the pond with canal water.

- Errors in seepage loss rate estimated from inflow - outflow method must be kept in view by planners/designers. Tests must be repeated to obtain reliable average value of loss rate. Inflow-outflow measurement over long periods using carefully calibrated regulators provide valuable data of seepage loss.

- Canal lining conditions, soil texture, watertable conditions etc. must be reported with measured loss rate.

- Measurements of roughness and sediment are necessary for design and operation of all canals and more so for lined canals since they have not enough scope for readjustment against altered conditions.

- Monitoring of canals by making actual measurements is considered a low priority job by the operating agencies of irrigation systems in Pakistan. Discharge ratings are old and their accuracy is a suspect. Irrigation Departments should be urged to improve upon this aspect.

- Since measured data is used in day-to-day operation, the responsibility of measuring hydraulic performance should rest with PIDs (Provincial Irrigation Departments). However, for special studies, other agencies/consultants may be asked to do the measurements.

- Whatever data is collected is not frequently/timely reported. Improvements should be done in this area.

- PID's do not make full use of collected data as a feed back to better maintain/operate their system. Similarly the data collected by other agencies is not used effectively as feed back. This situation requires improved coordination between various agencies.

- There is very much to be desired by way of interpretation of collected data for use in improving design and operation of canals.

- Lack of adequate fund was considered the major reason for not adequately monitoring the hydraulic performance of irrigation system. This is a very important aspect and requires adequate funding.

GROUP III: CONSTRUCTION

Facilitator: **J. Skutch, HR Wallingford, UK.**
Reporter: **Abdul Hafeez, IWASRI, Lahore, Pakistan.**

The discussions were mainly focussed towards the following salient issues:

- Selection of material, its quality and availability.

- Supervision such as quality control and the on job and institutional training for supervisory staff and other concerned personnel. Installation of well- equipped field Laboratory to perform the tests for quality control is very much desirable to ensure proper quality control.

- Enforcement of specified standards (Never play with specifications).

- Establishing of "Material Controlling Authority" for regulating and enforcing the standards for materials especially for construction materials.

- Selection of contractors on reasonable rates.

- Updated manuals of construction.

- Proper side slope and profile stabilization (subgrades and embankments compaction).

- Proper design based on detailed field investigations does help in achieving adequate construction standards.

- Feed back of field experience for future guidance.

- New methods and materials can be tried with a caution for the estimated durability of these linings.

General Remarks

Time and fund constraints often pose real impediments in establishing quality construction.

GROUP - IV MAINTENANCE

Facilitator: **Thomas E. Mitchell, USBR, Denver, CO., USA.**
Reporter: **Zaigham Habib, IIMI, Lahore, Pakistan.**

In response to the question about maintenance requirements, general opinion was that first of all canal prism should be kept integrated for any type of canal. It requires silt clearance, berm and bank preservation, protection of canal structures. It was further discussed that the variation in inflow should not be too much and water distribution from head to tail must be appropriate to avoid the sedimentation and to keep the maintenance needs minimum.

* For lined canal, it was pointed out that the maintenance needs are also related to the objectives of the required improvements. Different level and type of maintenance activities will be needed for the improvement in hydraulic performance as compared to the seepage reduction.

* Maintenance techniques were briefly discussed, it was mentioned that the roughness coefficient of lined canals usually increases in couple of years. Local remedies are plastering or replacement of tiles and slabs while polyethene materials are sometimes used in USA.

* In response to the second question; maintenance is done during the annual closer, which is usually sufficient period of time but in some cases requirements can be more extensive. The level of maintenance is mostly not achieved due to insufficient money and existing procedures.

* The effectiveness of the maintenance was discussed and it was pointed out that those systems work very well which are maintained properly. In many cases the required targets are not achieved for unlined and lined canals, for example equity and tail shortage is not improved considerably and for sufficient length of time for unlined canals, similarly the target of seepage reduction is not properly achieved. It was mentioned that the present O/M funds are too low, money are usually not available to meet the essential maintenance requirements. it was mentioned that in USA maintenance is a part of capital cost.

* Many suggestion to improve the present maintenance practices:

  (1) more comprehensive and updated O&M manual should be prepared,

  (2) proper and sticks should be developed,

  (3) in the present low funding situation, the maintenance requirements of a system properly evaluated and prioritized,

  (4) the need to improve the existing maintenance standard was stressed.

* In Pakistan Irrigation Department is responsible for maintenance at main canal and distributary level, farmers participation is at water course level, rather farmers are basically responsible at this level. It was mentioned that in China farmers participation has been contributed positively to improve the system maintenance and operations.

TECHNICAL SESSION: ECONOMICS OF CANAL LINING

FINANCIAL AND ECONOMIC ANALYSIS OF CANAL LINING IN PAKISTAN

Muhammad Shafique and A.A. Naqvi
Senior Economist and Director Economics, Planning & Investigation, WAPDA, Lahore.

ABSTRACT

Rise in demand of water for food production needs exploration of new sources of water. National Commission on Agriculture (NCA) has projected that agriculture productivity must increase at 5% per annum, to meet the national requirements, compared with historical average growth of 3.8% per annum. To meet these objectives Water Sector Investment Planning Study has estimated additional requirement of water to the extent of 33.3 MAF at farmgate by the year 1999/2000. Lining of distributaries and minors has been identified as a prospective mode of increasing water delivery to farms. Economic potential from this source has been estimated to be 4 MAF. The choice among alternative/competing development projects is made on the basis of least cost and optimum returns on investment. For comparison, costs per acre foot of water of various potential development alternatives of water resources have been computed. The economic cost per acre foot of water conserved from canal lining has been estimated to be Rs.988 at farmgate whereas the economic cost of tubewell water is in the range of Rs.210 per acre foot. The financial implication to provide subsidy to farmers by the government for the development of electric tubewells in the private sector has been estimated to be Rs.100 per acre foot. Similarly government's share in the watercourse improvement, as computed from data in Feasibility Report of Command Water Management, ranges between Rs.106 to 167 per acre foot. In case of canal lining, all cost, estimated to be Rs.1198 per acre foot of water at 1990 price level, has to borne by the government. Preliminary Economic Analysis of canal lining, based on marginal value of water, shows that canal lining is not feasible on economic efficiency criteria in fresh groundwater areas. The canal lining in saline groundwater areas is feasible, based on the level of costs and water saving shown in Feasibility Study of Command Water Management. However experience reveals that the cost estimates, prepared during feasibility level, escalate during construction. It is therefore very essential to collect time series data on costs and benefits of ongoing canal lining projects to confirm the economic analysis. The data may also be collected to meet the requirements of Indus Basin Model (IBM) to isolate the benefits of canal lining from other development activities which increase the agricultural productivity over time.

OBJECTIVES

Tremendous increase in demand of water for food production needs exploration of new sources of Irrigation Water. Canal lining is a mean of water conservation with potential for improved performance for equitable distribution of water between head and tail users. The economics of canal lining in Pakistan is yet controversial. The scope of this paper is to identify the broad scope of canal lining and also to develop financial and economic indicators to generate interest in economics of canal lining. Efforts are also to be made to identify economic data and research needs for exploration of this resource in future.

INTRODUCTION

The Pakistan National Commission on Agriculture (NCA) pointed out that in order to meet the demand of explosive growth in population at the rate of 3% per annum, a considerable acceleration in pace of agricultural growth is imperative. The commission viewed that the present agricultural growth averaging 3.8% per annum is inadequate; and instead agriculture must grow at 5% per annum (Government of Pakistan, 1988). This growth rate has been considered optimal on the basis that the best strategy for Pakistan is to give first priority to self sufficiency in food rather than to rely on export oriented agriculture growth to finance additional food imports. The additional water and non-water inputs (fertilizers, reclamation and control of waterlogging etc.) are considered essential to bring such a growth in agricultural productivity of Pakistan. Based on projected food requirements of the population and export needs the Water Sector Investment Planning Study (WSIPS) has been undertaken. The study has estimated the water requirements for the year 1999/2000 and 2012/2013. The additional requirements at farmgate, during 1999/2000 compared to base year 1990, have been estimated to be 33.3 MAF. The split of requirements during Kharif and Rabi is 19.2 MAF and 14.1 MAF respectively. These requirements for the year 2012/13 have been estimated to be 96.6 MAF. These estimations have been based on historical increases in yields of crops (WAPDA, 1990).

POTENTIALS FOR WATER DEVELOPMENT

The Committee on water resources and management in its report (1987) submitted to National Commission on Agriculture had estimated the future water potentials as shown in Table 1 (WAPDA, 1987). The data show the possible magnitude for development of water from various physical sources. The scope for conservation of water from lining of distributaries and minor canals was recognized to be 4 MAF. There could be deviation in the data on water potentials as a result of further research. For example finding of WSIPS on remaining groundwater potential is 8.3 MAF against 9.5 MAF shown in Table 1 (WAPDA, 1990). Further the report of the committee has not identified the possible saving of water within the system by optimal operational management.

The development of water potential shown in the Table 1 involves different types of works and investment implications. The surface water potentials can be exploited only with the construction of storage dams, remodelling of existing system and construction of new canals. Storage facilities require huge investment and longer construction period and political consensus. The storage dams even if started today will not be ready by the year 2000 to deliver water to the system. The possible alternatives till surface storage facilities are constructed are groundwater, watercourse improvement, canal lining and riverain area development.

Table 1. Potential for Water Development.

S.No.	Mode	Quantity (MAF/Year)		
		At Source	At Watercourse Head	At Farmgate
1.	Surface Water*	20.00	15.00	12.00
2.	Groundwater Development			
	i) Conventional	5.00	-	4.75
	ii) By skimming	5.00	-	4.75
3.	Watercourse Improvement		15.00	12.00
4.	Minor Canal Lining		5.00	4.00
5.	Riverain Storage**	12.00		8.00
.	Total	42.00	35.00	37.50

* Flow Diversion and Storage. ** Alternate for surface water storage.

Source: WAPDA (1987) National Commission on Agriculture - Report on Water Resources and Management, prepared by committee on Water Resources and Management.

The potential for the development of groundwater by conventional means can be exploited quite readily by increasing the utilization of existing tubewells and by installation of new tubewells. The potential for skimming of groundwater although quite substantial will be developed rather slowly since the technology for it has yet to be developed. The studies by Watercourse and Monitoring Directorate have shown that the improvement of watercourses as a mean of water conservation can produce quick results in respect of agricultural productivity. Monitoring studies have shown Benefit Cost Ratio of this programme in the range of 2:1 (WAPDA, 1984). The activity is divisible as the size of programme can be governed depending on the resources which can be allocated. In watercourse improvement and tubewell development farmers share major portion of capital costs.

According to prevailing technology in Pakistan, canal lining particularly of the existing system has to proceed at a slow pace as in the flowing system the work on canal lining can proceed during canal closures. In case the canals are closed for full season the farmers have to be compensated for crop losses. This will be an additional item in cost composition of canal lining.

Operational management of the system has potential of water saving and reallocation within the system. A study by World Bank has shown that the surpluses which can be reallocated are 1.945 MAF in Punjab and 5.814 MAF in Sindh (Masood and Kutcher). Trading/Bartering of surplus water within provinces or between provinces through operational management can increase the national agricultural productivity. Research by Qureshi and Eckert (1975) has shown substitution between water and fertilizers. This research has shown to attain optimally of water use by using less water by increasing the doses of fertilizers. Research by WAPDA at Mona Reclamation and Experimental Project has shown raising of crops with less number of irrigations in high watertable areas. The results of such research may be consolidated and policies framed to save/optimize water use within feasible economic framework. We feel, there is large scope for saving of water by integrated management of the system and substitution among water and non-water inputs by adopting optimal pricing policies; besides conservation of water by canal lining.

COST OF CANAL LINING

Economics of canal lining in isolation will convey no meaning. Economists aim at choices between alternatives to minimize the cost of production of resources or increase the productivity. Cost effectiveness, inspite of its limitations, focuses on least cost technique of development. For relative comparison of financial and economic cost of canal lining with other potential water production/conservation modes, costs per acre foot of water at farmgate has been worked out. These costs have been presented in Table 2. It may be noted that these cost reflect expenditures on production and conservation of water. The benefit like crop production or decrease in expenditure on drainage as a result of canal lining have been discussed in section on economic analysis.

Table 2. Economic Costs of Various Potential Water Developments Price Level per Acre Foot of water at Farmgate 1990.

Mode of Development	Financial (Rupees)	Economic (Rupees)
Surface Storage		
Kalabagh [1]	890	870
Canal Extension [2]	520	416
Canal Rehabilitation Programme [3]	200	
Canal Lining		
Command Water Management [4]	1198	988
Siran Right Bank Canal [5]	1066	864
Watercourse Improvement		
NCA[2]	439	320
Command Water Management [4]	584	428
Tubewells - PVC Strainer [6]		
15% Utilization		
Electric		
Metered	237	238
Flat	262	238
Diesel		
HSD	325	277
LSD	268	226
20% Utilization		
Electric		
Metered	199	210
Flat	200	210
Diesel		
HSD	270	231
LSD	218	184
25% Utilization		
Electric		
Metered	176	193
Flat	162	193
Diesel		
HSD	236	203
LSD	188	159

1 40% cost allocated to water and 60% to power generation. Financial costs do not include taxes, duties and IDC etc. costs updated to 1990 level using Index numbers developed by NESPAK. Life of Dam and canals assumed to be 50 years. Discount rate used is 14%.

2 National Commission on Agriculture, Report of committee on Water Resources and Management (1987).

[3] Rough estimates from WAPDA, Agro Economic Effects of Irrigation Systems Rehabilitation Project. Final Report 1988 (mainly Earthen Improvement in Punjab and Sindh, life assumed 25 years).

[4&5] Worked out from feasibility reports of Command Water Management Project and Siran Right Bank Canal project. Life of canal lining has been taken as 25 years. In case of watercourse improvement life span extends over 25 years with periodic replacement.

[6] WADPA Water Sector Investment Planning Study Main Report (Appendix B) life of the various components of tubewell ranges between 7 to 30 years.

For clarity, it may be noted that financial and economic costs have clear difference in economic terminology. Economic costs are worked out at efficiency prices and exclude all transfer payments such as taxes, duties and subsidies. To compute financial costs prevailing market prices are used.

The major competing water resources for investment in the short and long run are surface storage, canal extensions, watercourse improvement and groundwater development. For present study financial and economic costs have been worked out at 1990 price level to synchronize with the value of water discussed in detail in section on economic analysis. Financial and economic costs shown in Table 2 reveal that the cost of the canal lining is the highest as compared to other physical means of water production/conservation. These costs of canal lining have been based on data available in feasibility studies. Post project monitoring data on construction cost and water saved can reveal the real position. Comparison shows that costs of watercourse improvement are about 50% of the proposed cost on lining. Monitoring data from Irrigation System Rehabilitation Project (ISRP-1) reveal that the cost of conserved water from this project is in the range of Rs.200. However, the limitation of this data is that these estimates have been based on one year observation and data on water saved is the best estimate. Time series observations on the volume of water saved must be collected to confirm these costs. The financial and economic cost indicators on tubewell water show that tubewell water is the cheapest (Ignoring data on ISRP-1 programme), see Figure 1. From this analysis we can conclude that lining of canal is not a least cost alternative as compared to competing sources of water production/conservation. However, due to increasing gap between demand and supply of water in next two decades, the exploitation of this resource might be essential where feasible on Economic viability grounds.

METHODOLOGY OF ECONOMIC ANALYSIS OF CANAL LINING

The limitation of least cost analysis is that it ignores the benefits of the projects. A unit of water may not bring uniform benefits when applied in different areas. The utility of additional water will be very small in areas where water is abundant as compared to zones where water is a very scarce resource. In this background it is imperative to compare the benefits of water production/conservation in different areas. Standard benefit cost analysis can be applied to develop economic indicator like Internal Rate of Return which expresses the returns on investment when efficiency or real prices are used. The projects are accepted for implementation if the rate of return exceeds opportunity cost of capital.

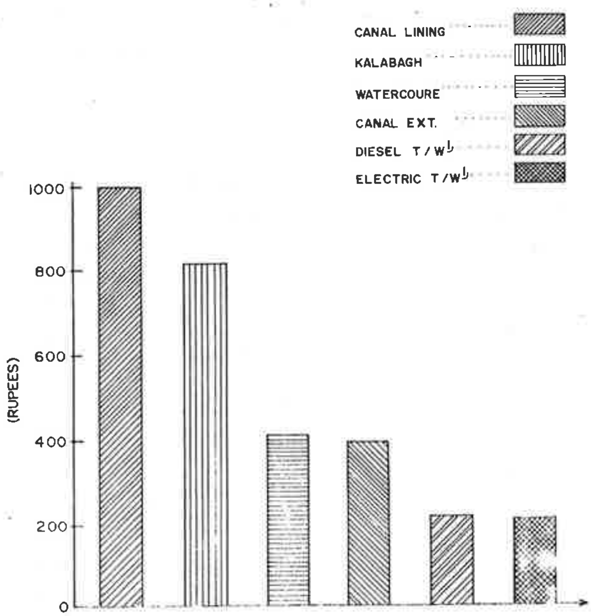

Figure 1. Economic Cost per Acre Foot of Water at Farmgate of Various Development Potentials.

The economic evaluation of canal lining for this paper has been based on the data provided in the feasibility study on Command Water Management prepared by WAPDA (1983). The reason for selecting this study is because the details of cost of lining and water saved has been provided in this study. Such post project data is not available from a published source. Hence we decided to analyse the estimates provided in the feasibility study to have some wisdom on the debate of economics of canal lining. In the feasibility study on command water management the economic analysis of whole package of command water management was accomplished. The potential intensities and yields with project were assumed and compared to without project condition and thus whole package was made feasible. We cannot separate the impact of different components of a project unless a simulation model is applied or marginal value of water in economic terms is used for the analysis.

ECONOMIC VALUE OF WATER

Kalabagh Consultants had used the average economic value of water, derived from the farm budget studies (Kalabagh Consultants, 1984). The World Bank used the Indus Basin Model for the economic appraisal of Kalabagh. This optimization model has the capability to produce information on marginal value of water in economic terms (Masood et. al., 1990).

The concept of marginal value of water can be understood from Production Function Theory and Law of Diminishing Return (Ferguson, 1972). A production function, is a schedule or mathematical equation, showing the maximum amount of output that can be produced from any set of inputs, given the existing technology or state of art. The production function behaves in accordance with the law of diminishing return. The law of diminishing return explains that as the amount of variable input (for example water) is increased, and amount of fixed input (i.e. land) held constant a point is reached beyond which marginal product declines. The marginal product of variable input is addition to total output assuming other inputs remaining constant. The average product of an input is obtained by dividing total product by total numbers of a variable input, assuming other inputs to remain constant.

As shown in Figure 2 production function has three stages. Stage-I covers the range of variable input usage over which average product rises. In Stage-II average and marginal product are declining and in Stage III marginal product is negative. From the data reported on value of water produced as a result of IBMR reported in WSIPS it appears that farmers in saline zone are applying water to the crop as operating in Stage-I of production function. In scarce water area the value of water increases and months with slack water decrease with the addition of water. This happens because the farmers plant additional crops till the saturation point is reached. To demonstrate this effect the data has been shown in Table 3. The data show that with additional water the value of water did not increase much in fresh groundwater area. However in predominantly saline groundwater zone the unit value of water showed an increasing trend. The economic value of water in 1990 prices derived from IBMR-III Model has been shown in Table 4. The data on economic value of water in fresh groundwater area show that the value are close to cost of tubewell water. In saline groundwater area the value of water is very high in some months and in remaining months the value is zero showing surplus water. However, these surpluses might disappear when additional water becomes available, as shown in Table 3.

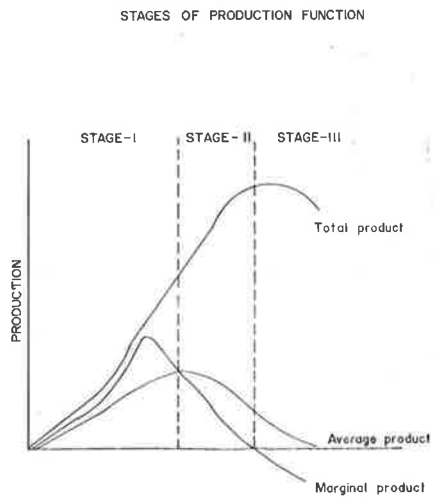

Figure 2. Units of Variable Input (Water).

RESULTS OF ECONOMIC ANALYSIS OF LINED CHANNELS

In the light of above theoretical frame work the sub projects viz Sehra, Naulaki and 6R from command water management feasibility study were selected for economic evaluation. The salient features of these sub projects are provided in Table 5. The table reveals that main source of future additional water supply is watercourse improvement. As regards the present water supply farmers in Sehra and Naulaki sub projects were receiving 83% to 86% of total water requirements. In these two sub projects besides canals, water comes from SCARP tubewells. In 6R sub project groundwater is saline and farmers were receiving 57% of total water requirements from canal supplies. It appears that in this project like other water scarce projects farmers are spreading water and attaining higher intensities.

Table 3. Economic Returns to Water.

WATER SUPPLY AT THE CANAL OUTLET:											
Zone Main Areas/Systems	Base Run			Impact of 1% Extra Water				Impact of 3% Extra Water			
	Slack water Kaf (000 AF)	MAF/Yr	Rs/AF	Months Extra Water Utilised	Slack water Kaf	RsM	added	Months Extra Water Utilised	Slack water Kaf	RsM	added
NWFP Kbul-Swat	70.1	1.81	532	All: Jan-Mar & Jun-Oct	67.6	8	0.8%	All: Jan-Nov	75.7	21	2.2%
PMW Thal-Paharpur	310.1	3.58	1100	SGW:Jan	268.8	103	2.6%	SGW: Jan,Apr,Oct	230.6	130	3.3%
PCW East-South Punjab	999.2	23.61	1466	FGW:Feb SGW:Jan-Feb & Sep-Nov	991.4	222	0.6%	SGW:Jan-Feb,Sep-Nov	820.9	1330	3.8%
PSW Jhelum-Haveli	597.6	7.06	1743	SGW:Feb & Nov	421.2	267	2.2%	SGW:Feb,Apr,Nov-Dec	225.6	440	3.6%
PRW Upper Chenab	32.9	4.70	2052	All:Apr-Jul & Sep-Oct	33.5	27	0.3%	All:Apr-Oct	33.9	65	0.7%
SCWN Ghotki-Rohri North	635.3	9.74	617	SGW:Feb	601.4	113	1.9%	FGW:Jul,Oct SGW:Jan-Mar,Sep-Oct	526.3	281	4.7%
SRWN Gudu-Sukkur Right	2035.3	11.24	381	All:Feb	2082.1	83	1.9%	FGW:Mar-Apr SGW:Jan,Mar,Sept	2171.3	108	2.5%
SCWS Nara-Rohri South	500.1	7.63	606	SGW:Jan-Feb & Sep	401.4	109	2.3%	SGW:Jan-Feb,Sep-Oct	243.9	307	6.6%
SRWS Kotri	2404.1	8.02	358	All: Mar & Dec	2397.6	19	0.7%	All:Mar-Apr	2494.5	16	0.5%
Overall	7644.7	77.39	1024		7265.0	951	1.2%		6822.7	2696	3.4%

Data soure: World Bank IBMR R21-23(22-Jun-90)

CCA: Cultivable commanded area Valuations in terms of value added at economic prices (VAEP)

FGW Index: Fresh ground water availability index (total private well capacity divided by canal capacity)-NWFP 0.28,PMW 0.42,PCW 0.76,PSW 0.92,PRW 1.46, SCWN 0.19,SRWN 0.05,SCWS 0.34,SRWS 0.00.

SGW: Saline groundwater zone.

Source: WAPDA (1990) Water Sector Investment Planning Study Main Report, Federal Planning Cell Lahore).

Table 4. Marginal Value of Water in Agro-climatic Zone of Indus Basin at Root Zone - 1990 Prices (Rupees)

ZONE	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
NWKSF	311	311	311			311	311	311	311	2717	311	
NWMWF	331	331	331					331	331	331	331	331
PMWF	352	352	352							352	352	
PMWS	2429	2429	2429							3008	3008	2429
PCWWF	318	318	318	318				318	318	318	318	318
PCWWS		2158	2158						3203	3203	3203	
PCWEF	313	313	313	313	313	313	313	313	313	313	313	313
PCWES			540						2216			
PSWF	314	314	314	314	314				314	314	314	314
PSWS	4830	4830	4830	4830	1453				4830	4830	4830	4830
PRWF	311	311	311	311		311	311	311	311	311	311	311
SCWNF	345	345	345								345	345
SCWNS	2424	2424	2424									
SRWNF		321	754	302							321	321
SRWNS			754									
SCWSF	345	345	345	345		345			345		345	345
SCWSS	2699	2699	2699						2699			
SRWSS			2314									
BRWF		321	321	310		310	310	310	310			
BRWS			3437									

SOURCE: Masood Ahmed & Gary Kutche - IBM-III, The World Bank Washington, DC.

Table 5. Salient Characteristics of Sub-projects.

Sub-Project	Water Saving AF		Cost of Lining 1983 Prices (MR) 1/		Intensity 2/			Present Water supply as a % of total requirements.
	Lining	Watercourses	Lining	Watercourses	P	W̲	W	
Sehara	9065	48900	24.9	33.9	118	120	130	83% (52 canal +31% TW)
Naulaki	7662	36600	22.70	20.40	105	110	120	86% (45 canal +41 TW)
6-R	8560	48600	21.06	35.95	127	131	141	57% (57% canal, saline groundwater)

1/ Government costs, add 5% contingencies and 20% Engineering costs to these base costs.

2/ P =Present, W̲=Without Project, W=With Project

SOURCE: WAPDA (1983) Feasibility Report - Command Water Management Project.

This is a typical example of optimization of return from scarce resource, that is water, by operating in Stage I of production function. As already discussed the marginal value of water in this project might be very high. Based on the explanation of economic theory we have used economic value of water of fresh groundwater area for Sehra and Naulaki. We have calculated the benefits at root zone accounting for conveyance losses of water.

For 6-R we have used the value of water computed in IMB-III for saline groundwater areas. In the 1st year of benefit realization, weighted average of value of water for month for which values appear has to be computed. However we have assumed that farmers will grow additional acreage and all months showing surplus water will disappear after a period of 5 years and high value of water will appear in all months. The economic analysis made on these assumptions shows that in fresh groundwater, where tubewells are operated for conjunctive use, canal lining is not feasible on economic grounds. The economic rate of return for canal lining in fresh ground water areas does not exceed 5% even if the value of water is assume to be double.

In saline ground water areas of Punjab, excepting PCWES zone, canal lining looks to be economically viable as the marginal value of water is relatively very high. In saline zones of Sindh value of water appears in a few months. This phenomenon may be attributed to high level of ground water. We can assume strong relationship among additional water supply, drainage and canal lining. These interdependicies are to be considered in a comprehensive economic analysis.

FINANCIAL IMPLICATION OF CANAL LINING

Government of Pakistan is facing huge budgetary deficit and situation on balance of payment aspect is also grave. During the year 1990-91, 64% of loan received was used to reimburse the debts. The collection from water rates are not enough to meet the O&M expenditures of Irrigation System. In view of these financial hard times projects with less financial implications shall be preferable to the government instead of capital intensive projects. In view of these prospects we have analysed, the canal lining and watercourse improvement programme included in Command Water Management Project from the point of view of sharing of cost between the government and farmers. The analysis in the table below shows that the entire cost of canal lining is to be borne by the government. However the cost of watercourse improvement is to be shared by farmers and government. The share of the government in case of watercourse improvement is shown in Table-6.

Table 6. Cost Per Acre Foot (in Rupees) of Water Saved at Farmgate, 1990.

Sub Project	Canal Lining	Watercourse Improvement		
		Government	Farmers	Total
Sehra	1198	158	536	694
Naulaki	1303	126	431	557
6R	1083	167	492	659
Pakpattan	1211	106	363	469
Niazbeg	760	109	369	478

Source: WAPDA (1983). Feasibility Study of Command Water Management Project.

The analysis in the table above shows the cost of canal lining is much higher as compared to watercourse improvement in all the sub projects. The cost of canal lining varies between Rs.760 to 1303 per acre foot of water saved. Whereas the cost of watercourse improvement ranges between Rs.478 to Rs.694 per acre foot of water. The analysis further reveals that government share in watercourse improvement ranges between Rs.106 to Rs.167 accounting for 22% to 25% of total cost for various sub projects. The remaining costs are to be borne by the farmers. In canal lining the entire costs are to be borne by the government and the present structure of Abiana rates does not allow recovery of capital costs which are huge. The subsidies on tubewell development in the private sector are also small. The advantage of private tubewell development in private sector is that the farmers have full control on utilization and they operate tubewells according to the water demand of crops. The control on utilization of water results into increase in intensities and yields and raise the income of farmers as compared to canal supplies alone. A study undertaken by WAPDA, for Government of Pakistan referred in NCA report, shows that the farmers using tubewells water were attaining 38% higher intensities and 27% higher net value of production per acre as compared to non tubewells users (GOP, 1988).

The conclusion of this analysis is that development of programme like water course improvement and tubewell development have less financial implications to government as compared to capital intensive programmes like canal lining.

EQUITABLE DISTRIBUTION OF CANAL SUPPLIES

The command water management study aimed at equitable distribution of water; between head and tail users, as one of the advantages of canal lining. A recent study entitled "Impact of Physical and Management Intervention on Canal Performance in Pakistan" (Valde and Rust, 1992) has revealed that desilting of canal is more cost effective in respect of equitable distribution of canal supplies among head and tail users. The reason for failure of canal lining programme has been contributed to poor construction and financial mis-management and significant interference in the dimensions of upper and middle reach outlets' structures that deprived the tail reaches of its fair share of water. Desilting of canal proved significantly cheaper and resulted in significant performance improvement. A programme of selective desilting based on the results of computer simulation of hydraulic changes following desilting gave the best performance and at the cost US$ 0.52 per hectare. The ratio of head tail inequality dropped from 4.20 to 1.29.

A more traditional approach to desilting whereby almost the entire canal was desilted yielded similar results, the inequality ratio of head and tail fell from 6.11 to 2.59. The investment is more expensive (US$ 2.20) per hectare as compared to selective technique but the recurrence interval of this type of desilting is likely to be much longer than the cheaper selective maintenance. The Authors have noted that there is lack of sedimentation data that will allow them to calculate optimal solution (Velde and Rust, 1992).

RESEARCH AND DATA NEEDS

In Conventional Economic Analysis of Irrigation Projects farm budgets for with and without project conditions are developed. In such analyses impact of various water development variables like canal lining, watercourse improvement and tubewell development is not isolated. While monitoring the benefits by using with and without project situations results are often misleading as some of the variables may also change in without project conditions.

In view of this situation it would be appropriate to start using optimization/ simulation models to isolate the impact of various components on benefits of a project. It is felt that expertise be developed to modify and use Models like IBMR and IBM-III to calculate the economic benefits of various components of a project. Such techniques should also be used in post project evaluation. The complementary requirements to use such models would be to develop skill to formulate data according to the needs. A data bank to cover hydrology, agriculture and economics, may also be set up within Planning Division of WAPDA. Water response function developed by Food and Agriculture Organization (FAO) has been used in IBM-III. Research on water response functions, covering interaction between water and non-water inputs under various price scenario should be a continuous activity in Pakistan for use in Investment Studies.

CONCLUSIONS

The cost effectiveness analysis shows that cost per acre foot of water saved as a result of canal lining is the highest among all known sources of production/ conservation of water. The preliminary analysis of canal lining has been undertaken on the basis of cost of lining and resulting water saving provided in the command water management study. The result of the analysis shows that canal lining is not economically viable in fresh groundwater areas where tubewell water supplement canal supplies. The canal lining seems viable in saline groundwater areas. This can also prove economically viable in areas of Balochistan and NWFP where high value crops are grown. The analysis of canal lining from data given in SIRAN Right Bank Canal Project supports this argument (WAPDA, 1992). The experience reveals that the cost of projects exceeds the estimated cost. Hence the economic viability of canal lining in saline ground water areas needs further investigation based on post project data of costs and seepage losses. The calculation of Benefits by using IBM instead of using value of water would be a realistic approach.

The financial analysis reveals that government spendings per acre foot of water on watercourse improvement are much less as compared to canal lining. Similar situation exists in respect of tubewell development. Only 40% watercourses have been improved in the Punjab. There is yet large potential for water saving by watercourse improvement in saline areas. Monitoring studies have already proved the economic viability of watercourse improvement programme. Similarly additional 8.0 MAF groundwater can be developed. Hence it would be advisable to complete the watercourse improvement in saline groundwater areas before starting large scale canal lining programme. Meanwhile time series post project monitoring data on cost and water saving from on-going canal lining projects should continue to be collected to firm up engineering and economic viability.

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CHANGES IN HYDRAULIC PERFORMANCE AND COMPARATIVE COSTS OF LINING AND DESILTING OF SECONDARY CANALS IN PUNJAB, PAKISTAN

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ABSTRACT

Observations on the hydraulic changes of lining of secondary canals in Punjab, Pakistan show that performance improvement objectives are not always achieved. If lining is justified on the basis of water savings through reduced seepage losses, then tail end areas should receive improved water deliveries. Observations in two distributary canals following lining do not demonstrate significant improvements in tail end conditions. Justification of lining on the basis of more stable water conditions is also hard to identify; reduction in the variability of discharges was not observed. Financial analysis of a recent canal lining experience in Punjab indicates that water savings would have to be unrealistically high, and sustained for long periods, if the initial capital cost is to be repaid through improved water conveyance efficiency. Furthermore, the hydraulic improvements achieved through alternative interventions appear to strengthen the argument that lining can be justified only under special conditions, rather than adopted as a wholesale approach to solving water distribution problems. Whatever the intervention, management control must be strengthened; lining is not a substitute for effective canal operational and maintenance inputs.

Key Words: lining, desilting, canal operations, hydraulic performance, seepage, financial analysis, economic impact, Punjab, Pakistan

CANAL LINING OBJECTIVES AND ASSESSMENT

Canal lining is often promoted as a long term solution to problems of water conveyance in canal systems*. The primary justifications used in support of canal lining are:

reduction in conveyance losses that improve hydraulic conveyance efficiency and reduce the contribution of canal flows to build up of watertables

* We are mindful of the caution urged by our colleague, Charles Abernathy, about entering the thorny thicket of the canal lining debate. His own recent contribution on the subject (Abernathy, 1991) is a succinct summary of key issues and pitfalls therein.

- establishment of more stable canal cross-sections that result in more manageable head-discharge relationships

- reduction in the maintenance inputs required on a recurrent basis

These apparent benefits require significant capital outlays, either at the time of initial construction of the system or when lining is retrofitted to existing canals. While there has been considerable effort expended in testing lining alternatives under controlled conditions, it is surprising to find relatively few systematic evaluations of lining under field conditions when it is subject to normal wear and tear.

To assess lining under field conditions, it is important to look at two main aspects:

- the changes in hydraulic impact of lining before and after lining to determine whether the desired performance improvements are actually achieved, and

- the economic costs and benefits of lining when compared to other potential uses of the same capital investment using appropriate discounting and with a realistic life length of the lined sections.

This paper presents field-based results and observations on lining for three secondary canals in the Lower Chenab Canal system in Punjab, Pakistan: Ghordour and Lagar distributaries in Upper Gugera Division, and Khikhi distributary in Lower Gugera Division. These observations were carried out over several years as part of the overall IIMI program to assess the performance of canal systems in Pakistan.

To facilitate the evaluation of the hydraulic changes consequent to and the economic implications of canal lining, the results also are compared with changes in similar canals in both Divisions that were subject to different levels of maintenance interventions.

STUDY LOCATIONS

In 1987, the first field research undertaken by IIMI in Pakistan was to evaluate the impact of lining in Lagar and Ghordour distributaries, two small secondary canals in Upper Gugera Division of the Lower Chenab Canal system, near Sheikhupura in the Rechna Doab of the Punjab plain. Work has continued on these canals through 1993, including monitoring daily discharges before and after a program of focussed desilting in 1989 and periodic observations to assess conditions of and changes in hydraulic performance as a consequence of other physical and maintenance interventions in 1992 and 1993.

Later in 1987, field work in Khikhi and Pir Mahal distributaries in Lower Gugera Division was initiated as part of a program to compare the impact of lining and major desilting on performance in larger secondary canals. Following intensive daily measurements at groups of watercourses along each canal, a program of periodic observations for one or two months a year was begun and continued to the present time. A brief description of each canal is presented below.

Ghordour distributary is located approximately 35 km downstream from Sagar Head, the beginning of Gugera Branch canal. Its head regulator is controlled by stop logs and the canal has a length of 20.7 km serving 37 watercourses with a total command area of 8380 ha. The design discharge into the canal is 1.415 m^3/sec.

Lagar distributary is located 40 km downstream from Sagar Head and its head regulator also is controlled only by stop logs. The length of the channel is about 19 km and 30 outlets serve a total command area of 6600 ha. The design discharge of Lagar is 1.075 m^3/sec.

Khikhi distributary is a very large secondary canal originating at Bhagat Head Regulator, the last structure along Lower Gugera Branch, over 200 km downstream from Sagar Head. The initial design of Bhagat Head Regulator was to proportionally divide all flows among the four distributaries originating there; now control is effected using stop logs so that rotations between the canals can be implemented whenever necessary. The total command area of Khikhi is 33,000 ha, including area served by several minors. The design discharge of Khikhi is 8.3 m^3/sec, and until 1992 its total length was 43.5 km.

Pir Mahal distributary is another large secondary canal that originates at Bhagat Head Regulator. Although longer than Khikhi with a total length of 47.8 km, the total command area is much smaller at 16,500 ha. The design discharge of the canal is 4.67 m^3/sec.

These four distributaries have many common characteristics. They have similar bed slopes, in the order of 1:4000; they have no cross-regulation structures; there are few drop structures (Lagar and Ghordour have none); the great majority of their outlet (*mogha*) structures are Adjustable Proportion Modules (APMs). Lagar and Ghordour have a designed annual cropping intensity of 50% per year [33.3% in winter (*rabi*), and 16.6% in summer (*kharif*)] although some watercourses were designed for 75% cropping intensities; the design cropping intensity of Khikhi and Pir Mahal is 75%, also with a kharif:rabi ratio of 1:2. An average watercourse has a design discharge of about 40 litre/sec serving a command area of 150-200 ha, but variability around this mean is considerable.

Each canal also was identified as having significant tail-end water problems that necessitated some form of intervention to try to restore design water surface elevations and discharges. The actual interventions described in the following section include selective desilting of critical sections, major desilting, partial lining, and extensive lining. This range of interventions permits some comparison between interventions to be made as well as an assessment of the impact of each intervention alone.

LINING AND DESILTING INTERVENTION PROGRAMS

This section briefly describes the four different interventions that have been the subject of detailed field investigation by staff of IIMI Pakistan since 1986.

Partial Lining

Both Lagar and Ghordour were identified as being problem canals in the early 1980s, and there had been a succession of complaints from farmers that water supply was inadequate in their tail reaches. Through the USAID-assisted Irrigation Systems Rehabilitation Project, which permitted significant flexibility to the Punjab Irrigation Department in the selection of canals for improvement, funds were allocated by the Chief Engineer, Faisalabad, to solve the water distribution problem in these channels.

The decision was made to line the lower third of each canal, leaving the upper two thirds in their unlined and somewhat deteriorated state. The lining material consisted of a single layer of bricks laid on hand-compacted earth, with the bricks bonded by mortar, but with no plastering. Although the canals were redesigned with a trapezoidal cross-section, no changes were made to either bed slope or elevation. Existing outlet structures serving the watercourses also remained unchanged; they were merely incorporated into the new lined section.

Lining of both canals was completed in approximately six weeks in January-February, 1985. This was accomplished by stockpiling bricks before the annual closure, and using outside contractors employing large numbers of casual workers. Many Irrigation Department laborers and field staff from adjacent canals were also co-opted for their labor and supervisory inputs.

The total cost of the lining program was Pak. Rs.3.32 million or US $208,000 (1986 $=Pak. Rs. 15.98). For Ghordour distributary the total cost was $108,500 or $1.68 per linear meter for the 5,830 m actually lined. Unit costs at Lagar were slightly cheaper ($1.58 per linear meter for the 5,550 m lined) because of the smaller cross-section involved. In terms of the total command area, the lining represented a per hectare investment of $13.42, but in fact it only benefitted about 50% of the total command area of the two canals, or a real investment of about $27 per hectare.

Extensive Lining

A slightly different approach to lining was adopted in Khikhi distributary. The basic design was similar, consisting of a single brick lining of both the channel floor and the side walls over hand compacted earth. Additionally, a 1.25 cm thick cement mortar plastering was to be applied over the bricks to provide a more watertight condition. All but the first 12.2 km length of the canal or nearly 75% of the channel was lined. As in the case of Ghordour and Lagar, watercourse outlet structures were not redesigned as part of the program, but changes were inevitable because of the nature of the construction process.

The scale of the task meant that it was impossible to complete the lining of Khikhi within the time frame of a single annual closure. Instead, lining proceeded through three annual stages mainly during the *kharif* seasons of 1988-1990. Construction of the lined channel proceeded upstream from the initial tail reach, and farmers continued to receive irrigation deliveries through a temporary by-pass channel constructed in the uncultivated right of way paralleling the canal. The use of temporary pipe outlets coupled with the removal and subsequent replacement of existing outlet structures in the sections being lined also meant that some modifications to outlet dimensions and elevation were bound to occur.

The approved cost of this lining project was Rs. 27 million or $1.25 million (1990, $=Pak. Rs. 21.60), or an investment of about $37.88 per hectare. In fact, there have been additional expenditures of about $100,000 on post-lining activities in the tail reach in a continuing effort to solve water supply problems. These changes are briefly noted below in section 5, however, their cost has not been included in the economic assessment of Khikhi's lining.

Major Desilting

In January-February 1992 the Irrigation Department undertook a major desilting of Pir Mahal distributary. The majority of the work in the upper half of the canal was done using bulldozers and excavators to physically remove the sediment from the canal and more or less restore the initially designed x-section. In the lower half of the canal and associated minors, desilting was undertaken by hand using locally available labor.

Although a major desilting of Pir Mahal had been anticipated for several years, shortages of funds had prevented the Department from implementing the project. Finally, $42,000 (1992, $=Pak. Rs.24.72) was allocated from the Department's own resources, a capital investment for the command area of 16,500 ha of $2.54 per ha. Actually the real investment was somewhat higher because unpaid labor was mobilized for some desilting work in the lower half of the canal from agency field staff, farmers and school children as part of the Punjab Chief Minister's province-wide 1992 desilting campaign. The value of those additional labor inputs cannot be quantified.

Rather ironically, a similar desilting exercise had been undertaken in Khikhi distributary in 1986-1987, soon after complaints about water conditions there had captured the attention of the late President, Zia-ul-Haq. However, work predated any field data collection programs in the area, and it is not possible to compare the results of these two activities. Nevertheless the Khikhi desilting program was reported to have been very successful and essentially the same methodology was used again in Pir Mahal. These experiences appear to have been important for the Department in formulating a strategy of major desilting of secondary channels as a consequence of capacity development through the Irrigation System Management (ISM) and Irrigation Systems Rehabilitation Programme (ISRP) projects over the past 10 years or so.

Selective Desilting

The final intervention involves the least financial and labor inputs. The analysis of water levels and discharges along Lagar distributary, observed in 1987-1988, strongly indicated that the persistent tail end supply problems there most likely resulted from sediment accumulation in certain reaches in the upper half of the canal. Using an IIMI-developed computer model of hydraulic conditions at Lagar, the probable impact of desilting only those sections where the bed elevation was unduly high was simulated. Simulation results suggested that only modest amounts of desilting would be required to greatly improve tail end conditions.

During the 1989 annual closure just four years after the last third of the canal was lined--a selective desilting was carried out in Lagar using usual maintenance resources. Although less sediment was removed than initially recommended, resulting tail end water conditions were better than anticipated, substantially restoring design conditions.

The total cost of this intervention was only $3,600 (1989, $=Pak. Rs.19.00), primarily the cost of the Department's own labor, or $0.52 per ha, and it was accomplished during the regular period of annual closure with no interruption of normal irrigation deliveries.

CHANGES IN WATER DELIVERY PERFORMANCE: EQUITY AND RELIABILITY

Changes Resulting from Lining

The evaluation of lining in both **Ghordour** and **Lagar** produced inconclusive results (Murray-Rust, 1987). In the absence of consistent, reliable data on before and after inflows into each distributary and tail end water conditions, the extent to which benefits had accrued were more speculative than definitive. Neither were there data on discharges into watercourses along either distributaries that might have permitted pre and post lining performance comparisons.

The only significant change noted following lining was that discharges into both distributaries had increased. This appeared to have been the direct result of bank improvement during lining so that earlier problems with overtopping and breaching in tail end sections had been alleviated. However, the increased discharge also reduced freeboard in the upper parts of the distributaries and may have led to an increase in breaches in those upper sections.

A final observation is that the lining of both Ghordour and Lagar was done without a proper evaluation by the Irrigation Department. At the time the intervention was undertaken, the type of lining adopted was seen as a model for substantial investments into the future. The absence of before and after measurements indicates an unwillingness to learn from further experience, implying that interventions of this type often are not made on rational hydraulic or economic grounds.

Khikhi distributary provided a much better opportunity to assess the impacts of lining (Murray-Rust et al., 1993). In cooperation with the Irrigation Department, sets of measurements were taken at four clusters of watercourses in head, middle and tail end reaches of the distributary, with the first set of daily readings preceding any intervention. These measurements of watercourse discharges, including discharges at the tail end of the canal, were combined with daily readings of discharges into Khikhi and at a few intermediate locations along the distributary to assess post-lining changes in water delivery performance.

The results with respect to *equity* show a surprising trend. The pre-lining data indicate that tail end watercourses were receiving more than their fair share, while head end watercourses were getting less than their fair share (Figure 1). Statistical analysis confirmed this trend is significant at the 1% level. That pattern of water distribution appears to have been the result of the heavy desilting undertaken in 1986-1987.

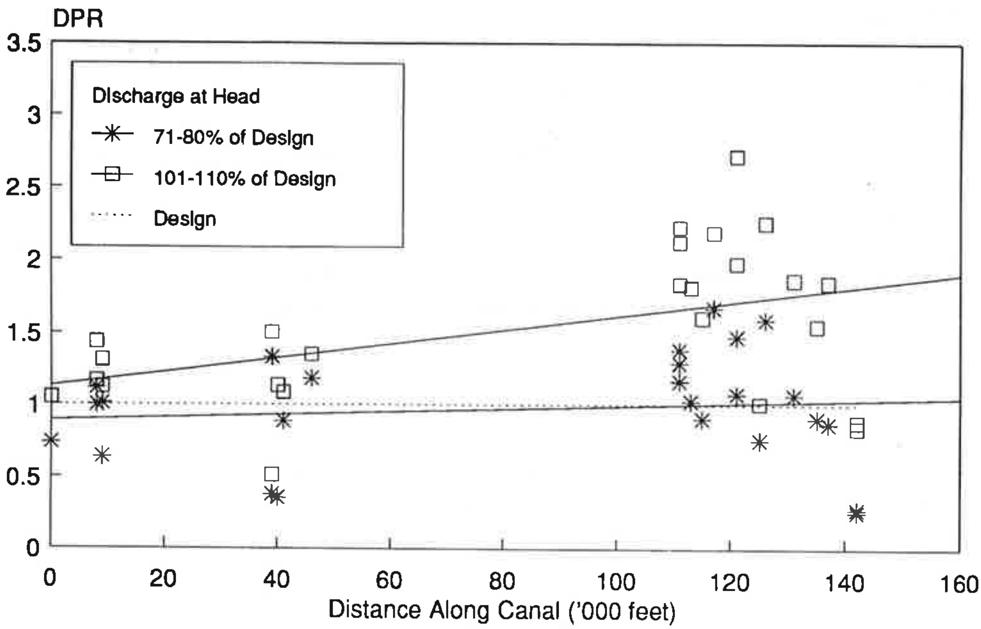


Figure 1. Delivery Performance Ratio (DPR), Khikhi Distributary After Desilting, Before Lining.

Although there are no accurate data available of conditions before and after that desilting, anecdotal evidence suggests that enough sediment was removed to restore a drop of over one meter in the measuring structure immediately downstream of Bhagat Head Regulator, a structure that had previously been submerged. Furthermore, there is reason to believe that the bed was over-excavated during desilting, thus reducing the working head for upstream outlets and allowing more water than designed to pass towards the tail. This conclusion is strengthened by analysis of the trends at two different levels of discharge. When the distributary head discharge was at or above design, tail end areas benefitted greatly, but when discharge was below design, there was no significant difference between the different watercourse clusters.

The favorable position of tail reach watercourses was soon reversed, and by the time the final phase of lining in the upper half of the distributary was being completed, tail end sections were experiencing severe water shortages (Figure 2). The steadily rising level of farmer dissatisfaction was not surprising. When canal discharge was at design or slightly above, differences between head and tail were not significant, but whenever canal head fell to 70-80% of design discharge, head end areas got significantly more (at the 1% level) water.

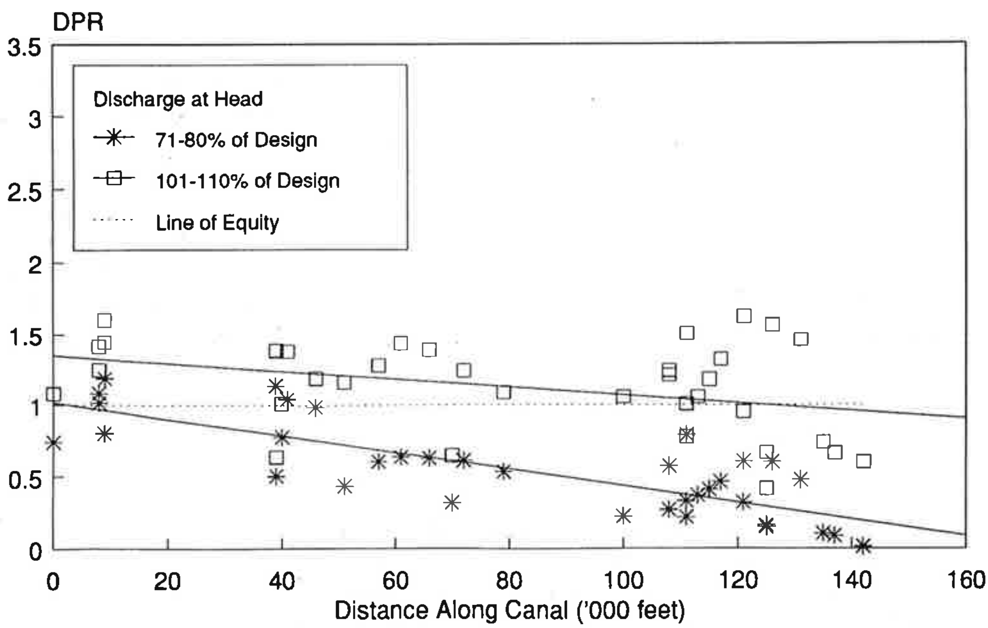


Figure 2. Delivery Performance Ratio (DPR), Khikhi Distributary After Lining.

This reversal of head and tail end watercourse fortunes strongly indicates that during Khikhi's lining something occurred that changed the overall pattern of equity. The likely causes are discussed in the following section.

In terms of *reliability* the measured pattern of water deliveries showed a similarly undesirable post-lining change. Before lining, the coefficient of variation (CV) of daily discharges over a several month period revealed no significant trend. There was only a slight increase in CV at the very tail end of the canal, increasing as expected whenever discharges dropped below design at the canal head. Following lining, however, there was a very significant increase in overall variation along the entire length of Khikhi, and a highly significant increase whenever discharges at the head were below design (Figures 3 and 4).

Changes Resulting from Desilting

Two additional sets of measurements in Pir Mahal and Lagar distributaries show the resulting impact of desilting on both equity of water delivery and reliability. These cases provide a striking contrast to the results obtained through canal lining.

Lagaı distributary continued to be a focus for part of IIMI's field measurement program following the initial assessment of its lining. As previously noted, it was soon clear that the primary cause of inequity in water distribution was not tail conditions, but rather conditions in the upper third of the canal. There erosion of the canal banks and increased elevation of both the canal bed and the water surface meant that upper end watercourses received more than their fair share of water. At the point where lining began, discharge was already well below design even when inflows into the canal were at or above design. Sufficient data were collected to permit a hydraulic model of the entire canal to be developed (Bhutta, 1990), and this model was used to identify priority reaches where desilting was needed to permit adequate water to flow to the tail. Subsequently a program of focused desilting was proposed to the Irrigation Department and implemented during the 1989 annual closure in January; the program included provision for an accurate assessment of the impact of this desilting.

In its effect on water distribution *equity*, the results of the focused desilting of Lagar were dramatic (Vander Velde and Murray-Rust, 1992). Before desilting, Lagar tail was more or less dry, and the tail third (*i.e.* the lined section) was receiving significantly less (at the 1% level) water than were the head and middle reaches. In the months following completion of this relatively modest desilting, tail end water conditions were not significantly different from the head, and most of the differences in outlet discharges could be attributed to variations in dimension and elevation of individual watercourse outlet structures (Figure 5). A similar improvement was noted in respect to variability of discharges at watercourse outlets.

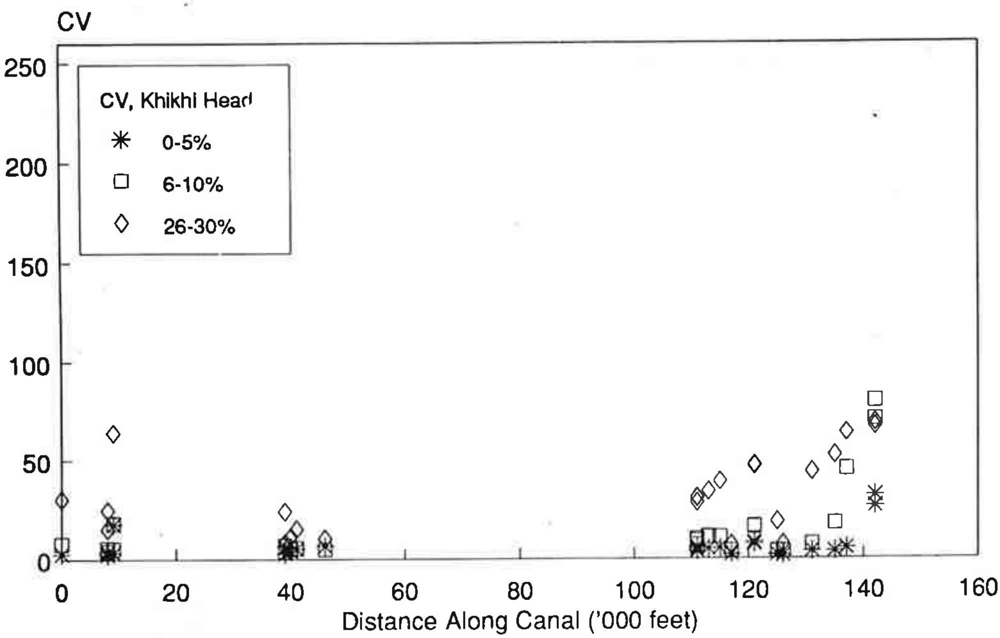


Figure 3. Coefficient of Variation, Khikhi After Desilting, Before Lining.

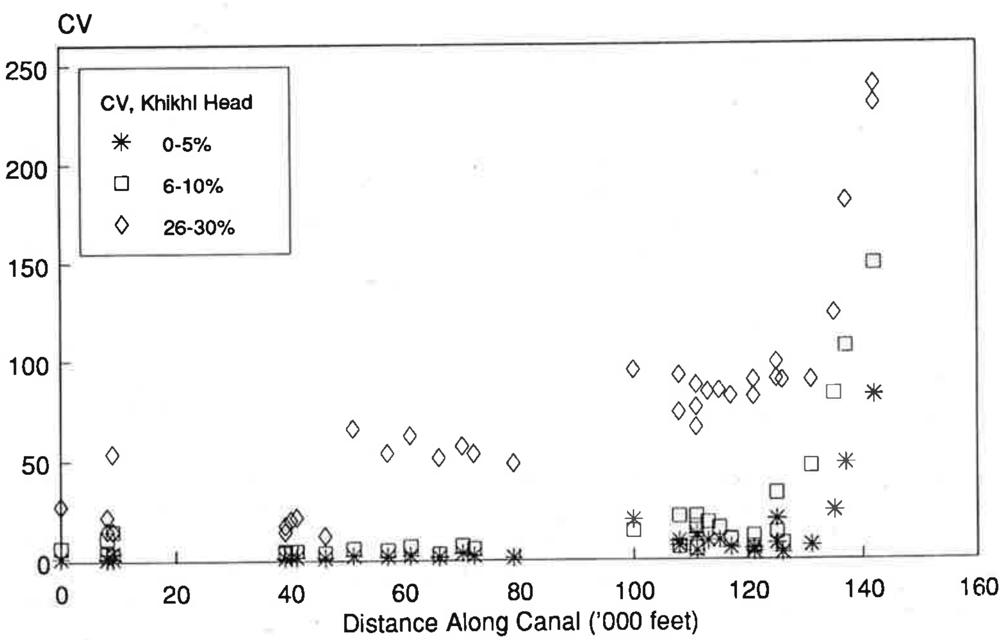
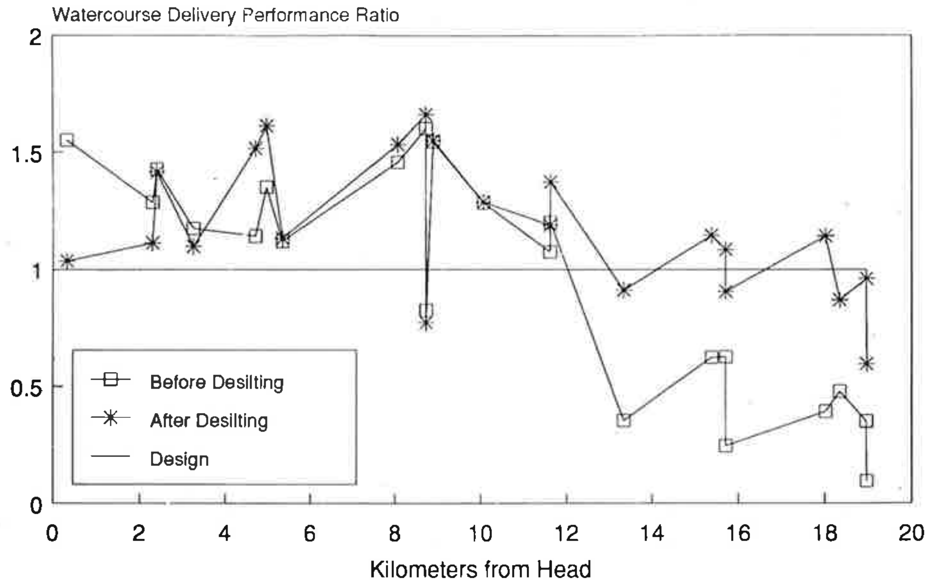


Figure 4. Coefficient of Variation, Khikhi After Lining.



Inflow discharge at design level

Figure 5. Lagar Distributary Water Distribution Equity.

Thus far, **Pir Mahal distributary** has shown a similarly favorable response to desilting, although the scale of the intervention was much larger than that at Lagar distributary (Vander Velde and Murray-Rust, 1992). Using essentially the same sampling framework as was adopted at Khikhi--several clusters of adjacent watercourses chosen for daily observations and measurement--the hydraulic conditions before and after desilting could be clearly identified. The changes in water distribution *equity* are almost as dramatic as those in Lagar (Figure 6). Before desilting tail end conditions were poor, but improved substantially afterward, although the head-tail discrepancy was not completely eliminated.

The impact on *reliability* of deliveries was even more positive (Figure 7). Before intervention, tail end areas were subject to rotational irrigations between the tail of Pir Mahal and Junejwala Minor at the bifurcation nearly two thirds of the way down the canal. Because conveyance efficiency was improved and discharges into Pir Mahal could be increased, these internal rotations were no longer needed, and water deliveries became two to three times more reliable for farmers.

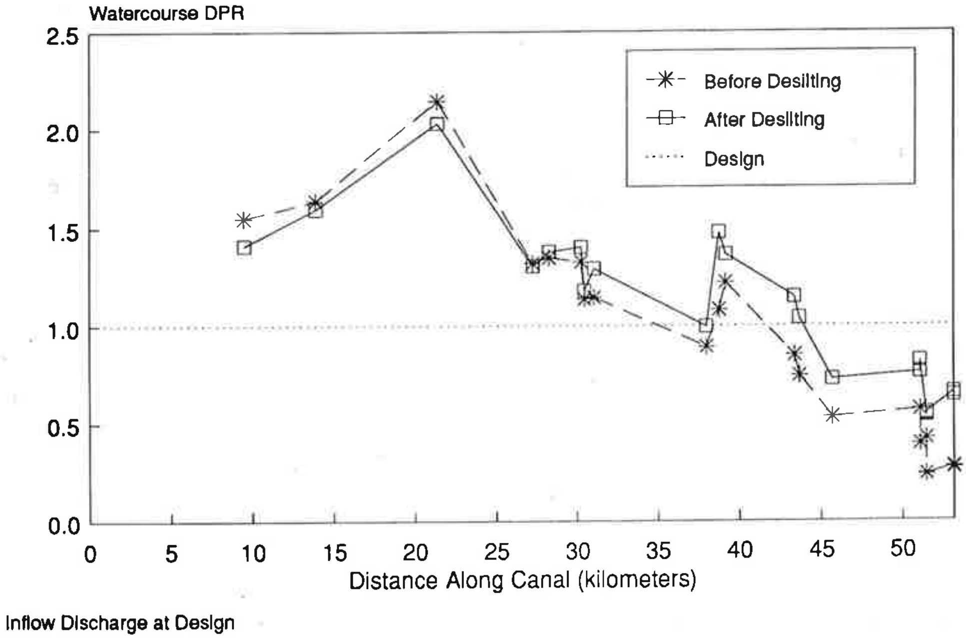


Figure 6. Delivery Performance Ratios, Pir Mahal Before and After Major Desilting.

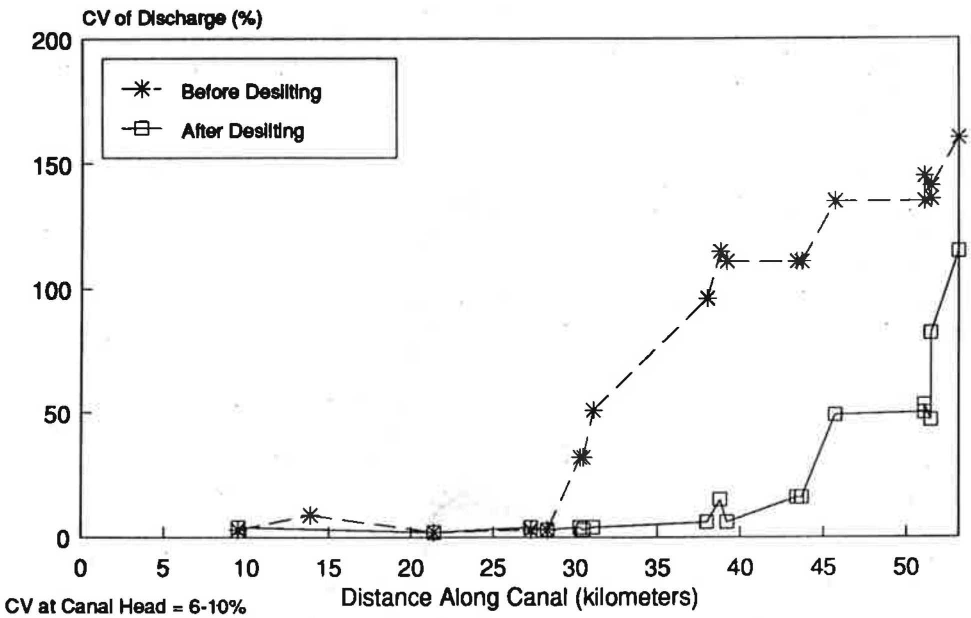


Figure 7. Coefficient of Variation (CV) Watercourse Discharges, Pir Mahal.

SUSTAINING THE BENEFITS OF LINING AND DESILTING INTERVENTIONS

Before proceeding to the economic analysis of the different interventions, it is useful to review some of the changes that have occurred in each canal following the different interventions. To determine whether one type of intervention is more or less beneficial than another, it is necessary to have some indication of the functional life length of the intervention to permit the capital investment to be discounted properly.

Lagar distributary was partially lined in 1985, but by 1988-1989 it needed desilting to enable water to continue to reach the tail. This by itself is not an indication of the life length of the lined section because the lining did not overcome the basic problem of inequity created by continuing sedimentation upstream of the lined section.

However, field observations since 1986 indicate that the lining has not lasted very well. In sections where it is at or below ground surface elevation, it appears to have maintained its structural integrity moderately well, although there are several sections where large cracks have developed and where slumping has occurred. By contrast, in raised sections where the canal bed is above the ground surface elevation, slumping has been common, and there are many sections where the lining has more or less disappeared. Undoubtedly, given their nature, the bearing capacity of soils in Lagar command is weak. Moreover, the lack of drainage behind lined sections has led to piping and collapse, and a few breaches have occurred in the lined sections.

Severe damage to lining also has occurred at many locations from tractor and buffalo traffic because insufficient bridges were provided to protect it, and in a few cases bricks have been removed for other uses. Finally, there is no evidence that deteriorated lined sections have had any serious maintenance; any damage either is left unattended, or earth is used to make temporary repairs that have become permanent.

Because lining is only effective in minimizing seepage losses when there are very few cracks present, it is inconceivable that this benefit could have lasted more than five years in Lagar, if that long. On the other hand, the integrity of the canal cross-section in the lined reach of Lagar has been sustained to a greater extent than is evident in the unlined reach. However, within three years, sufficient sedimentation had occurred to permit weed growth to re-establish, and there have been only limited efforts by the Department to maintain the lined section through occasional light desilting, usually by mobilizing local farmers.

Khikhi distributary provides two types of evidence on the relative life length of different interventions. It was desilted in 1986-1987 in more or less the same manner as Pir Mahal in 1992. By the time the first set of detailed observations were completed in early 1988 the tail end was continuing to perform at least as well as the head. Indeed, there is some evidence that the desilting by itself had been sufficient to overcome all of the problems that had been the basis of farmer complaints to the late President Zia. This suggests that an economic life length of five years may be realistic for the major desilting intervention. After that time the benefits likely will decline and have a much more limited impact on the economic analysis.

Lining at Khikhi, however, presents a less favorable picture. Even before the final phase of the lining was completed in late 1990, water conditions at the tail both of Khikhi distributary and Bachhrianwala Minor were so bad that farmers were cultivating a much reduced fraction of their holdings. To overcome these difficulties, in 1992 the tail outlets of both channels were taken out of command of Khikhi distributary, and new sources constructed for them from the Haveli Canal. The tail of Khikhi therefore "moved" upstream more than 2 km, a reduction of nearly 5% of the command area*. Not only did these changes cost more than $50,000, they also proved to be ineffective. In 1993, additional funds were allocated to supply these new tail outlets with water from the Haveli Canal, shifting Khikhi's functional tail a further 3.3 km upstream.

These physical changes may not reflect entirely on the lining activity. There is evidence that several interacting factors contributed to the post-lining decline in performance towards the tail. The factors include:

- Interventions by upstream farmers to obtain more water, particularly at Shorkot Minor, and the continued use of the temporary pipes installed from the parallel canal during lining;

- Unofficial enlargements of watercourse outlets during the lining process or installation of outlets at lower than designed elevations; both resulted in increased discharges into watercourses; and

- Increases in water surface elevation in lined sections from silt deposition in the canal after lining, changing the roughness coefficient used in the design of the lined section.

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* Bachhrianwala Minor was shortened by nearly 5 km. Before lining, the tails of both channels had been served by flumes passing over the Trimmu-Sidhnai Link Canal and the Haveli Canal.

In short, it is clear that the process of lining was not well controlled. In many locations farmers were able to establish informal increases in their water supplies which they would not have been able to do so easily without the lining project.

Finally, it must be recognized that the lining at Khikhi appears to be no more durable than that observed in Lagar, and in some ways it may be lower in quality. Bricks used in the lining were commonly No.3 grade rather than the stronger, higher quality No.1 brick that was specified, thereby increasing the likelihood of seepage once the overlying mortar begins to crack. There is also evidence that the ratio of cement to sand used in the mortar between bricks and in the surface plaster was lower than specified. Hence the long term durability of the plastering and its capacity to prevent seepage losses is questionable.

It is still too early to determine whether there has been significant sedimentation in **Pir Mahal distributary** following its major desilting in 1992. However, periodic measurements at key locations are continuing to try to accurately assess the rate of sediment accumulation and its effect on hydraulic performance.

FINANCIAL ANALYSIS OF THE IMPACT OF DIFFERENT INTERVENTIONS

A financial analysis of lining as described above requires that the objectives of the intervention be justified. In Section 1 it was noted that there were three primary benefits likely to accrue from canal lining: reduction in conveyance losses, establishment of more stable head-discharge relationships, and reduced cost of maintenance.

These probable benefits can be associated with two major operational objectives of the Irrigation Department. First is the re-establishment of the primary operational objective of equitable water distribution between all watercourses on the basis of their sanctioned allocation. The second is a reduction of canal losses to provide more *good quality* water to farmers to enable them to increase their economic livelihood. The analyses presented in this section directly relate to these two different objectives.

Finally, a financial analysis of canal lining or other physical interventions such as the desilting activities described above, also requires information on the capital costs involved, on expected life lengths, on the discount rate used to analyze the benefits so that they can be directly compared, on likely conveyance losses, and on the actual cost of water. The authors have used available data for and/or made several assumptions about each of these components which are briefly discussed below.

Data and Assumptions Used in the Financial Analysis

The **capital cost** is not as easy to determine as might be hoped. The data used are the sanctioned amounts based on the overall volume of work estimated at the design of the intervention. It is possible that actual sums spent on the work were slightly more or less than reported, and that somewhat more or less work was actually accomplished than planned. However, without more complete field measurement data, that is very difficult to quantify.

The estimation of **economic life lengths** used in the analysis are as follows, with an upper, middle and lower estimate assigned for each intervention:

- For annual selective desilting, the usual assumption of a three year life length may be optimistic. At Lagar, after the 1989 intervention, no serious desilting was undertaken until the province-wide self-help desilting campaign of 1992. Field data collected for the intervening years indicates that performance had declined by 1992 and the benefits of the 1989 desilting had more or less disappeared. The worst case scenario is that the work would have to be repeated annually; the middle case, therefore, is every two years.

- For major desilting, the evidence from Khikhi suggests that the benefits would have lasted at least three years*. This is taken as the worst case scenario. Clearly the benefits can not be sustained indefinitely, thus a best case scenario of seven years is estimated and middle case of five years selected.

- For lining, the benefits obviously have to last for a substantial time to be economically justified. Typically lining programs cannot be expected to last the full 30 years normally used for larger structures, and other work in South Asia (Upton and Chancellor-Weale, 1988) suggests that many of the benefits may be lost in 10 years. Thus the three scenarios selected for analysis are 5, 10 and 15 years respectively.

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* In fact, so far as can be determined, the Irrigation Department does not assume a life length for major desilting different than that for the more typical annual maintenance desilting; that life length is 3 years.

The **discount rate** also is somewhat arbitrary. For normal lending programs in Pakistan and elsewhere, a discount rate of 10% is used. In fact, the actual cost of capital in Pakistan is significantly more; therefore, values of 5% and 15% have been included in the analysis for comparative purposes.

Conveyance losses have been measured in Lagar distributary using inflow-outflow methods. Using data on discharge into the distributary and into all watercourses over a period of at least 7 days when discharges were more or less uniform, typical conveyance losses (including seepage, overtopping and water theft) have been calculated. These are presented in Table 1.

Table 1. Measured Conveyance Losses in Lagar Distributary.

	Inflow (% of Design Discharge)	Losses (% of Design Discharge)
March 1988	100	15
March 1989	100	16
March 1989	105	10
April 1989	105	12
April 1989	95	14

Note: All calculations are based on inflow-outflow method, with at least 6 days of uniform discharge into the head of the canal.

The average loss in the measured period varies from 10% to 16%, so for the purposes of this study, three values are selected for analysis: 10% for the optimistic scenario, 15% for the middle condition, and 20% for the worst case. (The reader is reminded that the worst case in this instance will give the most favorable benefit to lining).

The **cost of water** is much harder to determine. In Pakistan, surface water is not charged for directly; only the *abiana* or irrigation tax for the crop grown on a per acre basis is collected. On average, for a "typical" cropping pattern in the study area, this represents a charge of $6.80 per ha per year (Rs.170)*. This is equivalent to about $1.10 per thousand m^3.

This analysis does not incorporate the 25% increase in *abiana* announced in August, 1993 for Punjab. *Abiana* rates are also scheduled to increase 10% per year through 1998.

For pumped water, farmers are reported to willingly pay Rs.35 per cusec, or $14 per thousand m^3 when water deliveries are disrupted or inadequate (P. Strosser, personal communication), but it unlikely they could sustain economic agriculture at that price. A median figure for the sake of this analysis is taken as $US 7.50 per thousand m^3.

Financial Analysis Based on Re-establishment of Equity

The performance parameter that best measures the equity along distributaries is the ratio of the Delivery Performance Ratio (DPR) of head quartile to tail quartile outlets (Bhutta and Vander Velde, 1992). Delivery Performance Ratio is the ratio of actual to design discharge: in this paper it is specifically the ratio at the head of the secondary canal, and at the head of each of the sample watercourses. Using this ratio, the following information on performance in terms of equity can be summarized from the different studies in Lagar, Pir Mahal and Khikhi (Table 2). It can be seen immediately that the greatest reduction in inequity was achieved in Lagar distributary, while Khikhi shows a reduction in benefit to tailenders that makes any subsequent economic analysis of this parameter more or less meaningless.

Table 2. Delivery Performance Ratios Before and After Physical Intervention.

Canal Reach	Lagar		Pir Mahal		Khikhi	
	Before	After	Before	After	Before	After
Head	1.32	1.23	1.16	1.19	1.04	1.34
Upper Middle	1.32	1.38	0.94	1.28	0.90	1.07
Lower Middle	0.86	1.16	0.49	0.84	1.68	1.04
Tail	0.31	0.95	0.19	0.46	1.27	0.86
Head:Tail Ratio	4.20	1.29	6.11	2.59	0.82	1.55

It is possible to make a comparison of costs per hectare of each of the three interventions (Table 3). In terms of capital investment, lining at Khikhi costs $37.88 per ha, more than 10 times the cost of major desilting and about 60 times more than the cost of minor desilting. Assuming an estimated life length of 30 years for the lining, the annual cost per hectare would still be 20 times that of minor desilting.

Table 3. Comparative Costs of Different Interventions.

Canal	Activity	Head: Tail Ratio		Costs (US$)		Change in Head: Tail Ratio	
		Before	After	(000$)	($/ha.)	% Change	%$/ha.
Khikhi	Tail End Lining	0.82	1.55	1,250	37.88	-57	-2
Pir Mahal	Major Desilting	6.11	2.59	42	2.20	+144	+65
Lagar	Minor Desilting	4.20	1.29	3.6	0.52	+225	+433

Because of the apparent negative benefit of lining at Khikhi, the only meaningful comparison that can be made is between the two approaches to desilting. If the selective or minor desilting at Lagar needs to be repeated every year, than it is possible to justify major desilting with a recurrence interval of approximately five years, but if the effects of minor desilting lasts even two years, it will always be more beneficial than major desilting at these costs.

Financial Analysis Based on Cost of Water

A somewhat different approach to assessment can be made if some assumptions are used regarding the cost of water and the benefits of lining in reducing conveyance losses.

Table 4 shows the annual cost of different interventions using the assumptions described above for life length and the cost of capital. The major difference in the cost of lining versus desilting is immediately evident, even when mechanical excavation is used. In the worst case scenario, minor desilting lasting one year costs just over $0.60 per ha, while the most favorable lining scenario costs $4.98 per ha.

To understand the significance of the lining costs, Table 5 shows the value of water that could result, depending both on the overall value of water and the actual decrease in conveyance losses. These figures require some explanation.

For each canal, three levels of loss reduction are assumed (i.e. 10%, 15% and 20% of design discharge). This value is multiplied by the design discharge over a period of 336 days (*i.e.* allowing for an annual closure of 4 weeks) and the total volume of saved water calculated. This is then converted into an annual figure per ha using the different costs of water and the command area. An example of the calculations is shown for Lagar distributary below:

Design Discharge	1.075 m^3/sec
Saving at 10%	0.1075 m^3/sec
Daily Volume Saved	9,288 m^3/day
Annual Volume Saved (336 days)	3,121 $\times 10^3$ m^3/year
Value of Water @ $1.10/000 m^3	3,433 $/year
Annual Value per hectare	$0.52/ha/year

The same procedure can be used for each level of water saved, and for each assumption concerning the cost of water.

By comparing the data in Tables 4 and 5 it is possible to identify which combination of circumstances is financially justified. Whenever the value of water saved (Table 5) exceeds the annual investment indicated in Table 4, then lining could be considered. The results show that lining can never be justified in terms of the value of water saved if it is charged at the rate of the current *abiana* ($6.80 per ha, or $1.10 per '000 m^3. If water has the value paid by farmers for use of tubewell water, then lining is justified if its life length is in the order of 10 years or more, and the savings are about 15% of design discharge.

However, it should be noted that for a smaller canal such as Lagar, this means a conveyance efficiency of almost 100% (current losses are 15%), a life length of 10 years and a discount rate of 15%. Any less optimistic combination of circumstances will not justify the cost of water.

In the intermediate cost range, lining may or may not be justified economically using the same set of assumptions. Generally speaking, the lining has to last 15 years, and the proportion of design discharge saved be in the range of 15-20%. These two circumstances in combination represent rather heroic assumptions. Certainly considerably more supporting data would be needed before a sound investment decision could be made insofar as the performance of lining in both Lagar and Khikhi would indicate that such life length and water savings will not be attained.

Table 4. Annual Cost of Different Interventions ($/ha).

Total Cost (Cost/ha.)	LINING			MAJOR DESILTING			MINOR DESILTING		
	$ 1,250,000 $ 37.88			$ 42,000 $ 2.54			$ 3,600 $ 0.55		
Life Length	5	10	15	3	5	7	1	2	3
Discount Rate 5%	8.75	4.90	3.65	0.93	0.59	0.44	0.57	0.30	0.20
Discount Rate 10%	9.99	6.16	4.98	1.02	0.67	0.52	0.61	0.32	0.22
Discount Rate 15%	11.30	7.55	6.48	1.11	0.76	0.61	0.63	0.34	0.24

Table 5. Estimated Value of Water Saved by Lining ($/ha.).

Cost of Water ($/1000m^3)		1.1			7.5			14		
Water Savings (% of design discharge)		10%	15%	20%	10%	15%	20%	10%	15%	20%
Canal Lagar	Design Discharge 1.075 m^3/sec	0.52	0.78	1.04	3.55	5.32	7.10	6.62	9.93	13.24
Pir Mahal	4.7 m^3/sec	0.90	1.36	1.80	6.16	9.24	12.32	11.50	17.25	22.50
Khikhi	8.3 m^3/sec	0.80	1.20	1.60	5.48	8.21	10.96	10.22	15.33	20.44

Analysis Based on Increased Irrigation Intensity

The previous analysis assumes that the value of water saved can be equated to the capital cost involved in saving it. It still remains to be verified that the water will be used in such a way as to justify its value.

Analysis of the costs of minor desilting in Lagar indicate that there has to be an increase in the cropped area of approximately 490 ha (7.5% of the total command area) in order to generate sufficient additional payments of *abiana* fees, or an annual total of $3326*. This equals the cost of minor desilting if it has a life length of only one year. If the benefits last for three years, then it is possible to recoup

* Here and in similar calculations for the following discussion, it has been assumed that 100% of the *abiana* due on the increased cropped area would be collected. In fact, current levels of collection of assessed *abiana* in Punjab are considerably below that level.

the annualized cost if the cropped area increases by only about 220 ha (3.3% of the command area). Such increases in cropped area are feasible given that cropping intensities at the tail are significantly lower than in head end watercourses where there is no shortage of either surface water or fresh groundwater.

The annual cost of major desilting in the most favorable conditions (5% discount rate and seven year life length) is $0.44/ha. For Pir Mahal this means that annual increased income from *abiana* payments must be $7,260, or an increase in cropped area of approximately 1,068 ha (6.5% of the total command area). In the least favorable scenario, the annual cost of major desilting is $1.11/ha, requiring repayment of $18,000, or an increase in cropped area of 2,670 ha, about 16% of the entire command area. While this would be more difficult to achieve than in Lagar, it may not be impossible given that fresh water is at a premium in the tail reach and other parts of Pir Mahal command.

For lining, the situation is much more unlikely to be economic. In the most favorable case, the annual cost of lining is $3.65/ha. For Khikhi this requires a net repayment of $120,000, or an additional 17,700 ha of irrigated land paying *abiana*. This means that the annual irrigated cropping intensity in Khikhi command would have to increase to well over 180%.

One way to overcome these unsatisfactory economic implications as far as lining is concerned would be to substantially increase *abiana* in the command areas of lined canals, certain to be a politically difficult decision. Alternatively lining might be justified under a scenario where the investment is considered a mechanism to reverse a current trend of land abandonment in tail end areas, especially where increasing soil salinity and/or poor quality groundwater threaten the sustainability of agriculture. However, an analysis of these and other possible scenarios are beyond the scope of the present paper.

CONCLUSIONS

This study concludes that neither of the two lining activities investigated appear to have had significant positive effects on the hydraulic performance of the canals involved. In neither case is there evidence of improved water supply conditions at the tail end, either in terms of total volume or in terms of reliability. The only immediately tangible benefit is that more water can be delivered into lined canals as a result of concomitant improvements in canal banks that reversed the previous dangerously low freeboard condition.

The performance in hydraulic terms of alternative approaches involving either minor or major canal desilting was significantly better than lining. Moreover, both options appear to represent a more feasible strategy under most circumstances in the financial environment of Pakistan where capital is increasingly scarce.

Lining proves to be expensive, even though the lining types considered here were relatively less costly than other approaches. Even under the most favorable assumptions on life length and water saved, lining only just manages to prove viable if the value of water is close to the price currently paid by farmers for pumped groundwater. This means that there have to be very large increases in cropping intensity to generate sufficient *abiana* to justify the capital cost of the investment. It is difficult to imagine a set of circumstances where these most favorable assumptions will be valid.

If the cost of lining needs to be higher than present costs in order to make it more durable, then it is inevitable that current rates of canal water charges have to be greatly increased to repay the investment. This may be politically difficult, in which case lining becomes a subsidy rather than an investment. And, unless the relatively poor performance of lined canals can be significantly improved, even the subsidy argument is weakened.

Undoubtedly there are locations and conditions where lining is likely to be economic. It can be conjectured that the most favorable locations are those where underlying groundwater is saline and canal seepage rates are very high. However, the cost of lining has to be justified in terms of increased cropping intensities and the effective collection of *abiana* for those areas where increased cultivation occurs.

From the perspective of the foregoing comparative economic and performance analysis in the context of the Punjab experience and circumstances, it is clearly much more cost efficient to pursue ways of maintaining the original hydraulic function of canals through improved maintenance than through canal lining. Good annual maintenance continues to be highly cost effective and effectively implemented programs of periodic major desilting may be equally financially viable.

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ECONOMICS OF CANAL LINING - AN EVALUATION METHOD

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ABSTRACT

This paper outlines a method for the economic evaluation of canal and watercourse lining in a critical study made in Indian Punjab in 1988 (Upton & Chancellor, 1988). The study was a collaboration of HR Wallingford with IPRI Amritsar and the University of Reading and was funded by the Overseas Development Administration, UK and the Punjab Department of Irrigation, India. Canal and watercourse lining has been undertaken widely in the Indian Punjab. Initially construction took place in the regions where saline groundwater made the need to save sweet canal water more pressing. The lining programme has since been extended to other areas. Economic evaluation has compared construction and maintenance costs with the value of water saved through the seepage reduction resulting from lining. The study looks critically at the economic evaluation of the lining programme in Punjab where water lost through seepage is totally lost to the system and where seepage losses may be reusable. It is based on a range of budgeted estimates of the costs and benefits of lining. The general conclusion is that expenditure on lining programmes with current construction and maintenance practices is hard to justify in terms of economic benefit from seepage reduction, particularly where reuse of water occurs.

INTRODUCTION

In general in the Subcontinent demand for water is outstripping supply so that water is becoming a more valuable resource. This is in part due to population growth, which increases the demand for food, and in part to the adoption of new crop varieties which led to yields being more than trebled since the middle of the century, thus increasing the demand for irrigation water to grow them.

The new high yielding varieties produced better under continuous irrigation (Hayami D and Kikuchi 1978) and so added to the value of the productive resources, including water. Thus, reduction of wastage and enforced control is highly desirable. Lining of canals and watercourses is supposed:

* To lessen seepage losses and therefore increase efficiency of the conveyance system,

* To decrease the costs of maintenance and de-silting,
* To reduce waterlogging and control the rise of the water table,
* To improve equity by increasing the supply of water to tail enders,
* To accelerate the flow of water, thereby reducing channel filling times and other delays while improving water control.

It is difficult to ascribe an economic value to these last two effects although they are undoubtedly beneficial. However, it is worth noting that they could be achieved by other means than complete lining. Greater equity could be achieved by increasing the time allowance of tail enders to compensate for seepage losses. Faster water flow may be achieved by lining only the sides of canals, but not the base, with substantial cost savings.

The purpose of the study was to investigate the extent to which these supposed advantages occurred and to estimate costs and benefits and rates of return to lining. Clearly findings depend on local circumstances thus our analysis deals first with the most favourable scenario for lining where water lost through seepage is effectively wasted, and then, with circumstances in which lost water is reused. Different issues arise in relation to the lining of canals and the lining of watercourses and so arguments relating to lined canals and lined watercourses are treated separately.

In estimating and budgeting costs and benefits to be used in an evaluation; existing data was used in conjunction with information distilled from discussions both with professionals and researchers from the fields of engineering, hydrology and agriculture and with farmers who daily deal with the application of water to their land. The farmers first hand knowledge of the effects of lining on the water delivered to their land and their production system was a valuable resource.

CANAL LINING

A standard unit of comparison was required before costs and benefits could be compared. For the sake of simplicity a metre run of a typical distributary was selected. Constant returns to scale could be assumed since both lining costs and seepage rates depend directly on the area lined. In the 1988 study the Kotla distributary was taken as typical.

COSTS

To proceed to the budgeting exercise it was necessary to establish:

i) Cost of lining/m (c) i.e. difference in cost between lined and unlined channels/m.

ii) Difference in annual maintenance costs (m).

iii) Reduction in seepage (s) i.e. reduction in seepage/m multiplied by the time that the lining is in use.

iv) Value of water/m^3 (v).

The percentage rate of return on capital invested (p) is then given by:

$$p = \frac{(s.v + m)}{c}$$

NB. It is possible for s and m to have negative values.

The equation assumes an indefinite effective life for the lining. More realistically effective life is not indefinite and there is evidence to suggest that it can be very short indeed as we will discuss later. A finite period of 20 years was selected in the estimating procedure using the above data and annuity tables. In line with a more realistic view of the life of lining we assumed a negligible benefit for the reduction of waterlogging.

Costs of lining depends on the type of lining used and there are arguments relating to each alternative as to the availability suitability and durability. Therefore a range of costs must be considered each with its corresponding costs for maintenance and construction or reconstruction. It is necessary also to impute a realistic life for each alternative.

In the Indian Punjab the recommended lining used was brick masonry costing about Rs.30 per m^3 (Upton & Chancellor 1988) and the reconstruction method used was that of building the new lined canal parallel to the old unlined one which involved complications relating to structures and bridges.

The range of estimates of the net capital cost of lining adopted was from Rs.30/m^2 to Rs.60/m^2

The area lined per meter run of canal depends on the design characteristics of the canal. For the cup shaped Kotla canal with a design supply depth of 0.87m the lined area per meter run was calculated using a formula derived by Sharma (1964 p180), which gave an area of lining per meter run of 4.04m^2.

Using this figure with our range of costs per square meter the net capital of lining per meter run on this distributary was:

$$Rs.30 \times 4.04 \text{ to } Rs.60 \times 4.04 \text{ or } Rs.121.2 \text{ to } Rs.242.4$$

The remaining cost element to the considered is that of annual maintenance. Although reduction in maintenance costs and resulting costs are widely claimed for lined canals evidence suggested that for the Indian Punjab it was safer to assume that costs remained the same since the benefit of lining are critically dependent on seepage reduction. This allowed us also to assume that maintenance is adequate.

BENEFITS

The calculation of benefits requires information as to the reduction in seepage loss and the value of the water thus saved. The assumption of adequate maintenance earlier allows us to assume that the seepage rate in the lined channel is maintained throughout the life of the project. Our original realistic assumption of 20 years was based on a review of published data on seepage and desirability of canal linings (Deacon 1984). In the light of valuable findings a range of 10-40 years is considered.

Manuals for the design of irrigation channels in India suggest seepage rates for a 0.86 cumec (30.5 cusec) distributary of 2.1 cumecs per million m^2 of wetted area (6.8 cusecs/10^{6}ft^2) for a lined channel (see Government of the Indian Punjab 1977 p22, Central Board of Irrigation and Power 1975, and Central Water Commission 1984). However, researchers have recorded seepage rates from lined canals ranging from 0.0174 cumecs up to 5.69 cumecs per million m^2 (Dhillon 1987). This upper level is clearly much higher than the seepage from unlined canals. We therefore assume the upper limit of seepage from a lined canal is equal to that of an unlined canal.

The wetted perimeter for the existing, unlined, Kotla Distributary is 4.24m (13.91 ft) while that for the lined channel will be 3.1m. Hence the saving in seepage per million meters of run ranges from $(4.24 \times 2.1 - 3.1 \times 0.0174) = 8.85$ cumecs to zero, the modal value being 7.354 cumecs.

These figures must now be multiplied by the time (seconds per year) that the distributary is in use in order to arrive at the annual savings. Most distributaries are in use for more than 50% of the year. For example the Amritsar Distributary operated for 196 days in 1986-87. In the absence of other data, we assume that canal use may be extended up to 336 days with a mean value of 266 days annually. The total annual saving of water per meter run then ranges from zero up to $8.85 \times 336 \times 24 \times 3600 / 10^6 = 257$ m^3

Using modal, or mean, values as appropriate, the total annual saving amounts to $7.35 \times 266 \times 3600 / 10^6 = 169$ m^3.

VALUE OF WATER SAVED

It may be argued that the value of water, like that of any other commodity, should be measured in terms of the user's willingness to pay (see Dasgupta, Sen & Marglin 1972). However, in Indian Punjab, the private sale of canal water is illegal, although occasional sales do occur. Some farmers in the Amritsar District reported a selling price in early 1988 of Rs.100 per Pahr, this being three hours flow of a one cusec (0.028 cumec) watercourse. This amounts to a total quantity of water of $3 \times 3600 \times 0.028 = 306$ m^3. Hence the price of water is Rs.0.33/m^3.

An alternative approach is to estimate the total irrigation water requirement per hectare, together with the incremental net income per hectare obtained by changing from rainfed to irrigated cropping. This is based on the assumption that there is unirrigated land available within the culturable commanded area (CCA) so that water is the most limiting constraint. The extra or marginal return per m^3 of water can then be estimated. Agricultural data used in this manner again resulted in a calculated value of Rs.0.33/m^3.

Another approach based on the estimation of a stepwise water production function using a separable programming technique gave estimates of the value (shadow price) of water ranging from Rs.0.085 to Rs..0.559 depending upon the availability of water per hectare (Kumar & Khepar 1980). In connection with the World Bank feasibility study (1979a), it was estimated that the value of water at outlets ranged from Rs.0.2 up to Rs.1.0 per m^3, though data sources are not quoted. However, prices have clearly risen since 1979, so these estimates range much higher than those from other sources. These estimates serve to illustrate the wide range of variation in water value.

In these circumstances it was decided to carry out evaluations using water values ranging from Rs.0.16 up to Rs.1.0 per m^3, with a modal value of Rs.0.33.

COST-BENEFIT ANALYSIS

On the basis of the above figures we now calculate the annual net benefit per meter of lined canal as the value of water per m^3 multiplied by the annual saving:

$$\text{Annual net benefit per meter lined} = \text{value per } m^3 \times \text{water saved.}$$

Given the initial capital investment per meter lined, we can calculate the annual rate of return over 20 years, treating the annual net benefit as an annuity.

This produces a range of values for the annual net benefit from Rs.0 to Rs.257 the modal value being Rs.55.7. In turn we can now calculate the corresponding Internal Rates of Return giving a range of 0 to 129.4% with a modal value of 30.7%.

In order to illustrate the way in which the IRR varies within its limits with respect to changes in the values of the different components we have produced a series of three dimensional graphs. Sensitivity analysis was carried out for the full range of costs for each of the variables considered above. However, we illustrate only the parameters for which the IRR response was sensitive. This approach allows the method to be used to illustrate the effect of simultaneous changes in two parameters.

QUALIFICATIONS

Having produced this wide range of values in order to encompass the variety of conditions in Punjab, it is necessary to qualify some of the original assumptions.

There is some evidence to suggest that the reduction of seepage achieved by canal lining is much shorter lived than hitherto has been assumed in economic evaluations of canal lining projects. Our own assumption of a 20 year life for the lining implies, not only that the lining will exist for that period, but that the annual benefit attributed to the investment will continue over the whole period. In this case the benefit is the product of the volume of water saved and the value per unit of volume.

In reality both elements of this multiple are subject to variation over the project life. They are also subject to variation from place to place according to the physical conditions, technologies and process prevalent in the area.

Also, it should not be forgotten that there are considerable problems associated with the measurement of seepage in large canals. Calculations based on figures substantially smaller than the margin of error inherent in the inflow-outflow method must be viewed with some scepticism.

A major claim for benefit from lining relates to the supposed reduction in maintenance costs. System lining is claimed to result in significant reduction of siltation. Stability of channel shape and gradient was expected to ease the task of cleaning and to keep repairs to a minimum. This had not been found to be universally true and some designs are less effective than others. Repair when it is needed can be very costly and can result in substantial loss of water. Sediment problems arise in the catchment and sediment still has to be removed even from lined canals. Equity, however, does appear to be improved as a result of canal lining. There is probably some economic advantage from this increase in equity and there is, undoubtedly, an element of socio-political benefit. However, detailed study would be necessary to attempt any quantification of these supposed advantages.

These results are clearly subject to very large errors of estimation, as demonstrated by the sensitivity analysis. This is intended to be an economic analysis, which views costs and benefits from the point of view of society at large and takes no account of income distributional issues. No attempt has been made to estimate formal shadow prices. Given that prices of the main food crops in India are supported at levels somewhat higher than corresponding world prices a formal economic analysis might result in a somewhat lower rate of return. However it is doubtful whether it would produce a significantly different result. It is worth noting that for significantly larger canals than the case considered seepage rates are likely to be higher. It may therefore be possible for water savings to be higher and thus to increase the rate of return on lining.

WATERCOURSE LINING

Similar methods are used to evaluate the effects of watercourse lining. However the budgetary calculations are made easier by the fact that costs of lining and seepage rates are often quoted per meter run of the watercourse. The only complication is that, under the warabandi system, usage of the watercourse varies along its length. While the head reach, immediately below the outlet from the distributary, must carry water so long as there is any discharge from the outlet, the tail reaches only flow while the tail end farmers are taking their turns.

The benefits of lining, in terms of reduced seepage, are only obtained while water is in the channel. This had led several authorities to recommend lining only the upper reaches of watercourse where most of the saving in seepage will occur (see, Malhotra 1982, Khepar & Chaturvedi 1979, Khepar 1981, Goel & Belliah 1980, Goel & Chakrabarty 1984). For instance Malhotra shows, for one particular 5 km watercourse in Haryana, that by lining only 53% of the length, 91% of the seepage loss can be saved. Whereas the average duration of use, during a typical 7 day or 168 hour period, for the whole watercourse was 35 hours (21%), the average duration of use for the lined portion was estimated to be 60 hours (35.6%). The smaller is the lined portion as a proportion of the whole watercourse, the greater is the average duration of use of the lined portion.

These findings apply most strongly to branched watercourses, where only the 'main-stem' flows for most of the time but each branch only flows while a single farmer is irrigating. It is not difficult to show that if farm outlets (nakkas) were equally spaced along an unbranched watercourse and all turns were of equal duration, the average period of use over the whole length would be 96 hours (57%), although this figure should be adjusted downwards slightly to allow for longer channel filling periods for tail-enders. If 75% of the length was lined the average duration of use for the lined portion would rise to 120 hours (71%).

On the basis of studies dealing with this issue (Khepar & Chaturvedi 1979) the Punjab State Tubewell Corporation, which is responsible for watercourse lining, restricts the amount lined to between 75 and 86% of the total length. Given the wide variation in recorded figures, it is appropriate to consider a range of usage rates from 30 hours to 120 hours per week.

COSTS

After considering estimates from various sources a range of estimated averages from Rs.80 per meter run to Rs.110 per meter run was adopted.

Again the proponents assume that maintenance costs will be reduced by lining. However, whereas farmers normally take responsibility for the upkeep and desilting of unlined watercourses, they have initially failed to maintain lined ones. Arguably this is because the costs of repair are greater. For the calculation the maintenance cost is assumed to be negligible, as for the canals, and watercourse linings are assumed to have a life of ten years. The ponding method has been used to measure seepage losses from lined and unlined watercourses at IPRI Amritsar. The mean values found are:

3.5 cumecs per million m^2 of wetted area - unlined and
0.3 cumecs per million m^2 of wetted area - lined.

Since the wetted perimeter for lined and unlined watercourses, measured in this study, is similar at about 1m, the reduction in seepage per million metres run of watercourse is found to be:

$$3.5 - 0.3 = 3.2 \text{ cumecs.}$$

However, Makin (1987) measured seepage losses from watercourses on the Mudki distributary, lined some eight years earlier, and found a mean seepage rate of 3.7 cumecs per million m^2, which may even exceed that for unlined watercourses. At the other extreme seepage rates as low as 0.18 cumecs per million m^2 have been recorded. We therefore base our assessments on a range of reductions in seepage rates, from zero (equal seepage rates for both lined and unlined watercourses) to 3.32 cumecs per million m^2.

Assuming the watercourse, like the distributary discussed above, is in use for between 28 weeks and 48 weeks per year, and that the average duration of use per week, over the lined portion, is between 30 hours and 120 hours, the total annual water saving per meter run as a result of lining ranges from zero up to:

$$3.2 \times 48 \times 120 \times 3600 / 10^6 = 66.36 \text{ m}^3$$

Our modal estimate is:

$$3.2 \times 38 \times 60 \times 3600 / 10^6 = 26.27 \text{ m}^3.$$

COST-BENEFIT ANALYSIS

Using the same values per m^3 of water as in the analysis of canal lining, gives a total value of water saved annually (annual net benefits) per meter of watercourse from zero up to Rs.66.36. The modal value is estimated to be:

$$\text{Rs.}0.33 \times 26.27 = \text{Rs.}8.67$$

Given the initial capital investment per meter lined we calculate the annual rate of return over 10 years. Treating the annual net benefit as an annuity we can then produce a range of IRR from 0 to 19.3% with a modal value of less than 1%.

Sensitivity analysis undertaken for variations in the value of all parameters within the limits already adopted indicated that the IRR showed most response to variation in the time the lined watercourse was in use and the value of water. Steep rises in the values of IRR occur where the most optimistic assumptions for both these parameters are adopted.

To illustrate this point we have again used three dimensional graphs, varying two given parameters within the prescribed ranges to produce a range of IRR values.

QUALIFICATIONS

Watercourse lining has now been extended widely over the Punjab and is no longer confined to the areas where salinity is the major problem. The enormous length of the watercourse system has put the engineering resources of the state under pressure. Thus, it is appropriate to consider some qualification of the assumptions, on which our original range of values is based.

Use of local materials and building skills has resulted in a wide variation in the quality of the lined watercourses. Responsibility for maintenance has been a source of conflict. This situation has allowed considerable deterioration to occur causing poor conveyance of water, high seepage and the need for early major repairs. Evidence suggest that both seepage reduction and life of linings may have been viewed too optimistically to date. Makin (1987) studied seepage rates in a selection of lined watercourses of varying age up to 8 years in Faridcot District, choosing only channels with no obvious defects. A marked increase in seepage was recorded in channels over 3 years old; those from 4 to 7 years old showing rates higher than had been recorded in unlined watercourses. This, seemingly odd, result could be explained by a combination of one or more factors:

1. increased rate of flow in lined canals may result in increased seepage rates when cracks occur;

2. drying of the soil around the lined watercourse provides a greater hydraulic gradient when cracks newly appear;

3. where channels have been raised to provide good gradients seepage becomes leakage allowing faster loss.

Taking an average seepage rate for lined watercourses of all ages (up to 8 years) no significant difference from the rates in unlined watercourses was found.

High land values encourage maximum cultivation right up to the sides of the watercourses. The watercourse being small relative to the surrounding agricultural environment, is thus vulnerable to damage from humans, cattle and vehicles. The implication of these observations for the expected life of lining, is undoubtedly, to diminish expectations.

These latter issues, however, are less significant than the dendritic nature of the watercourses in reducing the rate of return. Whereas in some cases the lining of watercourses has been accompanied by realignment which has reduced the branched nature of the channel there are also cases in which the entire length of the watercourse has been lined, further reducing the average hours of use per week. Findings from field research suggest that, for some watercourses, the range of variables could yield an IRR that is equal to or less than zero.

CONCLUSIONS

Over a wide range of parameter estimates, the rates of return appear too low to justify expenditure on watercourse lining link. No doubt the costs of watercourse lining have, in practice, turned out to be larger than expected.

However the main factor weighing the economic balance against lining is the intermittent, and hence short duration, use of the watercourse on average under the warabandi system. It would appear that previous studies, which have suggested much more favourable rates of return to lining, have ignored this fact.

The situation is fundamentally different, of course, in other irrigation systems where watercourses flow all the time. The rate of return to watercourse lining in the Punjab could be increased by lining a smaller proportion of the length, concentrating on the head reaches only, as is done in the Pakistan Punjab (Dhillon 1987, Goel & Chakrabarty 1984).

GENERAL CONSIDERATIONS

Conjunctive Use

Where there is conjunctive use of canal and groundwater, seepage is not necessarily a loss to the system and the benefits of lining are much reduced. However there is considerable variation between districts in the dependence on groundwater. Canal and watercourse lining is most likely to yield economic returns in saline areas where water saved from seepage is a net addition to the supply of irrigation water. Even in saline areas shallow skimming wells can reduce the economic returns to lining.

There is much debate about how much seepage water actually returns to the aquifer and how much merely contributes to waterlogging. The World Bank in its 1979 appraisal report favoured a figure of 30% of seepage return, to the aquifer. However other experts claim that after a long time some 90% will contribute to recharge (Rushton personal communication). In these circumstances it is appropriate to test a range of different rates of reuse from 30% to 90%.

This means, of course, that the water savings due to reduced seepage lie between 10% and 70% of the original estimates. However the extra cost of pumping the water, which returns to the aquifer, must also be considered.

It is difficult to estimate the marginal cost of pumping water. Most published data on the costs of tubewell water include an allowance for the fixed costs of establishing the well. Thus the average cost per m^3 varies greatly according to the amount of water which is pumped. Given that the tubewell is already established, the marginal cost of additional pumping is little more than the cost of the extra energy. Energy costs vary not only in the cost per unit but in the method of charging and flat rate electricity charges mask the true cost of pumping groundwater in Indian Punjab so that in the example considered diesel costs were used at Rs.0.06 per m^3.

The benefits can now be recalculated for areas of conjunctive water use as ranging between

Rs.0.16 $\times$ 0.1 + 0.06 $\times$ 0.9 = Rs.0.07 where 90% return is obtained and
Rs.1.00 $\times$ 0.7 + 0.06 $\times$ 0.3 = Rs.0.72 where only 30% of seepage water returns to the aquifer.

These together with our earlier estimates of the reduction in seepage losses from canal lining yield annual net benefits per meter run ranging from zero up to:

Rs.0.72 $\times$ 257 = Rs.185.04

If these benefits are now related to the range of investment cost per meter run of canal lining, of Rs.121.2 to Rs.242.4 the annual rates of return over 20 years can be recalculated. The range of rates of return thus produced is from zero to 97%, however more importantly the modal value has now fallen to 7.7%, which is likely to be below the opportunity cost of capital.

Thus although canal lining appears to be an attractive economic investment, where seepage water is otherwise lost to the system, it is unlikely to be the case where conjunctive use occurs and seepage contributes to groundwater recharge.

Similarly the returns to the lining of watercourses under conjunctive use can be estimated. The annual net benefits, per meter run, now range from zero up to:

$$\text{Rs.}0.72 \times 68.84 = \text{Rs.}49.56$$

These benefits are compared with the capital costs ranging from Rs.80 to Rs.110 to arrive at the annual rate of return. The range from IRR values now produce runs from negative values to 19.2% but our modal figure is now less than 1%. A wide range of parameter values now result in rates of return of less than 1%.

The average duration of watercourse flow may be increased if they are used to convey tubewell water outside the established warabandi turns. Nevertheless this increased use is unlikely to swing the balance in favour of lining.

In this circumstance the lining exercise has been considerably less beneficial than was originally forecast, particularly in the case of watercourses.

EQUITY

Equity is not necessarily strongly affected by lining. In the situation where private conjunctive use exists, as it does in large areas of Punjab, then, because the greater proportion of water is supplied from the groundwater resources, more inequity must arise from the ownership of tubewells than from position on the distribution system. Where distributaries and larger channels have been lined, the capacity of the outlets to the watercourses has not been increased. Thus farmers see no benefit to themselves from lining, except where delivery to tail-end watercourses has been improved. Jairath (1988) made a detailed study of the relationships between socio-economic conditions, tubewell utilisation and irrigation costs identifying considerable disadvantage to small plot holders. As this source of inequity would remain unchanged as a result of canal lining the benefits assumed to flow from increased equality in delivery are much less where conjunctive use is widely and heavily practiced.

Where lining is undertaken successfully and seepage substantially reduced then unless there are changes in the irrigation practices and areas irrigated, then recharge to the aquifer will be reduced which will in the long run increase groundwater costs where conjunctive use is practiced.

However, where lining fails to maintain the reduction in seepage more distributional problems arise. Because of the reduced dimensions of lined canals less water is now subject to the same seepage rate as before lining which can only increase the plight of the tail-enders added to which the reduced surface delivery will have the effect of increasing demand for groundwater overall thereby increasing irrigation costs and accelerating the rate at which the water table is drawn down.

In either case the lining programme is changing the distribution of water resources albeit slowly. Estimates of the time taken for water lost through seepage to return to the aquifer vary around 10 to 15 years. The impact of changes in pump use is more rapid as may be the local impact of changes in cropping pattern.

In lined areas, where seepage rates may be returning to the levels of unlined channels, the Irrigation Department is faced with a difficult decision; either to increase releases in an attempt to maintain the design irrigation delivery thus reducing water saved, or to keep releases at their post lining levels and face the problems of reduced water delivery.

SUMMARY AND CONCLUSIONS

The general conclusion that must be drawn is that expenditure on canal and watercourse lining can be difficult to justify in economic terms. In those areas where seepage from canals is a total loss to the system, for instance because the groundwater is saline or there are drainage problems, investment in lining for main canals and distributaries can yield a satisfactory rate of return of about 30%. However, where much of the seepage contributes to groundwater supplies in conjunctive use systems, as is more commonly the case, the benefits of lining are much reduced. In these circumstances canal lining does not appear to be an economically viable proposition.

Watercourse lining over 75% or more of the length does not appear to yield an economic return even where seepage water is otherwise wasted. This is partly due to the high costs of watercourse lining to date. It is also due to the rather short duration of flow, on average over the lined portion, under the warabandi system. No attempt was made to estimate the returns to lining a small proportion of the length, say the top 30%, but it seems doubtful whether even this level of lining could be justified economically.

The situation is made worse by the fact that, under existing standards, of construction and maintenance, linings deteriorate rapidly. Within a period of six years in some areas seepage rates from lined distributaries and watercourses have risen to the same or even higher, levels than those from unlined channels.

The lining of watercourses may improve the supply of water to tail-end farmers. To this extent it contributes to increasing equity. However, this could be achieved at less cost by giving tail end farmers longer turns within the warabandi roster.

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SESSION REPORT:
ECONOMICS OF CANAL LINING

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Three papers addressing various financial and economic scenarios of canal lining were presented in this session.

In the first paper of the session entitled "Financial and Economic Analysis of Canal Lining in Pakistan", the authors M. Shafique & A.A. Naqvi have attempted to study financial and economic indicators of lining which are mainly based upon marginal value of water. In addition future research and data needs for achieving optimum returns by this mode of enhancing water supplies have also been addressed. Secondary data from reputed research work and findings of various planning reports provide the basis for the analyses presented. Indicators pertinent to economics of canal lining viz: water saving, cost of lining cropping intensities with and without, as derived from the canal lining projects in various climatological zones of Indus Basin have been presented.

It has been concluded that based on economic efficiency criteria, canal lining is feasible only in areas underlain by saline ground water in Pakistan. Lining is determined infeasible in fresh groundwater areas of the country.

The second presentation "Hydraulic Changes and Economic Impact of Lining of Secondary Canals in Pakistan" by D. Hammond Murray Rust and Ed. J. Vander Velde focuses attention in assessing two main and very important aspects of canal lining namely: a) the changes in hydraulic impact of lining before and after lining to judge whether the desired goals are actually being achieved, and b) evaluate economic costs and benefits of lining when compared to other potential uses. The findings of the paper are based upon IIMI's field based research for the three secondary canals of Lower Chenab Canal in Punjab, Pakistan. The paper contains a vivid picture of lining and desilting programmes carried out on these distributaries. Changes in water delivery performance with particular emphasis on equity and reliability have been studies. Delivery performance ratios before and after the physical and comparative costs of different interventions (lining, major desilting and minor desilting, presented and annual cost for these is worked out with changed assumption of life and discount rates (Table-4). similarly value of water is calculated by pricing total volume of water saved (assuming 3 water pricing and water saving) levels. Finally the analysis based on increase in irrigation intensity is also done. It is inferred that (a) the performance improvements are not always achieved, (b) lining proves to be expensive (though relatively cheaper types are considered here), (c) under the most favourable assumptions or life and quantum of water saved, the value of water is close to price paid by farmers for pumped water and (d) it is considered favourable at locations where underlying groundwater is saline.

Paper entitled "Economics of Canal Lining - An Evaluation Method" by F. Chancellor emphasizes to investigate the extent to which the benefits of lining (seepage reduction, decrease in maintenance cost, reduction of waterlogging, improve equity etc.) have occurred viz-a-viz estimate of costs, benefits and returns. To collect the relevant data observations were recorded from Kotla distributary in Indian Punjab. The capital cost of lining per meter run on Kotla distributary ranges between Rs.121 to 242. Quantum of water saved is estimated from the seepage rates as worked out by leading research organisations in Indian Punjab. Value of water saved has been arrived at using willingness to pay and marginal return, which yielded Rs.0.44/m^3 for the both cases. On this basis the annual net benefits average to Rs.55.7 and yield as IRR of 30.7% on an average. Watercourse lining and its related parameters namely a) extent of water saved, b) cost of lining and c) benefits have also been extracted from research work done by various Indian experts. Other aspects like conjunctive use and equity are also dealt. It is concluded that expenditure on canal watercourse lining hardly justifies in economic terms. Canal lining yield good results under saline/waterlogged conditions where it yields 30% IRR. For watercourse lining equity improves especially in the tail reaches.

GROUP DISCUSSIONS:
ECONOMICS OF CANAL LINING

Facilitator: **F. Chancellor (HR) Wallingford, U.K.**
Ata-ur-Rehman (NESPAK), Lahore, Pakistan.

Reporters: **Muhammad Shafique, Senior Economist, WAPDA, Lahore, Pakistan.**
Ghulam Muhammad Khokhar, Senior Economist, WAPDA, Lahore, Pakistan.

The discussions encompassed issues like:

a) seepage rates,

b) cost of construction (by various alternatives),

c) value of water,

d) On farm water management and

e) environmental issues. For establishing a workable economic analysis.

The discussion crystallized on following inferences:

1. Seepage Rates:

A) Though the Department of Irrigation is monitoring such records but these are of empirical nature and inadequate from view point of coverage. So it was decided that pre and post project monitoring of canal losses/seepage should be undertaken by an independent agency. To begin with these should be undertaken on a pilot project basis.

B) Life span for various lining techniques/types needs also to be found out from the experience of canals already lined.

2. Cost of Construction:

It was suggested that this should be mainly the responsibility of Executing Department to supply the pertinent informations on cost parameters of canal lining project. This no doubt will be done for various alternatives of lining. It was also decided that at this stage Economists should also be involved to ensure rigorous evaluation of indirect costs during construction stage. Estimates on O&M cost should also be compiled properly.

3. Estimation of Benefit:

It was decided that Economic Benefits of canal lining be isolated from other water production activities at farm level. To assign a proper marginal value of water saved through this innovation the economist should furnish it by a) preferably by using the IBM model (Pakistan case) and b) If there is no access to such model, computing it by estimate of alternative production values viz-a-viz cost of water from alternative sources and also compare with impacts especially for OFWM programme.

4. Environmental Issues:

It was also thought imperative to record such effects, especially land savings as a result of lining should be duly accounted for, both qualitatively and quantitatively. It was also emphasized that good and reliable information on social issues like:

a) equity,

b) water user association,

c) drainage costs, be included in the analysis.

TECHNICAL SESSION:
LINING ALTERNATIVES AND NEW MATERIALS

SEEPAGE MITIGATION USING SOIL CLAY AND ALGAE

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ABSTRACT

A field experiment was conducted on a red-brown earth (Natrixeralf) to find the effectiveness of spontaneously dispersed clay from sodic soils and the mechanically dispersed clay (by puddling) from calcic and sodic soils in reducing the seepage loss of water from a series of small dams (pits). The effect of inoculating algae in the pits on reducing seepage was also investigated. A plastic lined pit was used as a water balance control to measure incoming rainfall and evaporative loss. The results showed the effectiveness of dispersed soil clay in sealing the surface soil materials in the banks and beds of the pits. The dispersed clays from sodic soils were very effective in reducing the seepage to zero. When the clay concentration was above 8 g L^{-1} the sealing was complete, irrespective of spontaneous or mechanical dispersion from sodic soils. The mechanically dispersed clay from calcic soils were less effective in sealing because of the deposition of flocculated materials in the pore systems formed domains and generated microporosity. In calcic pits, the inoculation of algae reduced the seepage by 13 to 23% even though biopolymer (chlorophyll and polysaccharide) production was not found to increase as expected.

INTRODUCTION

Seepage from the earthen irrigation systems in northern Victoria, Australia, has been studied since 1893. While early studies were mainly concerned with the implications of seepage losses on the efficiencies of channel systems, current focus is both on quantity of water loss and consequent environmental degradation. While water lost to seepage reduces the water available for agricultural production, groundwater accessions from seepage losses contribute to rising water tables and the associated problems of salinisation and waterlogging. It is estimated that seepage loss in northern Victorian irrigation districts varies between 3% and 5% of the water delivered and this corresponds to 13% to 24% of total groundwater accessions (Webster, 1984).

Long term or seasonal changes in seepage rates have been noted on operating channels in distribution systems and in recharge ponds associated with groundwater replenishment projects (Jackes, 1980). Several investigators have reported that the gradual siltation and clogging of soil pores resulted in the development of layers of low hydraulic conductivity on the wetted perimeter of irrigation channels. Previous research concentrated on the effects of artificial sediments, particularly bentonitic clays, on the seepage from irrigation channels (Renfro, 1968). Flexible membranes, asphalt and concrete linings are generally expensive and have maintenance problems (Laing, 1974). Soil-cement mixtures can be used in some cases, but surface cracking might occur when the lining is exposed to drying conditions (ICID, 1967; Wilder, 1977). High installation and maintenance costs make these methods impracticable in many situations.

The chemical interaction of the soil and the channel water is an important factor affecting seepage. The channel soils, containing sufficient adsorbed sodium, in contact with water release clay particles which can seal the surface layers and reduce hydraulic conductivity. On the contrary, the presence of electrolytes (i.e., salt) can arrest the tendency of the clay particles to disperse and promote aggregation of soil particles which in turn will increase porosity of the soil medium and hydraulic conductivity (Rengasamy and Olsson, 1991). In laboratory studies using a number of channel soils, Ragusa et al.(1994) found that increasing turbidity of channel water containing dispersed clay can reduce the hydraulic conductivity and when the clay concentration was 10g L^{-1} water did not permeate the soil medium. They also found that when the salinity of the percolating water exceeded a threshold value, the hydraulic conductivity increased by >15% when compared with distilled water.

A second important factor affecting the hydraulic conductivity of irrigation channel soils is the growth of benthic algae and bacteria and the polymeric compounds they produce. Moracova (1971) has shown that algal growth can have a significant adverse effect on the overall efficiency of artificial recharge systems by reducing the infiltration rate of water. The effect of micro-organisms in reducing the hydraulic conductivity of soil columns has been shown to be via growth and production of polysaccharides (Allison, 1947; Vigneswaran and Ronillo, 1987) and polyuronides (Mitchell and Nevo, 1964).

Ragusa et al.(1994), using columns of channel soils, found that hydraulic conductivity was reduced to less than 22% of the original value within a month of inoculating the column with algae. Increases in polysaccharide occurred in the top 0-5 mm layer of the soil column. The reduction in hydraulic conductivity was highly correlated with the amount of polysaccharide produced and the algal and bacterial numbers. Further, in a separate experiment, they showed that clay sealing of soil bowls with the surface coating of a hydrophobic polymer effectively prevented saline water seepage from these bowls.

A separate field experiment was conducted to extend the laboratory work mentioned above which had shown novel and apparently economic methods of seepage mitigation to be successful in reducing seepage. The field experiment reported here aimed at finding the effect of spontaneous clay dispersion, clay dispersed by puddling, inoculating with algae and addition of salt on the seepage of water from the storage in field pits.

MATERIALS AND METHODS

Nine small dams or 'pits' (dimensions of 4m $\times$ 3m $\times$ 0.5m deep) were dug at the Institute for Sustainable Agriculture - Tatura centre farm at Tatura, Victoria. The soil type is red-brown earth and is classified as Natrixeralfs in U.S. Soil Taxonomy. One pit was plastic lined to serve as a control with zero seepage and to estimate evaporation from and rainfall into the pits. The three treatments that were tested in this experiment were salt effects (i.e., Na and Ca), puddling effects and algal effects. The salt treatment was to examine the differences in behaviour of the pits with predominant soil exchangeable cation being either sodium or calcium. The puddling treatment was to examine the effect of mechanically dispersed clay on reducing seepage. The algal inoculation was imposed in addition to these treatments to investigate the effects of algal growth and polymer production on reducing the seepage.

In the salt treatment, the pits were either filled with NaCl (1000 mg L^{-1}) water or saturated gypsum solution. After a week the saline waters were pumped out of the pits. The pits were then filled with relatively pure (100 mg L^{-1}) channel water and after a week again pumped out. This was repeated until the pit water had a low electrical conductivity (< 1 dS m^{-1}). Thus there were 4 pits for each cation. Two pits for each cation were puddled with a sheepsfoot roller on the bottom bed and banks so that the soil materials were well smeared and considerable amount of clay was dispersed and suspended in pit waters. A mixed algal culture (*Chlorococcum sp.* dominant species) was cultured in the laboratory in large volumes and sprayed on the surface of pits 1, 3 and 8 at the second stage i.e., after 93 days. Table 1 gives the details of the various treatments applied to the nine pits.

Seepage Measurements

The field program was commenced in January 1991. Seepage measurements were made twice a week for the 140 day duration of the experiment. Estimates of seepage were made by measuring water levels in the pits balanced against rainfall, evaporation and bore water elevation of piezometers around the pits. Water levels in the pits were determined by:

i) a gauge board with centimeter graduations and
ii) a burette with millimeter graduations.

Table 1. Treatments Applied to Pits at the Tatura Field Site.

Pit description	Stage 1 (Days 0-93)	Stage 2 (Days 94-140)
Ca-soil (algae)	Fresh water	Algae inoculation
Ca-soil (puddled)	Fresh water	Fresh water
Ca-soil (puddled+algae)	Fresh water	Algae inoculation
Ca-soil (control)	Fresh water	Fresh water
Plastic lined (water balance check)	Fresh water	Fresh water
Na-soil (high EC)	Saline water	Saline water
Na-soil (puddled)	Fresh water	Fresh water
Na-soil (puddled+algae)	Fresh water	Algae inoculation
Na-soil (control; low EC)	Fresh water	Fresh water

Rainfall data collected on the Tatura site by the Institute meteorological station was used and evaporation was estimated using type A evaporation pan to independently check the performance of the plastic lined pit (pit 5). After these readings were taken the water level within the pits was restored to a predetermined level using irrigation channel water. The volume required to refill each pit was determined using flow meters placed in the water delivery line. Once refilling was complete water levels within the pits and surrounding bores was measured again. The seepage rate per wetted area of each pit was calculated and is the volume lost to seepage per wetted area per unit time. This differs from the seepage rate per surface area which is a measure of the rate of vertical fall of the pit water level. A detailed explanation of the calculations are presented in McLeod (1993).

Preparation of Algal Inoculum and Inoculation of Pits

A culture of algae belonging to the genus *Chlorococcum* was grown in a glass container. The algal growth medium contained in 1 litre of distilled water: KNO_3, 1.5g; $K_2HPO_4.3H_2O$, 0.04g; $MgSO_4.7H_2O$, 0.08g; $CaCl_2.2H_2O$, 0.36g; Ferric citrate, 0.009g; Na_2CO_3, 0.04g. A gro-lite fluorescent light source was used to enhance the growth of the culture. Half the growth medium was changed each week, allowing a healthy culture to develop. All algal growth occurred at the base of the glass vessel displaying a benthic growth habit; no growth was observed in the bulk fluid phase. Pits 1,3 and 8 were selected for inoculation. The pits were inoculated twice (day 94 and day 133). Inoculation was accomplished by adding 4 litres of inoculant to each pit and allowing the algae to grow on the bed and banks of the pits. The inoculant contained 0.98 g L^{-1} algae on day 94 and 2.04 g L^{-1} on day 133. Measures of biological clogging (polysaccharides and chlorophyll) were made once a week, following algal inoculation as described in Ragusa et al.(1994). Control samples were taken just prior to algal inoculation (day 92) to determine background levels of chlorophyll and polysaccharide.

RESULTS AND DISCUSSION

The pits were dug in a soil type known as Goulburn clay loam (a red-brown earth; Natrixeralf in U.S. Taxonomy system). The top soil was removed in a previous experiment (Greene and Wilson 1984) conducted at this site. Therefore all the pit soils contained subsoil materials. The clay content ranged between 48-51% and the dominant clay minerals were illite & kaolinite. The organic carbon was < 0.8% and pH varied between 7.9 and 8.7. Because of earlier gypsum treatment in some spots within the pit locations, the exchangeable cation composition varied widely (for details see Greene and Wilson 1984). Therefore, the pits were made either sodic or calcic by treating initially with NaCl or gypsum solutions. The details of water chemistry in the pits after equilibrium conditions are given in Table 2.

The calcic pits were treated with gypsum solutions and hence, the water in these pits (1 to 4) had higher amounts of Ca^{2+} than Na^{+} resulting in very low sodium adsorption ratio (SAR; < 0.37). In puddled pits (2 and 3), Ca^{2+} was lower than in other two pits because of the exchange reaction of the deeper soil materials during puddling. There were changes in pH, EC and ionic concentrations after 92 days when it was assumed to have equilibrium conditions. The rise in pH above 8.2 indicates that CO_3^{2-} and HCO_3^- are in equilibrium with $Ca2^+$. In puddled pits the pH is above 8.5 and indicates the presence of small amounts of Na_2CO_3. The EC values in calcic pits are slightly higher than the threshold values (Ragusa et al. 1994) for flocculation.

Table 2. Chemical Characteristics of the Water in Different Pits.

Pit	Before equilibrium					After equilibrium				
	EC dSm^{-1}	pH	Ca^{2+} mmol L^{-1}	Na^{+} mmol L^{-1}	SAR	EC dSm^{-1}	pH	Ca^{2+} mmol L^{-1}	Na^{+} mmol L^{-1}	SAR
Calcic Pits										
1.	0.84	7.57	3.28	0.36	0.18	0.16	8.26	0.42	0.29	0.29
2.	0.30	8.06	1.26	0.35	0.29	0.22	8.97	0.68	0.36	0.34
3.	0.32	7.94	1.34	0.29	0.23	0.17	8.65	0.45	0.35	0.37
4.	0.91	7.55	4.12	0.36	0.17	0.21	8.29	0.50	0.32	0.32
Plastic Lined (Water Balance) Pit										
5.	0.19	8.00	1.00	0.32	0.33	0.29	7.92	0.66	0.82	0.67
Sodic Pits										
6.	8.33	8.00	0.54	15.4	19.9	6.42	8.13	0.46	12.0	17.0
7.	0.36	7.68	0.30	3.4	6.2	0.23	7.80	0.19	2.5	5.8
8.	0.31	7.80	0.30	3.0	5.5	0.25	7.83	0.20	2.4	5.4
9.	0.56	7.70	0.32	5.2	9.2	0.35	7.93	0.20	3.2	7.2

In sodic pits with low EC (7 to 9), concentrations of Na^{+} being higher, SAR values are above 5.4 resulting in high dispersion of clay particles in these pits. The turbid conditions in sodic pits might have caused low oxygen (suboxic) condition and hence, high $P_{carbon\ di\ oxide}$, resulting in comparatively lower pH. The EC values are slightly higher in sodic pits compared to calcic pits because of high concentrations of sodium. However, the EC values are far below the threshold values for the corresponding SAR as given in Ragusa et al.(1994) for the channel soils in the irrigation region. However, in pit 6 where saline water is used EC is far above threshold values.

The concentration of chlorophyll A did not change in sodic pits while in calcic pits there was an increase after algal inoculation (Table 3). Chlorophyll B and C declined in both sodic and calcic pits after algal inoculation. Polysaccharide concentration also did not change in sodic pits while in calcic pits there was a slight increase. These results, far from our expectations of increased production of biopolymers after algal inoculation, may be partly due to sampling error in taking soil samples from the sides of the pits and not from the bed. Most of the growth of organisms might have occurred at the bottom of the pits.

Table 3. The Average Concentration of Chlorophyll (A,B,C) and Polysaccharide in the Sodic and Calcic Pits.

Polymer produced	Sodic pits			Calcic pits		
	Day			Day		
	92	127	142	92	127	142
Chlorophyll A (μγ_γ^{-1} of soil)	13.0	14.5	13.7	21.2	32.0	31.5
Chlorophyll B (μγ_γ^{-1} of soil)	10.0	1.5	nil	8.6	nil	nil
Chlorophyll C (μγ_γ^{-1} of soil)	16.5	5.0	nil	7.0	nil	nil
Polysaccharide (mg g^{-1} of soil)	2.7	2.0	2.1	2.6	3.7	4.9

The average of seepage rates measured over a number of days in each stage are given in Table 4. In sodic pits with added fresh water, seepage was completely prevented. In fact, the seepage rates in pits 7 to 9 were negative, when the water level of plastic lined pit was taken as a base. The negative values were attributed to over-estimation of evaporation rates when using pit 5 as control. Because of the turbidity in these pits the evaporation rate might be different from the pit 5 with clear water. Measurements of temperature at the surface and bottom of the pits indicated that in turbid pits the temperature at the bottom was always lower by 2 to 4°C.

The concentration of clay in sodic pits with low EC (< 0.6 dS m^{-1}; Table 2) ranged from 8 to 12 g L^{-1}. In the puddled pits (7 and 8), initially the clay concentration was 20 g L^{-1} which after a week reduced to 12 g L^{-1}. The clay concentration above 8 g L^{-1} is effective in sealing the pores of the soil medium and reducing the water transport to zero.

These results are in accordance with the laboratory findings (Ragusa et al. 1994) which showed the influence of threshold electrolyte concentration (SAR-EC relationship) in reducing hydraulic conductivity of channel soil and the effectiveness of turbidity in reducing water permeability. This is further confirmed by the high seepage rates in pit 6 where saline water was filled and the EC fluctuated between 8.33 and 6.42 dS m^{-1}; these values are far above the threshold values estimated for the observed SAR values between 19.9 and 17.0.

Table 4. The Effect of Treatments on Seepage from the Pits.

Pit	Treatment	Days of measurement	Average seepage rate ($mm\ day^{-1}$)
1.	Ca-soil	0-92	11.5
		94-140 (algae inoculated)	8.8
2.	Ca-soil puddled	0-92	7.4
		94-140	7.3
3.	Ca-soil puddled	0-92	6.1
		94-140 (algae inoculated)	5.3
4.	Ca-soil control	0-92	8.1
		94-140	7.9
5.	Plastic lined (water balance)		0.0
6.	Na-soil high EC	0-92	6.9
		94-140	7.3
7.	Na-soil puddled	0-92	-0.9
		94-140	-0.4
8.	Na-soil puddled	0-92	-0.7
		94-140 (algae inoculated)	0.1
9.	Na-soi (low EC) control	0-92	-0.9
		94-140	-0.4

In calcic pits, SAR values are very low (< 0.37) and the EC values are closer to the threshold values resulting in clay flocculation. Even in the puddled pits, the dispersed clays flocculated with time. The seepage rate was reduced by 32% because of puddling. After puddling, the calcic clays seal the pores but not as effectively as sodic clays. Because Ca induces the formation of domains (aggregation of a few clay particles; see Rengasamy et al. 1984), micropores are generated resulting in water transmission at a reduced rate.

In sodic pits, the effect of adding algae could not be distinguished because the effective sealing produced by the dispersed clay is induced by sodicity alone. In calcic pits, algae inoculation reduced the seepage by 23% (pit 1). In puddled calcic pit (pit 3), the seepage was further reduced by 13% in addition to the effect by puddling. The production of biopolymers (chlorophyll and polysaccharide) was not found to increase in these pits as expected partly because of sampling error. A second reason may be that the inoculation may have caused a shift in the type of algae and polysaccharides which then led to reduced seepage without increasing the overall concentration of polysaccharides and chlorophyll as measured. Subsequent laboratory results (Ragusa and DeZoysa, personal communication) comparing the effectiveness of a range of organisms showed that the most effective organism in reducing seepage was not necessarily the highest polysaccharide producer.

The present study has shown the promising effect in reducing the seepage in ponds by using soil clay and algae. Low sodicity (i.e., SAR ~ 20) is sufficient to cause clay dispersion either spontaneously or by puddling. Earlier studies (Pepper and Burke 1990) have shown that high sodic soils in the banks of dams resulted in piping. This can be avoided by using low sodic conditions inside the ponds or channel and making the soils on the outside of the banks calcic. In irrigation channels the applied clay lining should have sufficient strength against the scouring effect of flowing water. Future research is necessary to test these methods in channel sections. Further, research on using specific micro-organisms and their products in strengthening the effect of clay sealing would facilitate economic ways of seepage mitigation in irrigation channels. The importance of cost in using different materials for channel sealing can be seen from the Table 5 (Rural Water Corporation, Victoria, personal communication). The position of the puddling and algal treatments in such a table now has to be determined.

The reduction in seepage rates observed in the pit experiments indicate that the successful application of one of these treatments should produce a measurable reduction in the seepage loss rates from an irrigation channel. The long term integrity of these methods and the cost of implementing, monitoring and maintaining them has to be considered in their assessment.

CONCLUSIONS

The field testing in the present experiment has shown the effectiveness of dispersed soil clay in sealing the surface soil materials in the banks and the beds of the pits (small dams). The Na-soil clays are very effective at a concentration >8g L^{-1} in sealing compared to Ca-soil clays dispersed after puddling. While Ca-soils do not produce dispersible clays by wetting, mechanical energy due to puddling induces clay dispersion. But, these clays flocculate even at comparatively low EC and form domains generating microporosity resulting in low water transmission. In Na-soils, even without puddling, spontaneous dispersion of clays reduces the seepage to zero. In calcic pits, the inoculation of algae reduced the seepage by 13 to 23% even though biopolymer (polysaccharide and chlorophyll) production was not found to increase in the present study.

Table 5. The Cost (1991 Value) and Effectiveness of Sealants for Earthen Channels.

Sealant	Thickness (mm)	Cost (\$ m^{-2})	Seepage (mm day^{-1})
Unlined (no sealing)			4-22
Chemically stabilized clay	Bed 200, Banks 150	78	0.5
Compacted, imported clay	450	15	0.5-2.0
Plastic lining	0.75	20	0-0.5
Bentonite	5	20	0.5-1.0
Concrete	100	80	0-0.5

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PRECAST PARABOLIC CANALS - REVELATION AND REVOLUTION IN PAKISTAN

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ABSTRACT

Canals lose water in several ways, not only in seepage but also leakage, dead storage and through incorrect management. This paper deals specifically with minor canals of capacity 30 cusecs and less, but most of the arguments apply to larger canals too. Past performance of lining in Pakistan and elsewhere has been dismal. Reasons are rooted in inflexible attitudes of designers, government rules and practices, corruption, and the misplaced ideals of aid agencies and financing institutions. Parabolic segmental construction offers for the first time in Pakistan the chance of constructing canals that will not disintegrate, will not leak, will greatly facilitate water management and maintenance, and will last for a hundred years. They are designed in high strength, non-reinforced concrete, and can be manufactured in small casting yards provided basic equipment for mixing, vibrating and curing is available. Engineering supervision is essential but need not be very intensive since production is concentrated in a small number of yards where quality can be easily controlled. On Swabi SCARP in North West Frontier Province of Pakistan, minor canals and watercourses serving a total of 200,000 acres are earmarked for lining over the next ten years. Four pilot projects have proved highly successful, and farmers are now demanding parabolics in preference to other methods. Their capital cost is less than more traditional alternatives, their life is longer, and private industry is gearing up for mass production.

Key Words: seepage, leakage, management, response time, dead storage, evaporation, absorption, parabolic, precast segmental lining.

CANAL WATER LOSSES

Water can be lost from the canal in several ways, including seepage, leakage, management, response time, deliberate damage, dead storage, evaporation, absorption. It can further be lost from the field as runoff or deep percolation. All of these can contribute to a build-up of salinity and/or waterlogging. If lining is to be considered as an answer to salinity, then the designers had better address all these modes and not just seepage alone.

Seepage from the canal can be heavy if the soil is permeable and the canal is unlined or badly lined. In designing a canal the aim is usually to limit the seepage loss to no more than 5 percent of the canal flow, either by lining or using a suitably impermeable soil with good compaction. In practice it is possible on small canals with high quality lining to reduce seepage loss to less than 1 percent.

However, too often the lining is badly constructed and seepage loss is high, especially where the canal runs in embankment. There have been plenty of cases when inappropriate lining has actually increased the seepage loss.

Leakage through gates, structures, and animal holes can be significant if the canal is badly designed and constructed or poorly maintained. Regular maintenance is the key to reducing leakage losses. We can differentiate between seepage and leakage, like this:

> Seepage is a natural steady process, which depends on the natural condition of the soil and occurs over a wide area.
>
> Leakage occurs at discrete points and is easily preventable or repairable.

Management Losses are usually the biggest source of water wastage, deriving from incorrect operation of the canal system. Gates and regulators left open when they should be closed can lead to massive water losses through spillage and bank overtopping. Farmers may divert excess water into local field drains if they are unable to shut down their supply.

The management of a scheme can often be hampered by deliberate damage to canals and structures caused by farmers, either in attempts to steal more water or to prevent their neighbours from getting it. This type of problem can have its root cause in social conflicts or in design faults, but can usually be nullified by sensitive management. Water lost through theft or deliberate damage is therefore treated as a management loss.

The response time of a canal system needs to be taken into account in management. Even on a small scheme it may take several hours for water to run along the length of the canal system. Any water still running after it is needed will be wasted. So gates and pumps in the upper reaches of the canal need to be closed in advance to allow the water in the canal to travel down to where it is required. Unless the canals are designed for rapid response, then water management can be extremely imprecise, especially if the delivery schedule is on demand.

Dead Storage is a volume of water that cannot be utilised. The term is more commonly applied to reservoirs in referring to the pond that remains below the lowest draw down level. Dead storage losses occur when water is let into a canal and it takes time for the dead storage of the canal to be filled before water flows along it. Unlined canals that are badly maintained can have large pockets of dead storage in which water is ponded. Due to their roughness and in order to keep velocities low to limit erosion, unlined canals have a larger cross-sectional area than lined canals, and careless maintenance can enlarge the section or over-deepen parts of the canal. The response time of an unlined canal can be seriously lengthened by its excessive dead storage. And when the canal is shut down, water will collect in pockets of dead storage and be wasted to evaporation or deep percolation. On some Warabandi operated schemes, the dead storage losses are recognised as a reason for adjusting the water charges.

An unlined canal in a clay soil will take up a lot of water into cracks in the soil, every time water is let into it after a period of drying out. This absorption loss is effectively dead storage, which has to be replenished before water can flow further along the canal. Any dry soil has a rapid infiltration rate to start with, before attaining a steady seepage rate. And the soil doesn't even need to be dry, the same thing happens in a canal that has only been closed for a day.

Absorption has a proportionately more drastic effect on small or less than design discharges than on the full supply discharge. Repeated filling and emptying of a canal, say on a short rotation of 12 hours, can result in big losses to absorption and dead storage. Filling a canal quickly is then of prime importance and is best achieved from the tail end upwards. That means keeping outlets closed until all reaches are filled and is an argument for undershot or notch type cross regulators rather than overfall weirs.

Evaporation Loss from a small canal is never very significant. It takes a very long and slow moving canal to lose much by evaporation. It can be important in the field however, if small amounts of water are applied to a young crop which does not cover the ground fully. A common problem in rehabilitation of a canal system occurs when the farmers are familiar only with basin irrigation for rice and, having dry-season water for the first time they attempt to grow a dry-foot crop. If flat basins are used for young upland row crops the water gets spread all over the place and much can be lost to evaporation from the soil surface. Irrigation water will thereby suffer an increase in its salt concentration.

Deep percolation losses occur in the field when irrigation water goes below the root zone and is lost to the plant. When applying water by surface irrigation methods, it can be difficult to get an even distribution of water across the field. In order to get enough water to the end of the field it may be necessary to put too much on at the start of the field, and excessive percolation loss is the result. Similarly, an irrigation application discharge that is too small can lead to excessive percolation loss due to the long travel time across the field. For this reason, the design duty of watercourses needs a lower limit of about half a cusec (15 litres/sec) in order to get a practical size of field application.

Runoff from over-irrigation in the field can be a serious source of wastage. Surface irrigation of dryfoot crops is often imprecise and difficult, unless the land is very carefully prepared before hand. It is quite common to find the drains running as full as the canals, so it's a good idea to look at the drains first in any inspection. If they're full then you know where to look for problems; over-irrigation or careless canal operation.

PROBLEMS TO DATE

In many countries in recent years, short life and bad quality have been the unfortunate keynote of canal construction and rehabilitation. The net effects are an expensive waste of time and money; an economic loss to the country, and often an adverse effect on the problems it was intended to solve. And many aid agencies are shying away from funding canal lining in the wake of past expensive and embarrassing failures.

It is easy enough to build a canal well enough to last a very long time, but there are many reasons why it may not be. These include shortage of money, technical naivete on the part of designers and decision makers, and deliberately built-in obsolescence.

We can categorise the problems depending on where they emanate from;- construction, design, operation, natural causes, maintenance, society, corruption, bureaucracy.

CONSTRUCTION DEFECTS

Poor Supervision

It's a common mistake on the part of funding agencies not to spend enough money on supervision. Inadequate supervision is inevitable when large numbers of small contractors are required to be supervised by a relatively small number of engineers. The paper work gets out of hand and the engineers don't have any time in the field. This often happens on big projects if it is a government strategy to generate employment for small contractors.

Unqualified Staff

A prime example is when a young, inexperienced engineer is put in charge of a project without enough supervision from more senior staff. The young engineer may not have enough force of personality to insist on good workmanship from his own artisans. Worse still, he may never acquire enough familiarity with good workmanship to be able to recognise it.

Obsolete Construction Techniques

Many government engineering departments still use designs of masonry lining dating from the days of the Raj, obvious of the fact that concrete is nowadays much cheaper and better, not to mention the fact that few modern masons have the skill to emulate their predecessors of 50 years ago.

Poor Soil Compaction

Any lining that depends on the earth banks for its support is liable to damage through settlement of badly compacted soil banks. Canal lining that has failed in this way is indicated by longitudinal cracks.

Concrete Compaction

Concrete is porous. And even more porous if it's a dry mix and not vibrated. Strength and watertightness come from good vibration. Yet it is still rare to see canal linings properly vibrated.

Concrete Curing

The process of curing cement mortar and concrete is often not fully understood by small contractors, nor regrettably by some supervising engineers. In canals the best way is to pond water in the canal soon after placing the concrete.

Poor Control of Concrete Mixing

Contractors have been known to substitute soil for sand, or clay instead of cement during concrete mixing. Even when the intent is less unscrupulous, the inclusion of dirt or organic material is difficult to avoid under the conditions of small contracts. The result is variable quality and weak concrete that breaks up rapidly under the action of soil and water. Erosion of weak concrete under the action of flowing irrigation water is common in Pakistan, where thick lining of lean mix concrete is standard practice on minors and distributaries.

DEFECTIVE DESIGN

Built-in Obsolescence

This concept seems to have crept into irrigation design from the car manufacturing industry, and for similar reasons, although in the case of irrigation it is misguided. Government irrigation departments seem to be generally unadventurous when it comes to designing irrigation schemes. They tend to rely on tried and tested standard designs which might have been originally done when labour and material costs were relatively cheaper.

Silt Deposition

Extract it, eject it, exclude it, or run it through to the fields, but don't let it settle out unless you are really prepared to dig it out every week.

Oversize Canals

It is a common mistake of inexperienced engineers to be over-conservative in estimating the roughness coefficient of a canal. The canal ends up larger than it needs to be and its response times are increased.

Unsuitable Materials

Stone masonry and fireclay bricks are often used for canal lining although they are more suited to building garden walls than hydraulic structures. The entirely inappropriate use of stone masonry is usually based on the following reasoning:

- It is labour intensive, perhaps using local small contractors in line with government policies of distributing the capital expenditure on public works over as wide a sphere of the population as possible.

- It uses low level technology, and can therefore be carried out by untrained or partially skilled local workers.

- It uses local materials, thereby reducing transport costs within the country and avoiding the need for imports.

- If it uses local resources then it must be cheap.

Most of these criteria can be met by concrete lining, and with a much greater degree of effectiveness than can be achieved by stone masonry. The contention that stone masonry requires little skill to construct is something of a fallacy;- in practice it is extremely difficult to make it watertight or crack free. It is easily disrupted by swelling soils, roots, animal activity and differential thermal expansion. During construction it is difficult to control quality. It is slow to construct. And it is always expensive.

Under-Design

Durability of canal lining is not always an important factor in present design philosophies. Early failure of lining is sometimes accepted as inevitable, and even desirable in order that future work in reconstruction may be assured. Sadly, the principles of sound engineering together with the needs of the farmer are not necessarily to the fore. Every time the canal breaks up, you need a maintenance contractor to rebuild it. If you get a percentage of every maintenance contract price, it makes good sense to design the canal to break up quickly in time for the next round of maintenance contracts, so you can rebuild it all over again.

Over-Design

If you're a designer with a vested interest in making it expensive, the same end result is achieved by simply designing things bigger and heavier than they need to be.

NATURAL CAUSES

Swelling Soils

Rigid canal linings that depend on the soil for their support are easily damaged by swelling soils. Soil movement is the biggest single factor in the destruction of stone masonry linings.

Animal Damage

Animal Damage is caused by Crabs, Rats, and Invertebrates, all of which burrow deep into canal banks and create a network of holes and tunnels. Not only are these holes a major source of direct leakage, but they contribute to collapse of the canal banks and lining. Due to the highly effective wormhole drainage system, the water is carried away as fast as it can get through the lining. The lined canal then leaks more than it did before. Cattle are a threat to the average small canal. This is one of the most compelling arguments in favour of parabolic canals. Cattle don't like walking on a curved surface.

People

Vehicles running alongside a canal can destroy it without even making contact. The downward wheel pressure has a horizontal component which exerts a strong sideways force on the canal lining. This is a common cause of failure in the rectangular brick canals of Pakistan.

Root Penetration

Weeds and grass can destroy a badly constructed canal in a single season. Stone masonry is particularly susceptible to root penetration as it effectively has a much greater length of joint, and hence potential lines of weakness, than other types of lining.

BAD MAINTENANCE

Siltation

Heavy Siltation can drastically reduce the canal capacity if you don't keep up with the cleaning programme. Silt removal must either be done manually or mechanically by digging out, or hydraulically by flushing. However the latter method is not usually possible in trapezoidal channels, especially if like stone masonry they have a rough surface.

Vegetation

The only way to control weeds and roots in very small canals is to get the farmers to clean them out regularly. Unfortunately most farmers don't see it that way. What's the point of cutting weeds that are going to grow again next week?

Masonry Repair

The repair of masonry is often difficult to organise, especially if it is under government control. Farmers may not have the necessary expertise or resources to carry out repairs themselves. Leaks in masonry may be difficult to detect and the amount of work and materials required may be difficult to estimate. It is often more effective and easier to plaster an entire canal rather than plug numerous small leaks in stone masonry.

FARMER INTERFERENCE

Unofficial Turnouts

Like most aspects of interference by farmers, the construction of unofficial outlets is a symptom either of bad system design or poor water management. Farmers often construct their own outlet structures, either by breaching the canal or by damming it and heading up the water so that it overflows the bank.

Water Charges Encourage Wastage

One of the main reasons why water charges don't work with small farmers is that they lead the farmer to think that as he's paying for the water he's entitled to waste it.

Social Quarrels and Wilful Damage

There may always be a reason for it, but bitter quarrels can arise over trivial disputes and end in physical damage that to the outsider seems out of all proportion to the alleged injustice that started it all.

Crops on Canal Banks

In Eastern Java four crops a year is not unusual, and every scrap of land is put to use. So no wonder the canal banks get covered in crops, notably Pigeon pea, pepper and legumes for fertilizer and fodder. But perhaps the worst of all is cassava, which has to be dug up when it's harvested. Marijuana, the ultimate cash crop, is another favourite for canal banks.

Theft

If it's moveable, it will be moved. The philosophy of making precast units light enough for easy handling is misguided. Always make them heavy enough to be not easily shifted.

CORRUPTION

The most damaging manifestation of corruption is the theft of key materials such as cement in order to finance bribes. This means that the construction quality suffers to the extent that concrete is too weak or too thin to do its job, and the structure falls down. This is common practice in India and Pakistan, where government engineers are obliged to obtain bribe money from contractors to pass on to their superiors. This would be less of a problem if the small local contractors were allowed to top up their tender prices by the 40 percent required for bribes. However the contractors are obliged to work to government schedules of rates which are invariably out of date and lower than the prevailing market rates for labour and materials. This means that the contractor has only two options if he wants to stay in business, he can cheat on quantities by pretending to have done more work than he actually has, or he can cheat on materials by putting too little cement into the concrete.

Parabolic segments were unpopular with Indonesian engineers, because they were too good. Since two thirds of their income derived from bribes from maintenance contractors, they would be out of pocket if the canals lasted too long.

Either way, this form of corruption is crippling the development plans of many countries, and it is compounded by the naivete of international aid agencies and financing institutions. You may not be able to stamp out corruption, but you can at least guarantee good quality of construction. The way to do that is to employ properly qualified independent supervising engineers, following long established procedures aimed solely at getting a high quality end product. It may be expensive in the short term, but it's a lot cheaper than having to rebuild everything after five years.

Institutional Inertia

The attitudes of national and international institutions and of companies engaged in planning and design are often to blame for a failed end product.

Aid agencies and financing institutions often have misinformed ideas on the requirements of an irrigation project. They tend to disregard proven engineering procedures in favour of naive ideas of social engineering, self-help, local materials, local expertise, and farmer participation. All these are laudable objectives but should not be allowed to by-pass the principles of engineering. Reluctance to publicly admit the existence of corruption leads to a false sense of security. Bribe money then has to be siphoned off secretly, causing irreparable damage to the quality of the works in the process.

Government departments are often hidebound by rules that are inflexible and outdated. Hence irrigation departments tend to adhere to old methods of design and standard procedures for tendering, estimating costs and letting contracts that may be far removed from the actual will of the market place.

Engineers involved in design are too often discouraged from trying new ideas. It is easier and often cheaper in terms of time spent in design to adhere to the old methods.

Present Practice

In NWFP of Pakistan standard practice for lining watercourses and new minors (i.e. watercourses that are being converted into minors as their capacity increases during rehabilitation) is rectangular brick, with a concrete base and plastered sides. For full profile lining of distributaries and minors it is 1:3:6 concrete up to 6 inches thick with a trapezoidal profile.

The rectangular brick canals are prone to damage from root action, soil movement and wheel loads alongside. The often quoted philosophy that they can be easily repaired by local masons misses the point. These canals need continual repair and maintenance, amounting to annual reconstruction in some places especially prone to damage from passing vehicles or animals. However, although in theory they may be easy to repair, unless money is forthcoming to pay for it they will not be repaired. And often the repair effort required approaches the effort required to build it in the first place.

Trapezoidal concrete lining is universally used, although the local practice of using low strength concrete is unusual. It is also bad practice. Firstly the concrete is easily eroded by flowing water. This is not only because the concrete is basically weak, but also because its inherent weakness is exacerbated by poor mixing and lack of vibration during placing. The extra thickness does not compensate for its lack of resistance. Secondly, concrete of such low strength (1500 psi) has no resistance to crack damage caused by bank settlement or other soil movement. And thirdly, it is prone to shrinkage cracking. Although lined canals may appear to be quite sound when flowing full, a close inspection during canal closure periods will reveal extensive damage from erosion and cracking especially at the junction of base and sides.

Introducing Parabolics

Parabolics are nothing new. They have been used extensively in many countries such as Russia, China, Malaysia, Spain, Syria and the Maghreb for many years. What is new is their gradual acceptance in developing countries such as Pakistan.

Precast units made to the full cross sectional profile of the canal have many advantages. They can be accurately made to hydraulically efficient and apparently complex profiles. They can resist lateral forces from swelling soils, and can resist shear forces induced by poorly compacted subgrades. They don't need backfill and can be made free standing, thereby reducing landtake. They can be installed by semi-skilled local contractors with minimal supervision. They can be installed in wet conditions.

Quality can be easily controlled, provided they are made in a properly equipped casting yard with basic facilities for concrete mixing, vibrating and curing. In fact, quality control is the main reason to insist on precasting. They must be properly designed, with full attention to jointing details, but if these basic rules are followed there is no better lining for small canals. Perhaps surprisingly, parabolic units are also cheaper than several more traditional methods.

Design

Field trials were carried out in Java, with parabolic segments of various strengths and various types of reinforcement, including steel fibres. The best design turned out to be mass concrete of high strength (400 kg/cm^2, or 5000 psi) without reinforcement. Reinforcement only adds to the cost, and induces internal points of weakness in the structure, especially if bonding is not good. As with all precast concrete, the biggest stresses occur in handling and laying, with lateral soil pressure an important factor. Hydrostatic forces from water in the canal are negligible. With this strength of concrete, you can cut down the thickness to 50mm or even less. Typical designs that have worked well in the field are given in Figures 1 and 2. Their hydraulic characteristics are shown in Figures 3 and 4.

Shapes - Parabolic is Best

Parabolics are a natural choice in every respect. There are no stress concentration points, so they don't break easily. The potential weak spots at the junction of base and sides are strengthened by the gradual thickening around this point. A flat base aids laying, increases strength at these weak spots, and is a natural result of inverted wet casting. Very importantly, neither cattle nor bikes will go near them. They are hydraulically good. They don't trap suspended silt and tend to be self cleaning over a wide range of discharge. They deflect the forces from swelling soils. And above all, they look beautiful!

Half round pipes of semicircular profile are theoretically the optimum shape for highest carrying capacity versus lowest material cost, but only with zero freeboard. However in practice this criteria is irrelevant because it is eclipsed by the inherent structural inefficiency of a design with constant thickness, and the increased hydraulic roughness due to the spun-casting methods usually employed. Nevertheless, half-rounds share many of the hydraulic advantages of parabolics, and because they are readily and cheaply available in most countries they can be a useful method of lining.

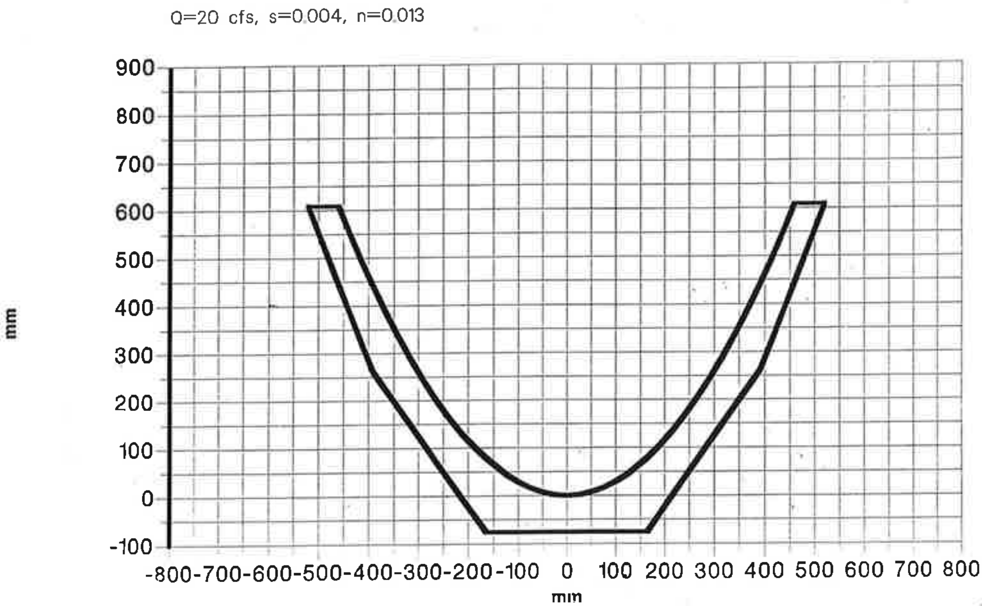


Figure 1. Precast Parabolic Segments 3'×2'.

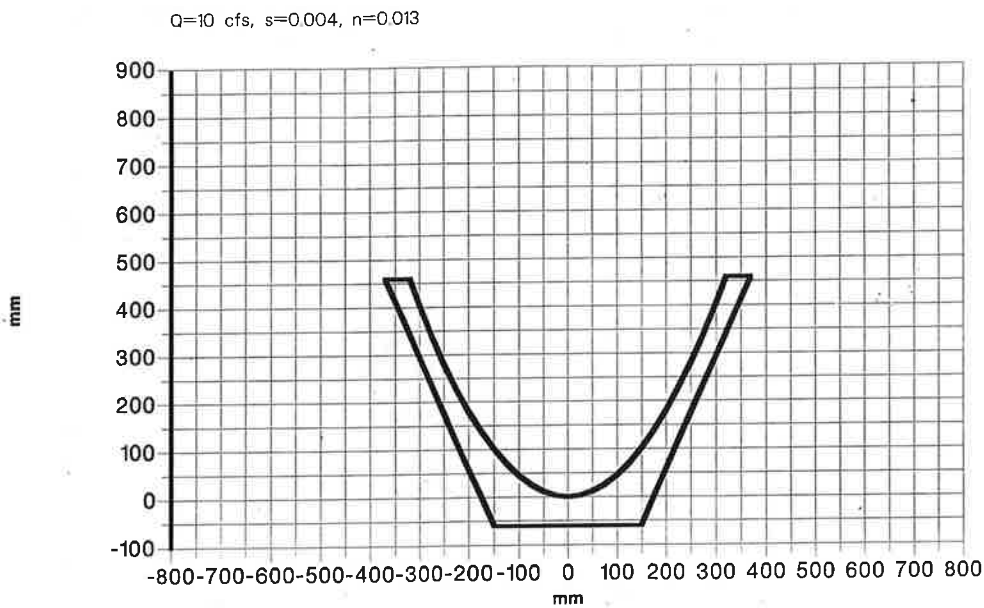
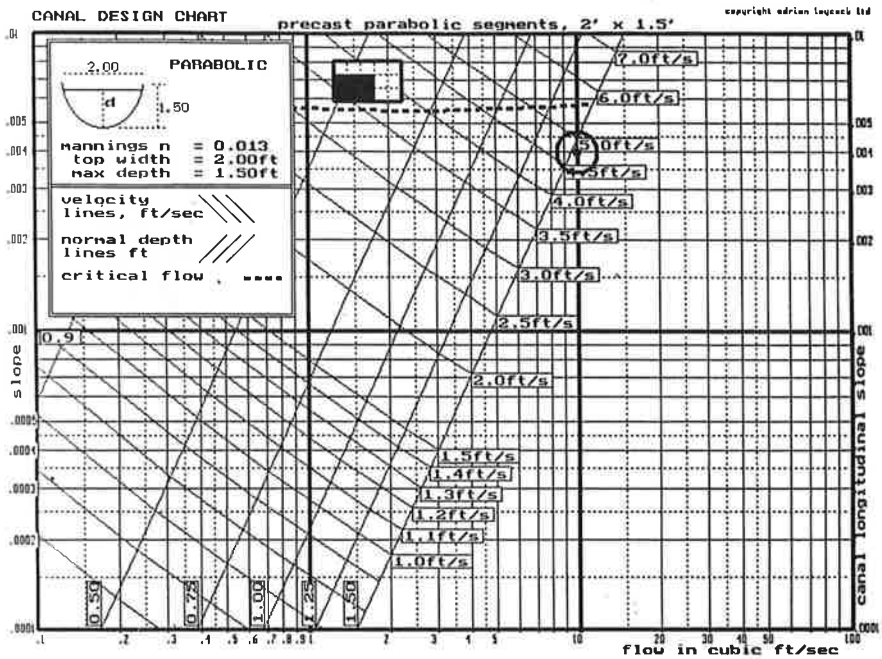


Figure 2. Precast Parabolic Segments 2'×1.5'.



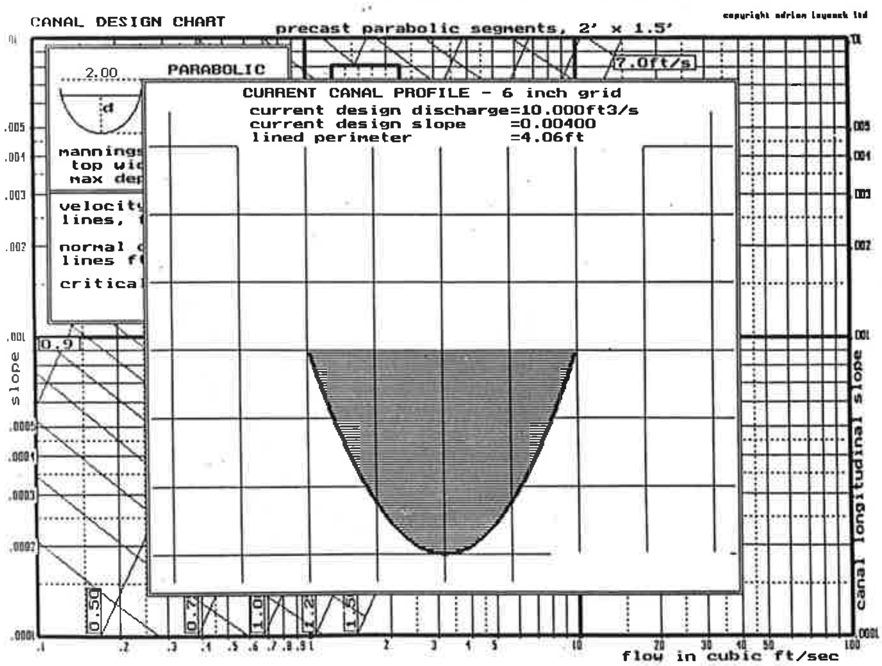
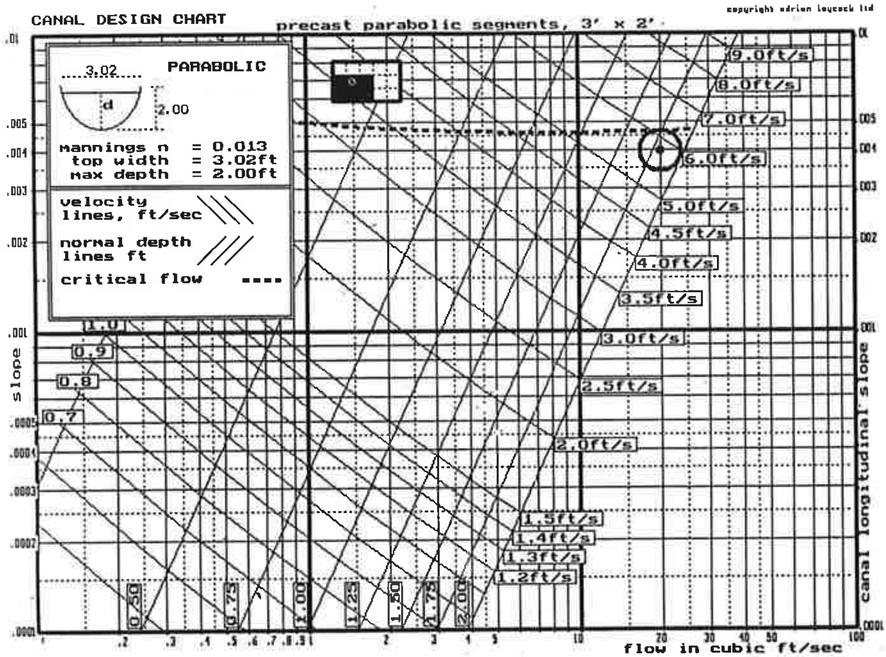


Figure 3. Precast Parabolic Segments 2'×1.5' (Canal Design Chart).



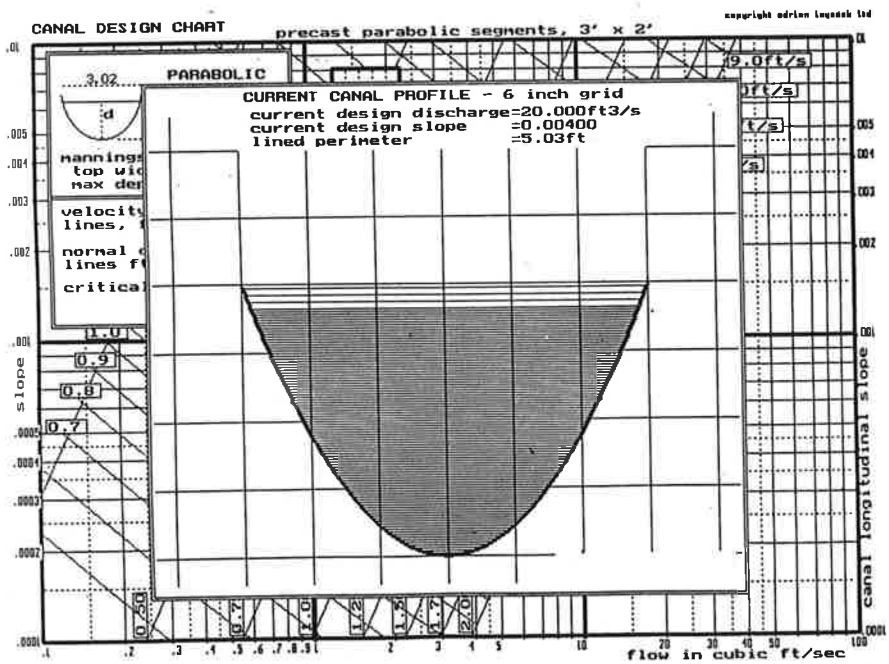


Figure 4. Precast Parabolic Segments 3'×2' (Canal Design Chart).

Trapezoidal precast units are all too frequently designed by less adventurous engineers. There is really no excuse for precasting trapezoidal or, worse, rectangular canals. It is easier and far better to make parabolics.

Size

The size of precast units has to be determined by the practicalities of handling, transport and laying. There is no theoretical limit, but if manual labour only is available, then the maximum weight for easy handling is limited to about 200kg. The minimum weight should be great enough to deter theft!

Manufacture

Some less ambitious engineers will tell you that the parabolic shape is too difficult to make. Actually it is easier to make a steel mould in the naturally flexing shape of a parabola than it is to make a trapezoidal one.

There are several ways of precasting, including wet casting with or without steam curing, hydraulic pressing, spinning, and plastering on to an inverted former.

Wet casting of inverted segments gives the best finished product. If steam curing facilities are available, 5 hours curing at 120 degrees centigrade is enough to ensure full strength. Otherwise, the moulds can only be stripped after 12 hours and the units kept wet for 4-7 days. Wet casting gives a very smooth finish and ensures a densely compacted and high strength unit.

The golden rules for making segments like this are:

- steel moulds
- proper concrete mixing
- proper vibration on a vibrating table
- proper curing

Modern mass production of small items such as building blocks or interlocking paving slabs use hydraulic pressing to force a cement/sand mixture into a steel mould. The mould is stripped immediately afterward and the curing process begun with immersion or exposure to water and, sometimes, heat in the form of steam. Pressed dry cast concrete is quick and cheap but there is a limit on the size of unit that can be precast. Trials in Java using locally available facilities in which the canal segments were cast on end had a maximum unit length of 1 meter. Their surface finish was somewhat rough due to the dry concrete mix, and vibration (provided by a horizontal vibrating table) was often uneven and incomplete near the top of the mould.

Building up is a method commonly used with thin ferro-cement and glass reinforced concrete. Layers of plaster are trowelled onto an inverted former, incorporating reinforcement at the appropriate juncture. It is easy to set up a manufacturing yard in the field. The process is labour intensive but quick, and the resulting segments are light in weight, although this is not an advantage if you are looking for something that will last a hundred years.

Jointing

The joints in precast segments are crucial. First, they must prevent leakage of water between precast segments. Second, they must restrict vertical or horizontal shearing movement between adjacent segments. Thirdly they must absorb any longitudinal shrinkage or expansion movement of the canal lining. And they should also act as location lugs for accurate and easy laying.

A scarf joint is best, having inclined overlapping faces with a gap of about 10mm for filling with fine mortar. Trials with a flexible bitumastic joint filler which would not crack under stresses from moving soils were not encouraging as it blew out under external water pressure with the canal empty. Flexible foam rubber joints have also been used as on the Maskane Project in Syria, but it doesn't last long and soon perishes or gets damaged.

In practice the vertical shearing forces even in the montmorillonite soils of East Java were found to be very small in relation to the horizontal forces on the canal sides. Mortar is therefore adequate for these joints, and although it will crack eventually it is easy to repair. High strength and plasticising additives can also enhance the durability of jointing mortar.

The lap joints should be laid in sequence so that the top lip is laid after the bottom lip of the adjacent unit is in place to ensure a clean joint surface. Most canals will be constructed from their head end down in order to get water flowing quickly or to avoid drainage water and silt being washed down slope and interfering with on-going laying work. Therefore the laps will 'point' up-slope. This may look wrong but in fact it doesn't matter at all as the hydraulic force of flowing water tends to suck out jointing material vertically and not in the direction of flow as many people think.

Laying

Laying precast units is easy because they don't require much preparation or compaction of the underlying soil. Even in wet or loose soil, they merely need a reasonably smooth and level surface to sit on and they can then be manoeuvred into position by tamping soil at the sides. In the wet soils it would have been impossible to lay any other type of lining. It's easier but not essential to lay them on a bed of sand, and a flat bottom on the segments helps.

Guide segments should be levelled in at about 20 meter intervals, then the intermediate segments boned in or laid to a string line. Backfilling of the sides should be done before jointing, to avoid disturbing newly mortared joints. Compaction doesn't need to be very thorough, its purpose is only to wedge the segments in place and stop them moving sideways. Unlike in-situ trapezoidal lining, the banks do not have to support the weight of the canal sides.

To summarise, precast parabolic segments are good because:

* high structural strength
* hydraulically efficient
* self supporting, don't need good compaction of the banks
* low land take
* quality is easily controllable
* they look nice - farmers perceive them to be good
* cattle don't go near them
* they are not expensive
* they will last for a long time

NWFP Experience

Four pilot projects are under construction on watercourses fed by the Upper and Lower Swat Canals, funded by ADB and SDC through Swabi SCARP. A total length of about 3000 feet have already been laid, with a further 4000 feet in progress. Four standard sizes of segment are in use, as shown in Figure 1. Each segment is 3 feet long, cast in an existing yard by a local manufacturer.

The first pilot project to be completed, at the Sugar Crops Research Farm, Mardan, reduced the response time over a 1000 foot length from 45 minutes to 7 minutes. The width of the channel reservation was reduced from 16 feet to 6 feet.

So enthusiastic was the farmers' response to these units that the Irrigation Department are now specifying them for all new minors on Swabi SCARP, and the Directorate of On-Farm Water Management are proposing to use them for all watercourse lining.

Costs

The capital cost of parabolic segments compares favourably with the two other methods in common use in NWFP, namely rectangular brick lining on a concrete base slab, and trapezoidal concrete lining 3" thick. However, when we consider the recurrent costs of repair, maintenance and replacement over the projected life of the project, parabolics look very attractive indeed. Parabolics can be expected to last at least 50 years without significant replacement, whereas on past performance the rectangular brick channels would need replacement or major maintenance after 10-15 years. Figure 5 shows a graph of capital costs and discounted annual costs indicating the discounted costs of parabolics to be only one fifth those of rectangular brick.

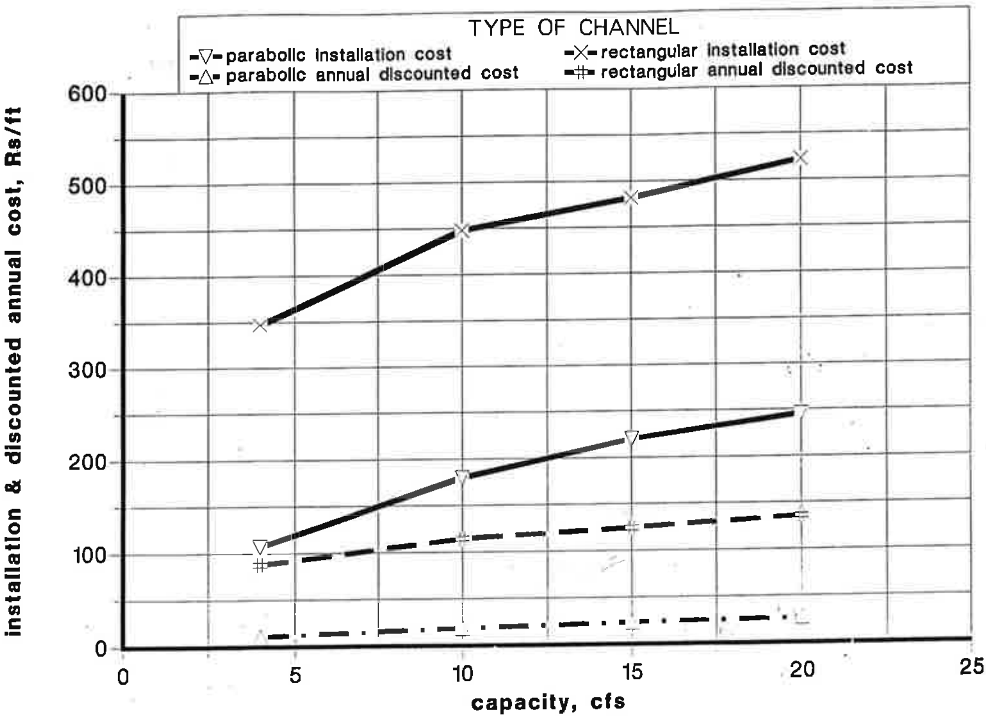


Figure 5. Comparative Costs of Canal Lining.

However, what these figures do not show is the high cost of failure. If a canal is allowed to deteriorate without being regularly repaired, the disruption caused to irrigation and resulting crop losses or crop returns foregone, together with the attendant risks of farmers' loss of confidence in the irrigation department and a breakdown in water management, can be much more costly than the canal itself. Parabolics carry a much reduced risk of failure. This in itself would be enough to justify their use.

UNLINED CANALS: THE GRATEFUL EARTH

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ABSTRACT

The limited reliable field data on seepage from lined canals is examined and alternative reasons for providing linings are discussed. The paper proposes that seepage should not be considered entirely as a negative effect since in some cases general benefits due to ground water recharge could be identified. Finally the paper proposes that alternatives to canal lining such as interceptor drains or scavenger wells provide a feasible economic solution to seepage problems. Examples of these systems on the Left Bank Outfall Drain Stage 1 Project are discussed.

THE NEED FOR LINING

A Historical Perspective

The need to transport water from its source to its point of delivery, for whatever purpose, has long generated a debate on the need to line. Canals have been lined for millennia, with great success in terms of durability and aesthetic appeal and time has resulted in the emergence of a plethora of lining methods. In more recent times canals have continued to be constructed following many of these *proven* techniques. But, why are canals lined? The need to line may conveniently be divided into two categories: obvious needs and perceived needs.

The obvious needs include those aspects which are more or less of immediate concern to both the planner and the user of a canal. They include protection against erosion, reduced maintenance, reduced section size where land constraints exist, structural safety and possibly other project specific issues.

The perceived needs are those needs which are more difficult to quantify are often associated with seepage. These include water conservation, damage to adjacent land and drainage costs resulting from increased groundwater levels.

There is little or no evidence that in the past planners have considered seepage as anything but a disadvantage to be avoided if possible. No cognisance is generally taken of the potential benefits of seepage such as the development of agriculture along the canal margins. Present experience in Pakistan suggests that seepage may be a usable resource which, in certain circumstances, could justifiably lead to the categorisation of seepage as a need. There do not appear to have been many cases such as the LBOD project in Sindh, where the adopted strategy for some reaches on major canals has been to provide specialised drainage to overcome the actual seepage rather than attempting to prevent it at source by lining.

A canal being planned on soils subject to seepage would traditionally be perceived to benefit from lining to reduce losses. The level of loss would generally be assumed to be dependent upon the type of lining adopted but would inevitably be assumed to be small. Presented in Table 1 is a summary of estimated losses, associated with rigid lining, quoted in popular texts over the past fifty years.

Table 1. Estimates Seepage Losses from Popular Texts

Source	Seepage (m/day)		
	brick/tile	**cement mortar**	**concrete**
Haigh, 1944 [1]	0.0500		
Sharma, 1944 [2]		0.0500	0.0100
Withers and Vipond, 1974	negligible		negligible
FAO, 1977			0.0300
Linsley and Franzini, 1979			0.0150
Varshney, Gupta and Gupta, 1983	0.0007		0.0004
HR, 1984	0.0300		0.0600

Notes: 1. based on the Haigh formula for a typical channel;
2. based on percentage savings from unlined canal seepage assumed to be 0.2 m/day.

The units used in this paper for representing seepage are m/day i.e. seepage rate per m^2 of wetted perimeter. These have been selected owing to their consistency of use in referenced texts rather than for any technical preference. It is important to note that when quoting seepage in m/day great care must be taken in comparing unlined to lined canal losses. The comparison should not be confused with relative volumetric losses. A lined canal carrying the same discharge as an unlined canal may have only half the wetted perimeter of the unlined canal and thus a volumetric comparison of losses would indicate a lower ratio of lined to unlined losses than quoted in this paper.

It is evident that the predicted losses are small, of the same order as evaporation losses which would be in the order of less than 0.01 m/day. In an alluvial plain with sandy or clay loam soils the seepage losses from an unlined canal would be expected to be in the order of 0.2 to 0.5 m/day. The perception that lining would create a substantial advantage is thus understandable.

It is interesting also to note that the theoretical losses presented above have, throughout recent history, been verified by field trials. As early as 1944 Sharma quotes tests carried out on the Bikaner Gang and Haveli canals. The results indicate losses of 0.03 to 0.05 m/day. More recent tests give similar results. The majority of these tests were however carried out either on newly constructed lining or under laboratory or research station conditions; the story is rather different when considering mature lining operating in a less than favourable maintenance environment.

Estimation of Seepage

Seepage losses from lined canals have historically been assumed to be minimal and , as such, the use of lining for seepage control has been an apparently attractive option when traversing permeable soils. Recent experience and research has suggested however that low levels of seepage from lined canals are only possible when a canal is new or following maintenance.

In order to establish realistic losses, actual seepage rates from rigid lining have been identified and are presented in Table 2. All the results are from field tests on mature canals.

The data indicate that the average seepage rate of mature canals is greater than sixty percent of that of a comparable unlined canal. Moreover, the average seepage rate of 0.2 m/day is five times greater than the average figure shown in Table 1 as frequently used for planning purposes.

The amount of reliable field data is limited, however, the results are confirmed by recent model studies on imperfect lining carried out by Hydraulics Research. Tests show that if 0.01 percent of the area of the lining is cracked and the groundwater table is high then the average seepage rate is the same as for unlined canals. In addition, recent numerical modelling (Wachyan and Rushton, 1987) shows that a

99 percent perfect lining can exhibit seepage equivalent to 71 percent of a comparable unlined canal.

Table 2. Estimated Seepage Losses from Mature Canals.

Source	Seepage (m/day) brick/tile/ concrete lining	Seepage (m/day) unlined canal	Ratio of lined to unlined losses (%)
Goldsmith and Makin, 1989			
Mudki Distributary	0.299	0.50	60
Kadulla Irrigation Scheme	0.120	0.13	92
Periyar Vaigai Project	0.110	0.37	30
Periyar Vaigai Project	0.080	0.18	44
Paul and Dhillon, 1989	0.492	0.50	98
Bithu, 1990	0.109	0.20	55
Average	0.200		63

Contemporary Needs

The contemporary planner of irrigation canals requires information on which to base a realistic analysis of the need to line. Indeed, in the case of rehabilitation the arguments may even be considered, if a little skeptically, as the need to unline or at least not continue to ensure the integrity of the lining.

The most difficult facet of this analysis is the determination of the benefits associated with canal seepage control. Realistic losses must be estimated, preferably based upon field measurements of similar canals in the area. The temptation to quote standard losses relevant only to new canals must be resisted strongly.

The planner will of course also be faced with the decision of how to allocate recurrent expenditure for operation, maintenance and replacement. As already mentioned, lower seepage rates are not only possible with new canals but also with well maintained lining. Great care must be taken to be realistic. The maintenance of large feeder and distributary canals is a difficult exercise limited to the canal closure period when time is too short to carry out anything but the most essential repairs. The repair of lining cracks is therefore not always a feasible option.

OLD ISSUES, NEW SOLUTIONS

To Line or Not to Line

The methodology for determining the need to line is well established and need not be reintroduced here. The methodology should however take into consideration new data and new criteria. On the subject of new data the influence of more realistic seepage rates has been discussed. The subject of new criteria may also be related to canal seepage; is there a potential advantage to be gained from the transport of water to agricultural areas where the water is transferred, by seepage, from being a surface water resource to a groundwater asset? What is leakage to the irrigation engineer is recharge to the groundwater engineer.

This suggests that the planner should also take into account all components of recharge from irrigation returns. Varshney et al (1983) quote a pattern of loss of water from the canal head as being typically:

main canals and branches	15-20%	av 17%
major and minor distributaries	6-8%	av 9%
field channels	20-22%	av 21%
field application	25-27%	av 26%
evapotranspiration by crops	28-29%	av 27%

This suggests that installing 100 percent efficient canal lining above the field level would only reduce overall losses to groundwater by one third. In contrast, the entire recharge to groundwater may be available for agricultural use as evidenced by falling water levels in parts of Punjab.

The above discussion considers the entire command area below the canal head as a single unit for general comparisons. In reality it may be worth considering discrete zones in which the dominant processes vary.

The criteria to be examined include:

- is the canal command or the zone in question short of water or irrigable land or both?

- is any zone underlain by aquifer material from which water can be or is being extracted by tubewells?

- are watertable and soil conditions alongside the major channels suitable for horizontal drains?

- is aquifer storage an important means of allowing farmers to meet daily and seasonal irrigation demands?

- is transfer of water through the aquifer an important means of supply to areas out of command of the main canal system because of elevation or dissected topography and surface drainage problems?

Consideration of the above should be in relation to how much water is leaking, how certain is the estimation and location of the principal amounts of seepage, what are the consequences of this seepage and whether or how to recover it. The following case histories illustrate the form of the analyses.

The LBOD Experience

The Project

The Left Bank Outfall Drainage project was identified during studies which started in 1962 and was recognised as being central to the improvement and sustainability of irrigated agriculture in Sindh. The major component is the Spinal Drain which during Stage 1 runs from south of Nawabshah and discharges at Shah Samando creek into the Rann of Kutch. The LBOD project includes surface and sub-surface drainage, canal remodelling and surface storage. Control of waterlogging and salinity are major objectives. The LBOD project area is shown in Figure 1.

In the case of the Left Bank Outfall Drain Stage 1 Project (LBOD) the selection of the 0.5 million ha area is such that most of the mid-command area is underlain by saline groundwater and irrigation losses have brought the watertable up to the point where additional salinisation may be occurring due to evaporation.

The area is irrigated by diversions from the River Indus at Sukkur Barrage and further expansion of irrigated agriculture is constrained by lack of water rather than land. Indeed the present state of waterlogging and salinisation is such that returns to increases in irrigation supplies are minimal unless drainage is also provided as described in Lee et al (1989). At present a US$ 750 million package of surface drains, horizontal and vertical sub-surface drainage and associated electrification, reservoir construction and irrigation remodelling and watercourse improvements is under construction. Construction prices and test results from this programme are a particularly useful source of data for consideration of seepage control at major canals.

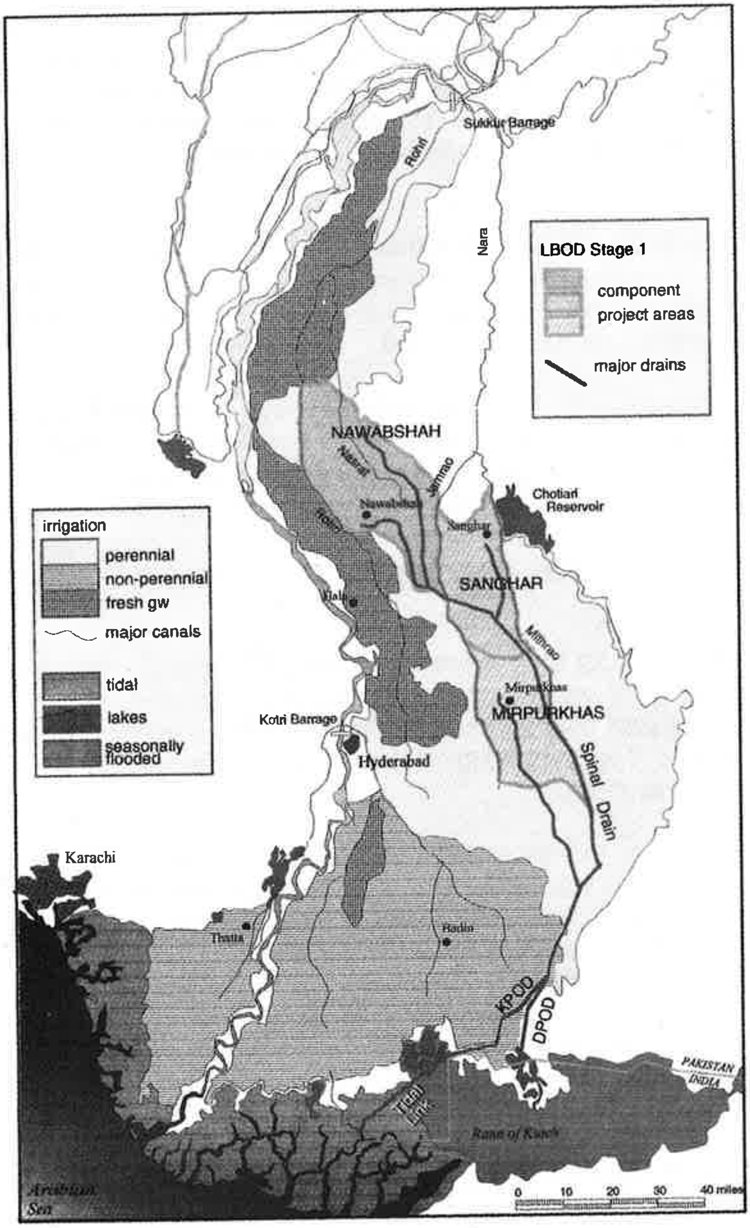

Figure 1. Project Area.

Seepage rates were originally investigated during the Lower Indus Project (HTS/MMP (1966) by a number of techniques. These included command water balance, differences in gauged inflows and outflows for individual reaches, infiltration and ponding tests during canal closures and modelling of the rise and fall of the groundwater mound at the canal over the one month closure period. It was shown how the latter data could be interpreted to give bulk permeability results providing a porosity or specific yield (Sy) was assumed for the surrounding ground, the derived permeability being fairly insensitive to the actual value of Sy chosen.

The canals are mostly in fill, the land gradients are flat and the area is mostly underlain by a relatively high permeability and uniform aquifer in which tubewells can be built at economical prices. The aquifer is overlain by fine grained alluvium on which the best irrigable soils have developed.

There is no regional fresh groundwater body available to be exploited by irrigation tubewells and which can benefit from irrigation return flows. However, there are significant lenses of fresh water floating on the regional saline water in the vicinity of the larger canals as a result of seepage. Investigations of these lenses have included both finite element modelling to simulate lens build up and water balance and surface geophysical investigations to measure the extent of the freshwater lenses.

The investigations in the LBOD area are possibly unique insofar as the water chemistry of canal seepage is radically different from that originally in the aquifer. This difference has facilitated both the model studies and the collection of field data to calibrate them. The investigations have allowed some significant conclusions to be drawn as follows:

- With the rise in overall watertables at mid-command, freshwater lenses can reach a state of dynamic equilibrium whereby the seepage loss is balanced by evaporative losses from the lens. As the lens initially spreads, the watertable rises in the strip adjacent to the canal (itself reducing seepage) and evaporative losses then increase. In the case of a new canal command with an initial depth to water of 50 feet and canal dimensions and aquifer properties typical of the Jamrao Canal, the model study showed that lens growth after 25 years was almost complete.

- Since canal geometry and mid-command water levels are measurable, the seepage rates within a reach can often be estimated by back analysis providing the extent of the lens is known.

- The vertical electric sounding technique has proved capable of fairly accurate definition of the depth to the saline interface. By carrying out soundings over a cross section of say 1 or 2 Km perpendicular to a canal the entire lens can be mapped.

- Mapping of freshwater lenses then allows the high and low seeping reaches to be identified directly with a resolution of a kilometer or less.

The recovery of the freshwater from lenses can then be tailored to the amount of water in the lenses and thus the seepage. The techniques for doing this are by use of horizontal or vertical drainage as described below.

Interceptor Drains

The LBOD interceptor drains comprise one or occasionally two buried corrugated PVC drainage pipes running parallel to the canal whose seepage is to be intercepted. The nearer drain is buried around 10 m from the toe of the canal embankment and where a second drain is installed it is usually 30 m from the near drain. The drains are fed to a pump station each of which then drains around 1700 m upstream and 1300 m downstream of the canal bank. The difference in length is a result of the gradient along the canal. The drainage effluent is generally fresh and is returned directly to the main canal with a pumping lift of around 7.5 m.

The recently completed Nawabshah Interceptor Drain contract includes around 137 km of buried pipe along the Amurji, Nasrat and Gajrah Branch canals and 54 pumping stations as shown in Figure 2. An extensive post-construction testing programme was planned to review the performance of the installed drains.

All drains are installed to a depth between 2 and 3.5 m; the minimum depth being fixed by the efficiency of interception, the maximum by the capacity of the trenching machines used. The Nawabshah contract allowed for 10 percent of the pipe to be wrapped in a filter fabric rather than the traditional gravel surround. This is potentially a more economical solution since no suitable gravel source exists within the project area.

Circular pump sumps were constructed by caisson sinking. Sumps contain two baffle walls and are fitted with twin vertical lineshaft turbine pumps operated by a motor control unit. Pump and sump sizing is such that the maximum number of motor starts is 10 per hour. Vertical lineshaft pumps were selected on the basis of ease of operation, ready availability, commonality with tubewells and discounted costs.

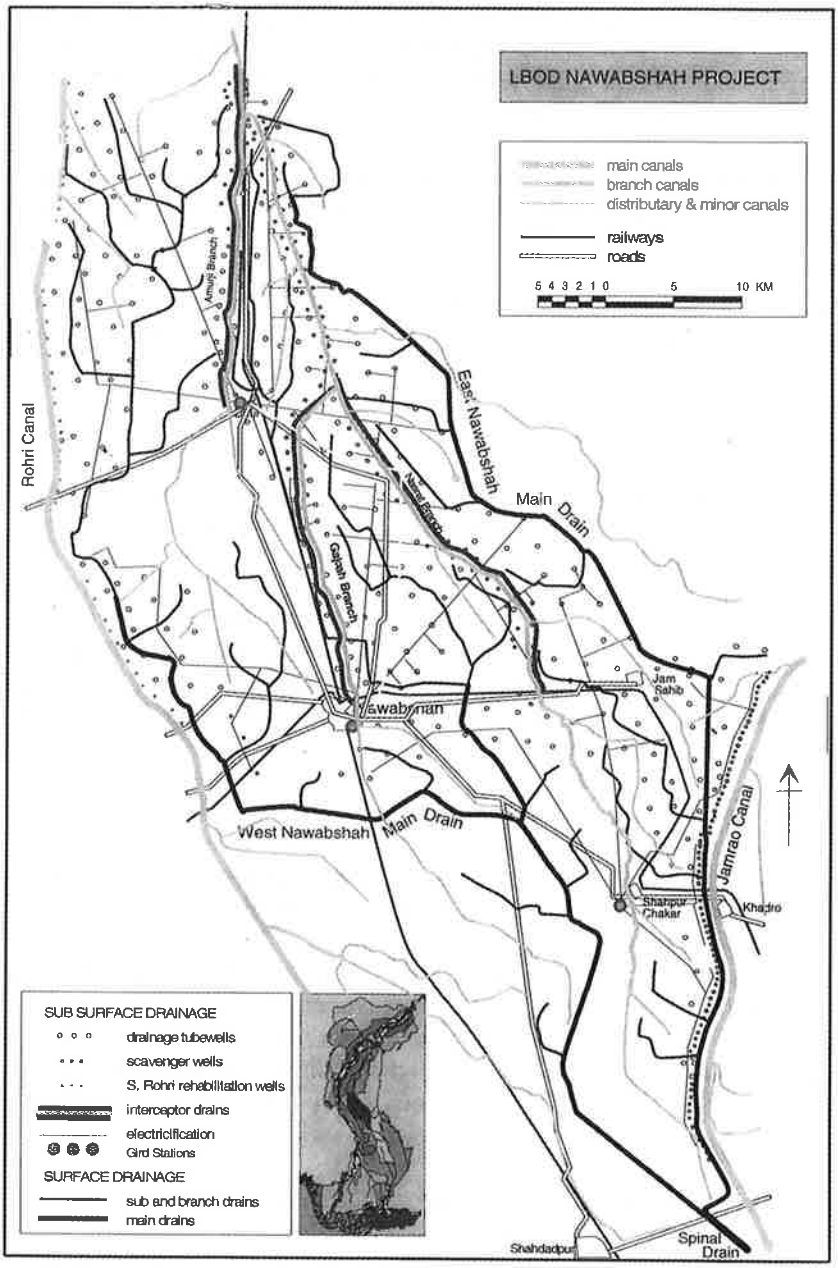

Figure 2. LBOD Nawabshah Project.

A comprehensive testing and monitoring programme was undertaken to verify the quality of construction and to calibrate the finite element model used for the design. The programme comprised:

- 10 hour discharge test at every sump to verify pump sizing and quality of construction. Discharges of individual drains in each sump were measured. Hydraulic gradient within each drain run was measured in manholes (where available) and using a bubble gauge to measure the change of water level in each end riser.

- 7 day tests on selected sumps in which the watertable response was measured in several piezometer arrays, in addition to the basic data collected during the 10 hour tests.

- Long term monitoring of pump operation and discharges at all sumps. One or two long term experiments are planned in which the watertable response would also be monitored in piezometers.

The test programme suggests the following:

- The average sump discharge after 10 hours is 63 l/s (maximum 175 l/s). The minimum was 12 l/s although this may be due to blockage.

- The yield at a sump often shows only a very gradual decline between the first hour and the end of an extended test 7 days later.

- Lowering of the watertable occurs very slowly and storage changes and reduction in saturated thickness may influence discharges for several weeks.

- Fabric wrapped drains tend to have higher entry losses than gravel surround drains.

The final use of the tests was to check the design process and in particular, calibrate the steady state finite element models used.

These models have shown how the proportion of seepage recovered increases as the drain is installed closer to the canal or deeper below ground level. These locations also increase the seepage induced from the canal (which may reach 40 percent) but this also increases the cost of the system. The design models predicted an average sump discharge of 32 l/s (max 63 l/s, min 15 l/s) and the differences with the observed yields are explained as follows:

- Operation of the mid-command drainage scheme will reduce inflows to interceptor drains. Present water levels are often higher than the boundary conditions assumed in the model.

- The simple two layer anisotropic system of the model comprises a 4m thickness of lower permeability cover to the main sand aquifer. In reality the thickness of the superficial deposits varies and some drains broke through into the main aquifer during construction. These drains have high inflow rates.

- The short term discharge exceeds the steady state discharge because of dewatering as described above.

The modelled inflow rates are very sensitive to the value of horizontal permeability used whereas the original canal seepage is more dependent on vertical permeability. Thus some of the differences between observed and predicted flows are caused by differences in horizontal permeability. It is expected that calibration can be again checked once the steady state watertable profiles are available. This would add to the comparisons above, which are based on discharge alone.

The model studies indicated that a parallel drain would often discharge at around 40 percent of a single drain at the standard offset. The field tests confirm this. The models also predicted that the recovery of original canal seepage was limited to between 30 and 50 percent for the maximum depth of installation and that the design discharge incorporates some 25 percent induced seepage. Additional mid-command or seepage tubewells would be needed to drain the remaining 70 percent to 50 percent of canal seepage.

The future LBOD Interceptor contract in Sanghar and Mirpurkhas which includes a further 170 kilometers of drains along the Jamrao and Mithrao Main canals as well as along the West, Dim and Shahu Branch canals as shown in Figures 3 and 4. Interceptor drain location is being targeted at reaches where the inflow rate will exceed 14 l/s per kilometer. Soil piezometer and surface geophysical investigations of lens geometry are being used to identify reaches of potentially low seepage.

Scavenger Wells

Scavenger wells are a variation on a standard tubewell whereby the component diameters permit two pumps to be installed. The shallow set pump skims off freshwater for irrigation use. The deep pump is set below the position of the saline interface taking into account future upconing.

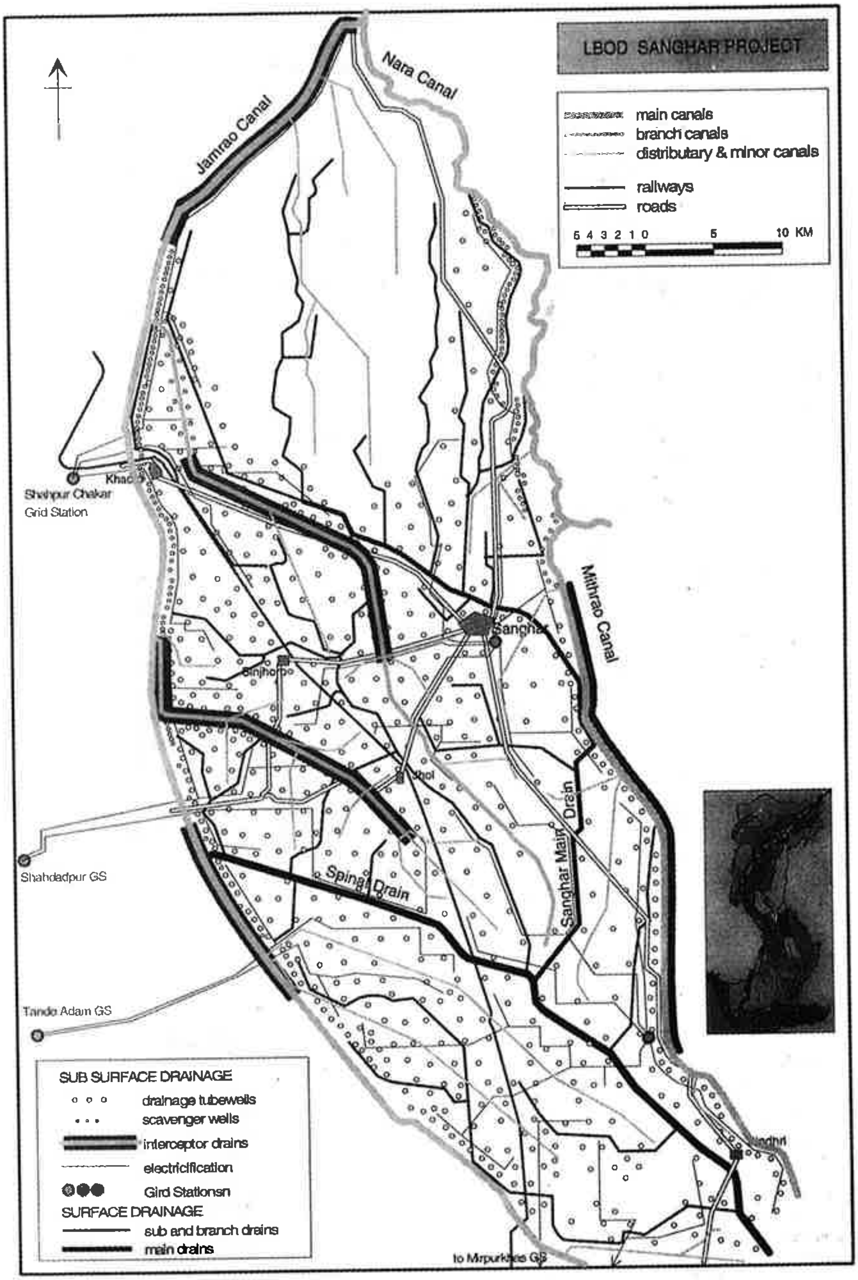

Figure 3. LBOD Sanghar Project.

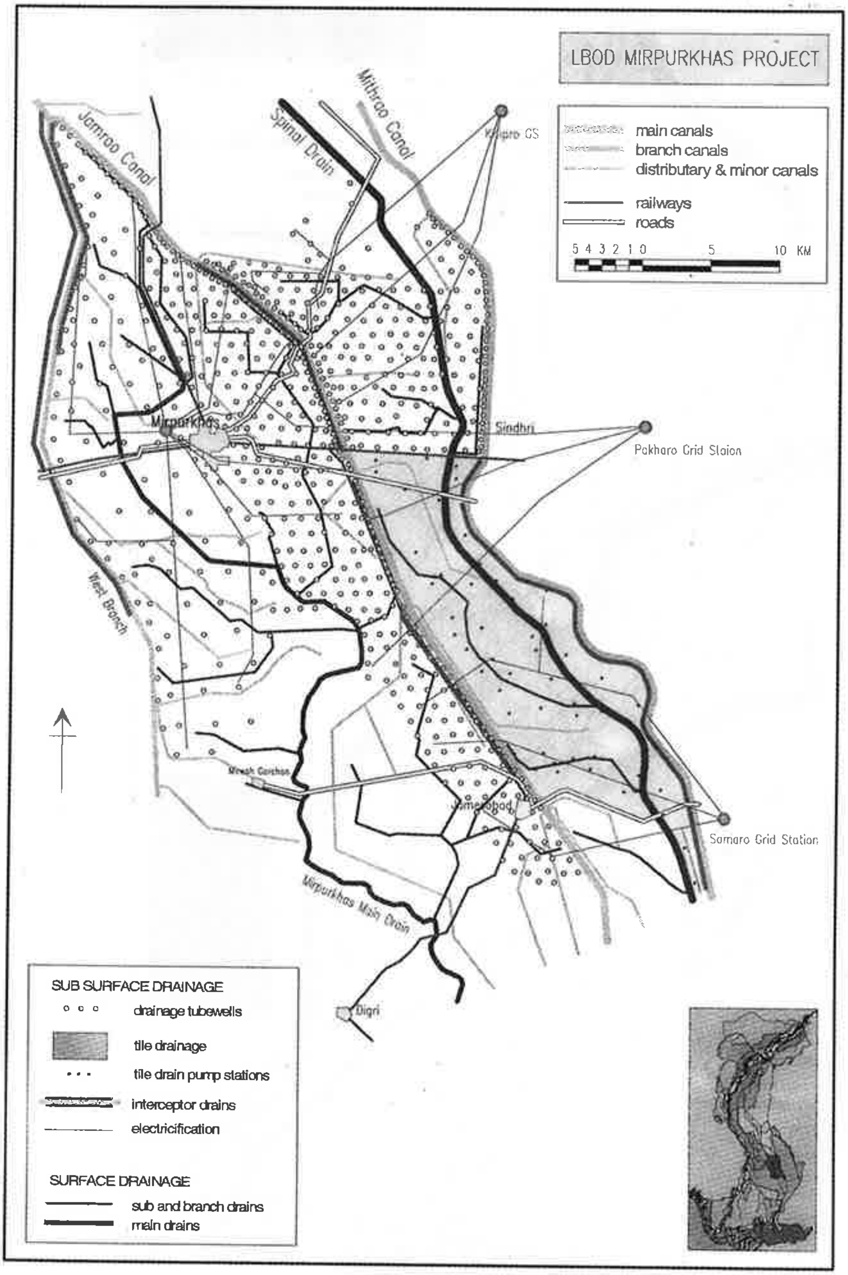

Figure 4. LBOD Mirpurkhas Project.

Detailed studies were carried out for the LBOD project in 1988-1989 through the ODA funded Scavenger Well Study and Pilot Project (SWSPP). The SWSPP has been described in the Study reports to ODA and WAPDA (GDC and BGS 1990, Kitching and Shearer 1991) and through a series of five parallel papers presented at the Saline Water Intrusion Meeting at Barcelona in 1992 (Stoner and Bakiewicz 1992, Beeson et al 1992, Williams and Price 1992, Shearer and van Wonderen 1992, van Wonderen and Jones 1992). These papers covered the historical development of the concepts, field investigations and pilot well construction and testing, simulation modelling and design criteria and implementation.

At present some 191 scavenger wells are under construction in the Nawabshah area as shown in Figure 2 along the west side of the Jamrao Canal as well as the Nasrat and Gajrah Branch canals for an estimated cost of US$ 8 million. Downhole geophysical logging and water sampling from discrete horizons indicates that the VES used to plan the wellfields gave reasonable estimates of the saline lens geometry and thus provide a basis for computing the eventual freshwater recovery. Pump testing in completed scavenger wells has proved that the hydraulic performance is more or less as expected and that the design pumping lift is likely to be around 9 m for the 56 and 42 l/s discharges.

A further 187 scavenger wells are intended in the Sanghar area as shown in Figure 3, along the east side of the Jamrao Canal and the west side of the Nara Canal.

Economic Comparison

The results of the LBOD seepage control techniques can be compared and then considered against the alternative of canal lining.

Interceptor Drains

The Nawabshah interceptor drains should provide drainage to around 60 km of canal at a capital cost of US$ 17 million. The total tested pumpage is 3.6 m^3/s of which a conservative estimate would be 60 percent was original canal seepage and 40 percent induced seepage. The net present value of the power costs over 20 years at a 7 percent discount rate and assuming 60 percent wire to water efficiency (n) and a marginal power tariff of US$ 0.05 /kWh is given by:

Power	= 9.81 Q H kW	where Q is flow m^3/s and H is lift (m)
	= 0.26 MW	
Gross power	= P/n = 0.43 MW	
NPV	= $10.6 \times 430 \times 365 \times 24 \times 0.05$ US$	
	= US$ 2.0 million	

It can be assumed that the benefit of the interceptors is solely attributable to the freshwater produced because the drainage benefit to farmers in the canal strip may not be significant. Some additional seepage control will still be necessary to dispose of the water bypassing the interceptor and the cost of this may not vary that much whether or not the interceptor option is adopted.

The interceptor drains thus recover 2.2 m^3/s of an original canal seepage of around 3.9 m^3/s. Expressed in unit terms, if the original canal seepage is around 65 l/s/km, around 70 percent of the seepage is recovered for a total NPV of US$ 0.32 million/km. This high recovery rate probably reflects a number of short term effects and may fall below 50 percent in the long term as mid command drainage becomes effective.

Scavenger Wells

The Nawabshah scavenger wells should provide drainage to around 55 km of canal at a capital cost of US $ 8 million and with an installed capacity of some 5 m^3/s of freshwater which when pumped for 14 hr/d would approximate to the original canal seepage. The operating costs, using similar assumptions to the above, also include pumping out the saline water and based on a daily operating factor of 0.6 are:

Net Power $= 9.81 \times 10 \times 9 = 0.88$ MW

Gross power $= P/n = 1.5$ MW

NPV_{op} $= 10.6 \times 1500 \times 365 \times 24 \times 0.6 \times 0.05$ US$
$=$ US$ 4.3 million

The economic analysis of scavenger wells is more complex because there are additional costs and benefits to be considered. Operation of the scavenger wells induces additional seepage from the canal but the amount of this is likely to be around 10 to 15 percent i.e., much less than for interceptors. The cost of the saline disposal system needs to be considered. One simple approach is to assume that the cost of this system is not attributable to the canal seepage but to the irrigation excess in the strip of land. Equally, the eventual expansion of the freshwater lens as the non-renewable saline water is removed will permit an eventual rise in the amount of freshwater recovered. The induced seepage has therefore been ignored from this simplified analysis.

The scavenger wells therefore intercept the 85 percent of the original seepage of 65 l/s/km at a total NPV of US$ 0.2 million /km. They therefore appear to be a cheaper option than the interceptor drain although their use is limited to areas with suitable lens development and available saline disposal.

Lining

A report on bed lining prepared for the NRA in UK suggests that the raw material cost (1990 prices) for a clay or asphalt liner would be around US$ 7.5 /m^2. Excavation and bed preparation could double this price. The Nawabshah canals have a wetted perimeter of typically 30 m and so the unit cost of lining would be at least US$ 0.45 million /km excluding contractual costs.

Although not applicable to the LBOD example it is worth noting that the actual costs of lining in UK streams affected by low flows would normally be much greater due to the need to include protection against uplift. For streams of a high environmental quality, lining work can be ecologically disruptive and extra costs are incurred in overcoming this.

CONCLUSIONS

In the prevailing environment of increasing water shortage there is a very real need to increase the efficiency of irrigation networks which frequently operate at an overall efficiency of less than 40 percent. Ways of improving efficiency include the reduction of seepage from the canal network.

The planner must however be aware of the two issues identified above:

- lining may in the long term only reduce seepage to 60 percent of that of an unlined canal; and

- water seeping from a canal is not necessarily lost but rather transferred to an alternative resource category.

Where there is no regional aquifer to benefit by recharge from canal seepage, there may still be advantages in fully mobilising the natural hydraulic impedance of the canal bed and merely recover the freshwater from the surrounding ground along the larger canals.

In water short and land surplus command areas with high water tables, it may be feasible to avoid irrigated agriculture in a strip alongside the canal and let natural evaporation dispose of the seepage. Indeed, this evaporative loss might be increased and made economically productive by suitable planting of fodder or fuel wood crops.

In conditions where recovery of freshwater has a high economic benefit, canal lining on major canals appears to be more expensive in capital terms and is no more efficient than scavenger wells if these are feasible. Lining also appears to be more expensive than interceptor drains but may be more than twice as efficient. If however the lining's effectiveness falls to say 50 percent or if the lining has to be replaced or expensively repaired, lining's apparent advantage would disappear. The final consideration has been that the construction of seepage recovery measures on LBOD has been carried out without any interruption to the irrigation supply.

ACKNOWLEDGEMENTS

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ALTERNATIVE CANAL LINING APPLICATIONS

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ABSTRACT

The purpose of this paper is to present alternative lining applications, besides the traditional linings. The most common reason for not using these alternative linings is their increased cost; however they have specialized engineered applications where they may be considered useful. These alternative linings, their specialized applications, and their potential benefits will be discussed.

INTRODUCTION

Lining irrigation canals helps to conserve water and moves water more efficiently. First, lining reduces canal seepage which prevents the loss of water from the distribution system. The loss of water is not only economically undesirable, but the lost water could seep onto adjacent lands and have added detrimental effects. Secondly, a more hydraulically efficient canal cross section can be achieved. With lining, the friction of flowing water can be reduced, or a more efficient canal prism geometry can be used. A hydraulically efficient cross section allows higher flows through a smaller channel. For new canals this will reduce the amount of right-of-way, and the associated cost of purchasing the right-of-way. For existing unlined canal systems that are upgraded by lining, a more hydraulically efficient canal cross section means potentially more capacity is not increased, this leads to more flexibility and efficiency in operation. Lining can also reduce channel erosion which will reduce the cost of maintaining the canals or channels systems.

Traditionally, the most common types of lining to achieve these benefits have been earth linings, concrete linings or PVC (polyvinyl chloride) linings used in trapezoidal shaped sections. There has been a great deal of research and application of these types of linings on Reclamation distribution systems. Reclamation publications on these traditional linings are as follows:

1. Linings for Irrigation Canals, Bureau of Reclamation, 1963 (Out of print).

2. Design Standards No.3 - Canals and Related Structure, Bureau of Reclamation, 1967.

3. Performance of Plastic Canal Linings, Report No. REC-ERC-84-1, Bureau of Reclamation, 1984.

4. Performance of Granular Soil Covers on Canals, Report No.REC-ERC-81-7, Bureau of Reclamation, 1981.

5. Bureau of Reclamation Practices for Design and Construction of Concrete Lined Canals, ASCE Conference Paper, 1975.

6. Interim Report on Canal Linings Used by the Bureau of Reclamation, Bureau of Reclamation, 1988.

Different types of alternative linings, their special applications and their potential benefits are discussed here.

SEMICIRCULAR CANALS (ZERO SLUMP CONCRETE)

Engineers in Spain have developed a method of constructing semicircular canals using zero slump concrete and have been using this method of construction successfully since 1961. Zero slump concrete is defined as concrete having a slump of less than 0.5 inch which may be achieved with a high cement content. Semicircular canals have a more hydraulically efficient cross-sectional geometry. When first examined, this might mean reduced cost for construction; however, other factors must be considered. Reclamation's report, "Evaluation of Semicircular Canals," 1984, summarizes these consideration. Before a semicircular section is selected, a feasibility study should be done comparing it with a trapezoidal section. One of the major factors in choosing a design for a semicircular section is the central angle θ (see figure 1). Semicircular sections generally have steeper side slopes than trapezoidal sections. This requires that the soil either have an adequate internal angle of friction, or that it is stabilized either by overexcavation and backfilling with selected material or chemical treatment of the soil (see "Stabilizing Soils" below). The central angle θ may also be reduced, but this reduces the hydraulic efficiency of the section. If the angle θ is reduced enough, the section can be even less efficient than a trapezoidal section. Therefore, semicircular sections require at least moderately cohesive soils and they are not adaptable to cohesionless soils.

Other advantages to be considered for semicircular sections are reduced right-of-way, possible reduction in excavation and concrete quantities, and a possible reduction in seepage area of the canal prism. Semicircular sections are stronger in uplift loads, and they may work better in areas with high groundwater; however, this might be offset by a decrease in strength for lateral loads. These advantages must be compared with the disadvantages of a possible increase in the difficulty in construction and modification in structures required. For maintenance and safety, semicircular sections would probably be more difficult to repair, and their steeper side slopes would be more dangerous to animals trapped in the canal. In general, semi-circular canals also seem to be best suited for canals with flow capacities less than 1,000 cubic feet per second.

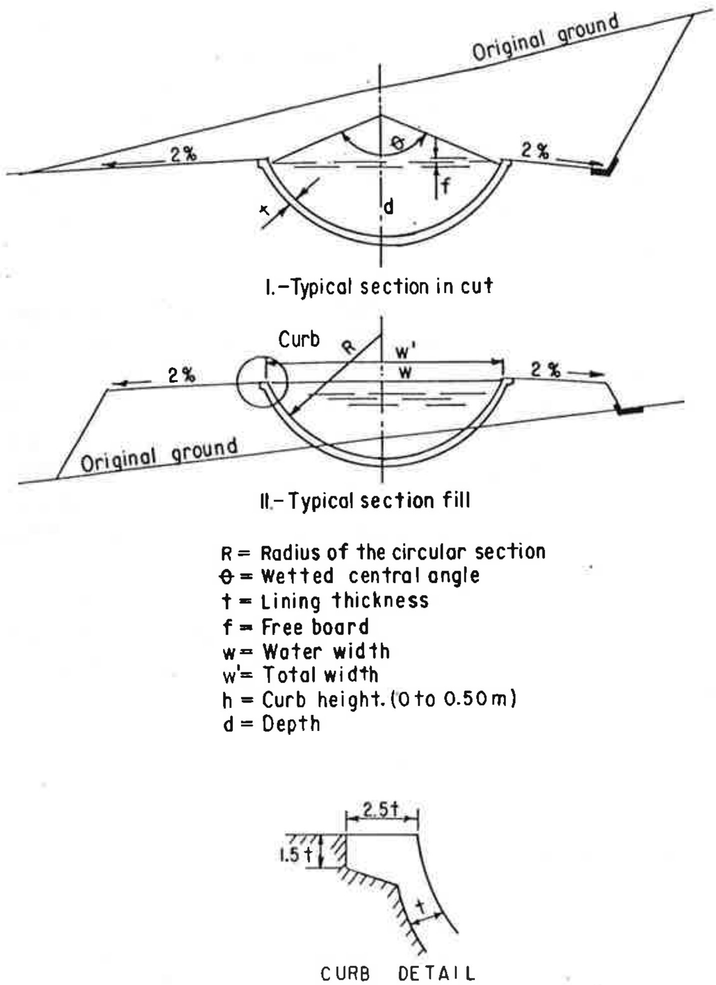


Figure 1. Semi-circular Canal Prism.

Semicircular canals have some potential cost saving advantages, and they should be studied in more detail if the initial conditions seem favourable to this method of construction.

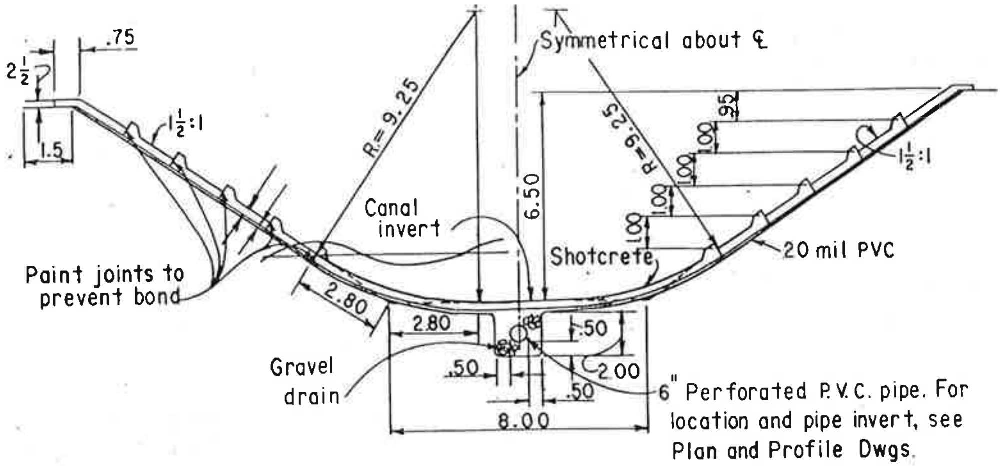
SHOTCRETE OVER GEOSYNTHETIC

The Bureau of Reclamation has designed lining for approximately one mile of canal with shotcrete over a geosynthetic on the Towoac Canal for the Dolores Project in Colorado. This method of construction was chosen for several reasons. First, one mile is too short a reach of canal to economically use a custom-built lining machine. Second, this project was a canal rehabilitation where the canal was only out of service for a short time in the year, and this method was chosen to complete this work in this short time. Finally, this area is on a steep hillside with silty material, and it must be extremely watertight to prevent any failures. An underdrain was even added to collect any seepage before it entered the embankment.

Figure 2 shows details of this type of lining. Certain construction considerations are required for the PVC. After the canal subgrade is prepared by excavating, trimming and dragging, 20-mil PVC is installed on the subgrade. A prefabricated drainage composite is installed directly on the PVC lining. The drainage composite is manufactured with the symmetrical nodal configurations on one side so that the flat backside can be installed directly on the PVC lining, and a nonwoven, needle-punched geotextile is bonded to the nodal configuration. The shotcrete is then applied to the needle-punched geotextile. This is required so the shotcrete won't slump on the 1½:1 surface. Several longitudinal open joints and transverse open joints every 30 feet are provided to allow drainage of water between the shotcrete and the PVC lining. The shotcrete is pneumatically applied concrete placed directly onto the needle-punched geotextile. It has a 3,000 pound per square inch strength, and a wet-mix process was used to better control the composition of the mixture. Only the accelerator is allowed to be added to the mixture at the nozzle. The allowable slump for the shotcrete is 3 inches.

STABILIZING SOILS

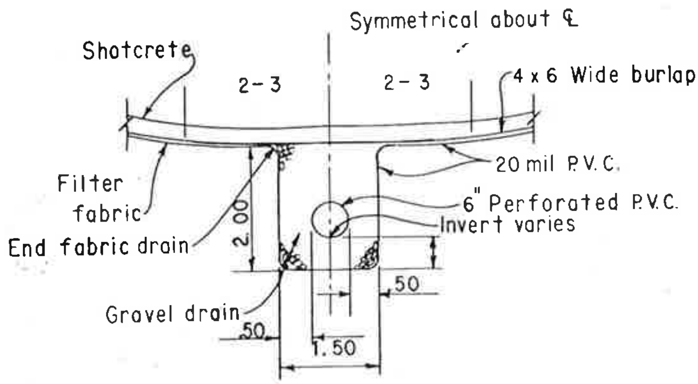
Soils are stabilized for any combination of the benefits of reduced permeability, increased tractive force, and increased stability leading to steeper side slopes on canal prisms. The most common methods of stabilizing soils are mechanical stabilization and chemical stabilization. Mechanical stabilization includes overexecavating and refiling with suitable material or addition of fine grain soils like bentonite to previous soils. Common chemicals that have been used for successfully for years to stabilize soils include resins, petrochemicals, sodium silicate, lime and Portland cement. Recently, fly ash has been tested for soil stabilization and has potential for being a cost effective method.



DETAIL OF LINING
(Dimensions in feet)

HYDRAULIC PROPERTIES

Q	A	V	r	n	s	b	d	HB	HL
345	86.43	3.99	3.16	.017	.00045	8.00	5.44	8.20	6.50



DETAIL OF DRAIN

Figure 2. Towaoc Canal - Shotcrete Canal Section.

Fly ask is a fine dust particulate material collected from flue gases of coal burning powerplants. Since it is largely a waste product, its use for stabilization is a good method of disposal. Although the chemical composition of fly ash varies, the calcium oxide (CaO) constituent is most likely to affect soil stabilization. The effectiveness of fly ash can also be increased by combination with small amounts of Portland cement, hydrated lime or calcium sulfate. Different mixtures of fly ash are required for different soils. Tests are reported in Reclamation's report "Tests for Soil Fly Ash Mixture for Soil Stabilization and Canal Lining," 1986.

Soil stabilization might be sufficient by itself as a canal liner or it might be used in conjunction with other methods of linings to increase their effectiveness.

CONCRETE OVER GEOSYNTHETIC

The combination of concrete with geosynthetics is being used to solve unique canal construction problems. In India, low density polyethylene (LDPE) film covered with brick tiles is being used successfully for canal linings. Like all hard covers, the brick protects the geosynthetic LDPE film from large animal's hoofs and from vandalism. Hand placing brick tiles, however, would be too expensive except where labour is very inexpensive. The combination of concrete with geosynthetics seems very important in placing lining in existing unlined canals that cannot be dewatered. One method tested in India is a grouted mattress lining where two layers of a specially woven synthetic fabric are positioned and filled with fine grain concrete. This sinks to the canal bed underwater as it is filled with concrete.

Another method by the Bureau of Reclamation is a slipform method on the Coachella Canal. In May of 1990, Reclamation plans to line a 1½ mile reach of the Coachella Canal with a 30 mil PVC membrane cover topped with 3 inch monolithic slipform concrete. The design flow is 1,600 cubic feet per second; however, maximum usage is usually 1,000 cubic feet per second. The section is as a prototype to evaluate environmental impacts, verify construction techniques, and refine cost estimates. A hard surface was chosen rather than earth to facilitate cleaning of the canal, and animal escape curbs are to be slipformed in the concrete (see Figure 3). The concrete mixture included antiwashout additives and chemicals are to be added to the water during placement to counteract any adverse pH. Turbidity and effects on fish and wildlife are being studied on an ongoing basis. The lining is to be placed in the early spring when flow demands and canal velocities are low. The concrete will provide a hard surface to protect the PVC, and open longitudinal joints are spaced at 1.5 feet apart to provide relief points for the hydrostatic pressure between the concrete and PVC lining.

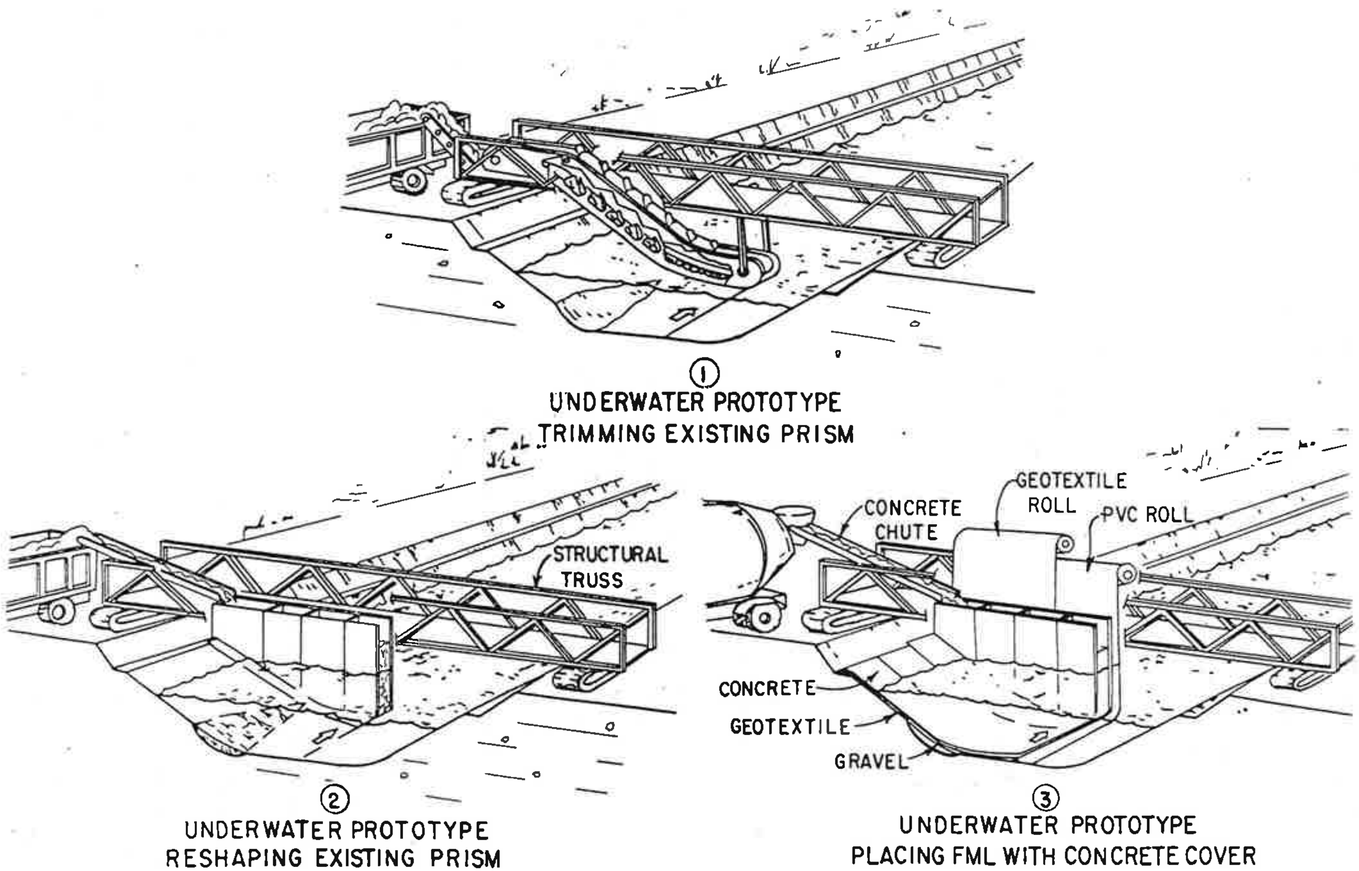


Figure 3. Conceptual drawing of underwater lining.

Some of the advantages of underwater lining of operating canals are as follows:

1. Should provide maximum seepage control.

2. No interruption of canal operations except for the brief time required to pass a turnout.

3. The new prism will provide a larger canal prism than a relocated canal and thereby provide an operational storage pool at least as large as the one presently available.

4. The need for acquiring additional or new right-of-way is not a factor to be considered.

5. The hard surface concrete lining can easily be cleaned by dredge or the side slopes scraped to remove hydrilla, moss, and silt deposition.

6. The lining will withstand relatively rapid water surface fluctuations, thereby providing desirable operating flexibility.

7. This alternative should provide a substantial cost savings over a relocated canal as it eliminates the need for a large excavation and canal bank construction effort and should shorten construction time. Overall construction traffic in the area should also be reduced.

8. When all the research and environmental studied are completed and incorporated into the designs and specifications, no adverse impacts are expected from the construction. The canal should be safer for deer and large mammals and above all, will save water.

REPAIR AND REHABILITATION

Various types of lining material have been developed that are almost exclusively used for repair and rehabilitation. These are generally specialized materials for specialized applications.

Many older canals were lined with concrete, and over time the concrete has deteriorated. When it becomes ineffective to seal cracks or replace individual panels that are damaged, the concrete can be covered with different materials to rehabilitate the canal. While the old concrete is not as watertight as desirable, it provides a hard surface subbase to support a watertight lining material. One of Reclamation's earliest experiences with this type of lining was in 1964 when 750 feet of the Contra Costa Canal was overlain with 1/32 inch butyl rubber lining. Because of shrinkage and ozone cracking, this lasted only a couple years. Recent research has shown that thick (100 mil) high density polyethelyne, hypalon (chlorosulfonated polyethylene), asphalt with plastic sprays, or reinforced bitumen could be considered for this application. However, the material chosen must be able to withstand ultraviolet sunlight rays, weathering, and large animal traffic.

One recent example of a rehabilitation process for an existing concrete lined canal was the rehabilitation of the Putah South Canal of the Solano Irrigation District in Vacaville, California. The designs for this job were prepared by Summers Engineering, Inc. of Hanford, California. In November 1989, 2 inches of shotcrete lining with 2 pounds per cubic yard of fibermesh fibers was placed over a 40 mil textured high density polyethylene, the polyethylene was attached to the existing concrete lining. Approximately 5,000 feet of canal was rehabilitated at a cost of $300,000 at approximately $18.09 per square yard ($5.85 per square yard for 40 mil textured high density polyethylene, $0.54 per square yard for fibermesh, and $11.70 per square yard for shotcrete) for the lining, which did not include surface preparation for the concrete. Since this was a small job, this price per square yard was higher than for a large job.

Many of the same materials used to overlay concrete can be used as exposed linings to rehabilitate unlined earth canals. In 1987, the Kennewick Irrigation District in Kennewick, Washington installed reinforced bitumen lining material over earth as an alternative to PVC lining covered with earth and gravel. Earlier installations of PVC had weed rooting in the cover material that will eventually have to be removed with the possibility of the cover being reduced or the PVC damaged. The reinforced bitumen lining provided a watertight lining that will hinder weed growth. While the reinforced bitumen is initially more expensive than the PVC installation, some of the cost is offset by less earthwork during installation and hopefully less maintenance cost in the future.

COST COMPARISON

Before any lining is chosen, comparative costs should be made to determine the most economical lining. This section presents a cost estimate for different types of lining material based on 1989 prices for large lengths of canals in the United States. This section should be used as a guide in determining the factors for a cost estimate. As with all cost analysis, new material, improved manufacturing or construction techniques or market forces can make the analysis change in the future. This section is, therefore, only a guide to comparative costs of different linings.

Concrete and PVC Lining

Concrete lined canal sections generally have steeper side slopes and faster velocities than PVC lined canal sections. This reduces the initial right-of-way required and the total earthwork. A comparison of the installed cost per square yard of lining material without the right-of-way and other earthwork costs is as follows:

(a) Concrete lining per square yard	
Preparing foundations for concrete lining (trimming)	$ 1.00
Furnishing and placing unreinforced concrete in canal lining 3 inches thick (.0833 cubic yards per square yard x $50 per cubic yard)	$ 4.16
Furnishing and handling cementitious material (.0235 tons per square yard x $110 per ton)	$ 2.58
Providing joints in unreinforced concrete lining (0.75 linear feet per square yard X $0.70 per linear foot)	$ 0.52
Total Cost per square yard	$ 8.26
(b) PVC lining per square yard	
Preparing subgrade for PVC lining	$ 1.00
Furnishing and placing 20-mil PVC lining	$ 1.50
Furnishing and placing gravel cover over PVC lining (12 inches thick - 0.33 cubic yards per square yard x $ 5.00 per cubic yard)	$ 1.67
Total cost per square yard	$ 4.17

These costs are based on gross area of linings. Although the reduced area of concrete will have to be determined for the specific flow conditions, it is not uncommon for concrete sections to have 60% of the area of PVC sections. Therefore the net cost of concrete is \$8.26 x 60% = \$4.95 per square yard which is comparable to the cost of PVC lining.

Concrete with Geosynthetics

Concrete with geosynthetics applications increases the cost significantly as shown in the following estimates:

(a) Shotcrete over geosynthetic per square yard	
Preparing foundations for lining	\$ 0.50
Furnishing and placing a prefabricated drainage composite	\$11.00
Furnishing and placing 20 mil PVC lining	\$ 2.50
Furnishing and placing 3 inch thick shotcrete (.0833 cubic yards per square yard x \$250 per cubic yard)	\$20.83
Furnishing and handling cementitious material (.0235 tons per square yard x \$110 per ton)	\$ 2.58
Total Cost per square yard	\$37.41
(b) Concrete over geosynthetic for underwater placement per square yard	
Preparing foundation for lining underwater	\$12.00
Furnishing and placing 30 mil PVC lining underwater	\$ 3.00
Furnishing and placing 3 inch thick concrete underwater (.0833 cubic yard per square yard x \$ 100 per cubic yard)	\$ 8.33
Furnishing and handling cementitious material (.0235 tons per square yard x \$110 per ton)	\$ 2.58
Total cost per square yard	\$25.91

Specialized Application

(a) Asphaltic concrete 3 inches thick (.0833 cubic yard per square yard x $50 per cubic yard) - This material is often sprayed with a plastic coating for durability, and if it is placed over concrete, a drainage composite is often required between the concrete and the asphalt. These can increase the cost per square yard significantly.	$ 4.16
(b) Furnishing and applying fly ash for soil stabilization (.068 tons per square yard x $50 per ton) - This assumes fly ash is mixed 25% by weight for 6 inch thickness of soil and the unit weight of soil is 120 pounds per cubic foot.	$ 3.38
(c) Furnishing and installing the following exposed linings:	
1. 100 mil high density polyethelyne per square yard	$15.00
2. .036 inch thick Hypalon reinforced 10 x 10 per square yard	$10.00
3. Reinforced bitumen canal lining per square yard	$10.00

CONCLUSION

Many types of materials and methods are available for lining canals, and careful comparisons need to be made to choose the most cost effective and engineering effective.

SESSION REPORT:
LINING ALTERNATIVES AND NEW MATERIALS

Dr. Muhammad Abid Bodla
IWASRI, Lahore, Pakistan.

This session consisted of four papers revealing the successful experiences with canal lining alternatives and new materials. The first paper "Seepage Mitigation Using Soil Clay and Algae" was presented by Michael Patto due to inability of the author P. Rengasamy to personally participate in the Workshop. The paper showed effectiveness of soil clay with and without puddling and also with and without biological action (Algae formation) to control canal seepage. The paper further elaborates testing of sodium and calcic soils testing for use as lining alternatives. It is shown that sodium clays with the concentration > 8g/l are very effective for sealing canal beds, particularly in soils having low EC values. During discussion following the presentation concerns were raised about impediments to algae growth in bed under flowing conditions. The phenomena was explained to be taking place because of increased turbidity of water as soil clay is dispersed. Responding to a question as how to maintain exchangeable sodium percentage (ESP) under flowing waters, the author informed that the methods are still under investigation.

In his paper "Precast Parabolic Canals, Revelation and Revolution in Pakistan", the author A. Laycock presented case study of these innovative lining sections from the trial canal lining installations in Swabi SCARP area in N.W.F.P. province of Pakistan. The paper shows that by introducing precast parabolic sections, the installation costs have been reduced to half of the cost of brick lined rectangular channels. The technology allows to cast high strength concrete (5000psi) portable parabolic sections with low maintenance costs. Discussion on the paper included questions regarding joints reliability, hydraulic efficiency and sediment transport capacity of these sections. The debated characteristics were believed to be improved by the author. It was generally agreed that the parabolic sections are not new in Pakistan but have been tried earlier. Further, these sections cannot be favourably considered under flat land conditions of Punjab where heavy bed loads also prevail.

The paper "Unlined Canals - The Grateful Earth" by M. Haigh presented the other side of the picture advocating that the lined irrigation networks do not attain the targeted efficiency, but pose ecological disorders on the other hand. It is suggested that interceptor drains or scavenger wells may be promoted as other alternatives to lining. Discussions following the paper reflected that the experience with interceptor drains from LBOD suggests that 40 % of the seepage water carried by interceptor drains owes merely to the seepage losses induced by installation of these drains while the remaining 60% is the original amount of seepage water.

Last paper of the session entitled "Alternative Canal Lining Applications" by Thomas E. Mitchell highlighted the USBR experiences including lining applications comprising shotcrete over geosynthetics and use of stabilized soils for lining canals. Discussions on the paper viewed these applications as providing remedies to site specific problems and indications were that implementation of these alternatives may not be economically viable under general conditions.

GROUP DISCUSSIONS:
LINING ALTERNATIVES AND NEW MATERIALS

GROUP I: NEW MATERIALS AND METHODS

Facilitator: **M. Badruddin, IIMI, Lahore, Pakistan.**
Reporter: **M. Saleem Bashir, IWASRI, Lahore, Pakistan.**

Following issues were raised and discussed by the group:

1. What are the problems posed to lining?

It was concluded after long discussion that bricks and tiles available in the market are sub-standard and cannot be used for lining now a days. In 1986 it was decided by the Irrigation Department to use concrete with ratio of 1:2:4 instead of 1:3:6 due to changed conditions such as mechanized farming and tress passing etc.

2. What factors affect the quality of lining?

The following points were spelled out:

i) Lining material
ii) Compaction of the grade and sub-grade.
iii) Soil salinity
iv) Quality control
v) Lack of proper operation and maintenance etc.

3. Is new lining material promising?

After long deliberations on the merits and de-merits of conventional and new lining material (rubber membrane), it was agreed that new material can be used as lining material provided cost is evaluated.

4. Can interceptor drains be used as alternative to lining?

From the discussion it was concluded that interceptor drains may be one of the alternatives to lining but its effectiveness has not yet been known. Although some interceptor drains have been installed in LBOD project but there is not a sufficient experience with Pakistan to decide as alternative.

GROUP II: ALTERNATIVES AND NEW MATERIALS

Facilitator: **M. Y.A. Aziz, MPWWR, Cairo, Egypt.**
Reporter: **Dr. M. Mehboob Alam, IWASRI, Lahore, Pakistan.**

Six questions were designed to cover various aspects of alternative method and materials for canal lining. Questions and the ensuing discussions are given below:

Question-1: Problems to be solved by adopting new materials and methods for Pakistan:

- Use of new materials is under testing. If they proved to be economical and effective for seepage control, can be adopted.
- Look for the availability of materials.
- New materials can be adopted in conjunction with brick/concrete not in isolation.
- Rehabilitation: either construct a parallel canal or use gabions method with membrane.
- Value of 'n' can change.
- Other alternative could be precast concrete blocks connected with wires.
- Issue: How to improve "n" in old lining.
- Methods and techniques could be differentiated keeping in view the old and new lining.

Question-2: Most promising new methods and technique:

- Laboratory and field trials be done.
- A lot of reluctance in adopting new methods.
- New techniques be started from water courses at pilot scale.

Question-3: Cost implications:

- Identify with field trials.
- With machines, cost can be reduced by improving efficiency.
- What is the cost of not doing it.

Question-4: Implications for construction and maintenance:

- Proper engineering procedures be following.
- Economic perspective is the main consideration.
- Think of other ways of putting value to things instead of economic.

Question-5: Alternatives to canal lining such as interceptors and scavenger wells:

- Need continuous power supply, may not be convenient.

Question-6: Methods in running canals

- Gabions method.

GROUP III: NEW MATERIALS AND METHODS

Facilitator: **Thomas Mitchell, USBR, Denver, CO., USA.**
Reporter: **Shafiq-ur-Rehman, IWASRI, Lahore, Pakistan.**

Question-1 What are the problems that could be solved by adopting new materials and methods?

<u>Problems discussed</u>

- Cracks specially in rigid lining.
- Joints
- Expansion cracks etc.

Conclusion

It was decided to promoted Geo-synthetic and membrane lining for the future projects to solve the above problems.

Question-2 What new methods and techniques are more promising?

Discussed	Remarks
- Pre-cast parabolic section	Siltation in Flat areas
- In-situ concrete lining	High cost
- Brick lining	Poor quality bricks
- Geo-synthetic & membrane	Easy installation

Conclusion

Use of parabolic section is recommended in areas with sufficient slops for higher velocity as no siltation occurs.

Question-3 What are cost implications?

- Due to short canal closure period it is not possible to line the canals with rigid materials. Therefore it was recommended that flexible lining should be used.

- Mechanized construction can improve efficiency.

Question-4 What are the implications for construction and maintenance?

- Geo-membrane can easily be replaced if damaged.

Question-5 Are interceptor drains and scavenger wells an alternative to lining as a water saving measure?

- Interceptor drains are not sufficient to control seepage from canals.

SESSION: REVIEW-I

Chairman: Dr. K. Sanmuganathan, Head ODU, HR Wallingford, UK.
Reporter: Dr. Muhammad Abid Bodla, IWASRI, Lahore, Pakistan.

This session provided a forum of discussion for participants of various group discussion sessions to formulate an overall review/critique of the deliberations held within various groups.

The discussions resolved upon following themes and issues;

- Effectiveness of different lining types especially concrete is largely influenced by the construction and workmanship quality in addition to watertable position and prevalent soil and other local conditions in alluvial plains of Punjab.

- Quality preparation of subgrade plays significant role in lining durability.

- An information network to disseminate and share canal lining experiences and technological improvements and innovations need be established.

- Under IPTRID program, IWASRI, Pakistan has been identified as one of the network centers on irrigation and drainage in partnership with HR Wallingford at UK, ILRI at Netherlands and CEMEGRAF at France.

- Cost effectiveness of interceptor drains as lining alternative has not been adequately investigated. Interceptor drains can still be effective in watertable control, even if not significantly improving on seepage control.

- Reasons for lining vary in different parts of the globe, ranging from water saving and improvement in hydraulic performance in China and Pakistan, for instance, to enhancing irrigation potential in Egypt.

- Some kind of 'Material Standards Authority' need be set up in the country to ensure proper vigilance on quality of construction materials.

- Constraints on time and funds coupled with prevailing defilement and corruption mainly lead to the unwanted early deterioration of canal linings in developing countries. Regulatory systems have generally not worked well in Pakistan.

While considering the lining economics, its intangible benefits should also be given due consideration. Lining does reduce drainage requirements and the resulting benefits are accounted for in 'value of water' and 'crop productivity' functions.

SESSION: REVIEW-II

Chairman: Shams-ul-Mulk, Member (Water) WAPDA, Pakistan.
Reporter: Philip Lawrence, HR Wallingford, UK.

Review-II session comprised filling in of questionnaire proformas by the Workshop participants in an attempt to list out and prioritize a set of issues pertaining to canal lining and seepage evaluations that need research and investigation. The concept was that the participants were free to assign any amount out of a fictitious US$ 10 million research funds available to issues they thought important provided of course the total does not exceed the available amount.

Research issues as presented for the above exercise during the session are listed as follows:

1. Investigate the utility, appropriateness and costs of alternatives to lining like scavenger wells, cut-off drains and other devices.

2. Gather, collate, interpret available data including costs & collect additional supplemental data to develop a reliable information base to assist planning, design and performance assessment.

3. Develop a set of criteria in the form of a checklist to scrutinise designs for their holistic nature.

4. Identify new materials and develop new methods of construction appropriate for quality management and ease of maintenance.

5. Evolve better methods of estimating seepage rates routinely from large lined and unlined canals.

6. Develop methods to analyse water balance in a region to help identify incremental contribution of canal seepage to conjunctive use, waterlogging and secondary salinisation.

7. Evolve standardised methods to monitor improvements in hydraulic performance.

8. Develop a better understanding of sediment deposition and erosion in lined sections to assist effective management of sediment entering lined canal reaches.

9. Develop possible surface treatment measures to assist rapid maintenance and seepage reduction from lined sections.

10. Train farmers to maintain watercourses.

11. Evolve viable means of controlling ground water table near lined canals to prevent structural damage.

12. Evolve and field test appropriate methods of rehabilitating lined canals passed their useful life.

13. Update and publicise design, construction, operation and maintenance manuals.

Following ranking of the research issues associated with the average amounts assigned have been determined on the basis of 48 proformas filled in by the participants during this final review session.

RANK	ISSUE	ISSUE NO.	AV. SCORE
1.	Seepage measurement	5	1.12
2.	Information base	2	1.07
3.	Alternatives to lining	1	0.97
4.	Regional model	6	0.93
5.	Rehab. of old canals	12	0.93
6.	Methods to monitor hydraulic perf.	7	0.82
7.	Sediment in lined canals	8	0.71
8.	Rapid maintenance	9	0.66
9.	Check list to scrutinise designs	3	0.58
10.	Means to control GW	11	0.57
11.	Manuals for designs/cons/O&M	13	0.49
12.	Manual to help farmers maintain water course	10	0.40
13.	Materials and methods of construction	4	0.28

CLOSING ADDRESS

Shams ul Mulk
Member (Water), WAPDA, Pakistan.

Ladies and gentlemen,

This is the time for me now to give my final concluding observations. All good things come to an end and so is this Workshop. I must congratulate all of you for holding a very successful Workshop. It has been very well structured both organizationally as well as from the stand point of the technical inputs.

The issues that you have been involved with in the past few days have been only one generic problem. But as you have seen from the list of the issues that arose out of it, a large number of issues have emerged through the Workshop deliberations that have a bearing on diverse disciplines. I am sure that we are not going to leave this Workshop with a conviction that we have resolved all the issues. But I think, as I was explaining to my colleagues just before I came into this room, there has been an awareness and each one of you especially most of those of you who work in Pakistan and our friends, colleagues and brothers from the friendly countries of Egypt and China will realize that they are faced with such problems. They will understand that these are the areas of importance and then there is a background for the multi-disciplinary problems and issues that are connected with this subject.

I will urge all the participants that they should not consider that with the conclusion of the Workshop, their pursual of the knowledge on lining has also come to an end. I will argue let us use this only as the beginning. That from now onwards having become aware of the issues and its multi-dimensions you will continue to pursue it personally and that you will also pass on this exposure which you had in these few days to your colleagues who are with you. The greater is the number of people who are becoming aware the greater will be the effect of this Workshop. I was very impressed with this proposal of networking. I think somehow or the other we should develop or indeed refine our management of these workshops in such a manner that some sort of contact is maintained with the participants even after a Workshop is over. Some lead organizations may keep their files open for a few years so that if one of the participants wants to share something or wants to contribute something or wants to gain something from the experience of his colleagues who attended that Workshop, then that facility should be made available. I think this is an issue on which perhaps Dr

Sanmuganathan will give his consideration too and perhaps he could develop some ways and means of doing that. We have a long way to go. As you have seen, we have merely identified areas in which additional work is needed and even with the best possible efforts you can never predetermine when a research problem is going to be an answer in terms of practical solutions. So it is not something you are going to know we started today and in two years you will know that we have answered to the research issues that you identified today. But I think all journeys start with the first step and I think if we take this as a first step to be followed by other steps because no journey ends up with only one step. So if all of us take this as a first step that you have taken in the direction, I think this should be a great contribution to our understanding of the issues that are relevant to the lining of canals.

For a country like Pakistan and for our colleagues and friends from Egypt and China, specifically for the developing countries, we have greater stakes because we do not have the financial resources to attempt huge investments on the things that last only for five years. We do not have the financial resources for large scale rehabilitation soon after the project has been launched. We cannot afford to pay a price for inadequate concepts, inadequate planning, inadequate detailed engineering, inadequate construction methods and inadequate operation and maintenance methods. We do not have the money to pay for it and we must understand and realize that the best investment that there ever was, was investment in quality. There is nothing better than it. Investment in quality is the most important and the most durable and the most sustainable investment that anybody can ever make. There are occasions where we are tempted not to pay a rupee more to secure ninety nine rupees that have already been spent and I think we must understand that we should not fall to such short-sighted and short lived temptations.

I am sorry, I am perhaps giving more attention to this construction quality because yesterday I had very lengthy discussions with some colleagues who had come from Venezuela from the organizations which also are building a lot many dams and have built already some big projects. They had come all the way from Caracas to exchange experiences with us that we have had in WAPDA. They wanted to share WAPDA's experience in managing, operating and maintaining large hydraulic projects and construction of large multi-purpose projects and therefore, I spent a lot of time yesterday with them sharing our experiences. And perhaps I am giving more time to this because I am also obsessed with quality. I make no hesitation, I feel no shame in admitting it and saying it. The word obsession perhaps is not a very good term but when used for quality I think all its bad things go away because it is used for such a good thing.

So, ladies and gentlemen, I thank you all for coming here. Our friends and colleagues who came from outside Pakistan, I thank you all for the endeavours that you have been through in the past few days. I thank you all for the willingness and the frankness with which you have shared experiences with each other and with which you have spoken on this forum. I thank you all for having been bound with this for four days. I wish you all safe journey back home, very successful professional successes and careers, and personal well beings.

Thank you very much.

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(18-21 OCTOBER, 1993)

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61.	Mr. Thomas Mitchell	Engineer	USBR	Federal Centre, Denver, Colo., USA	
62.	Dr. K. Sanmuganatham	Head, ODU	HR Wallingford	UK	
63.	Mr. Philip Lawrence		-do-	-do-	
64.	Ms. F. Chancellor		-do-	-do-	
65.	Mr. J. Skutch		-do-	-do-	
66.	Mr. F.A. Zaidi	Joint Secretary	MOWP	Shaheed-e-Millat Secretariat, Islamabad.	P. 822426
67.	Mr. Nasar Iqbal Dodhy	Consultant NESPAK	NESPAK	1-A, Faisal Town, Lahore.	-
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69.	Shuja Ahmed Junejo	Superintending Engineer	Irrigation & Power Department,	Government of NWFP, Peshawar.	P. 270148 P.601303 Replacement of Aziz Sheikh, Secretary, I&P
70.	Mr. Mansoob Ali Zaidi	Superintending Engineer	Derajat Canals Circles	D.G. Khan	-
71.	Mr. Abdus Salam Khan	Chief Engineer	Irrigation & Power Department	Govt. of Balochistan, Quetta.	-
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