ITIS 5

Information Techniques for Irrigation Systems

PROCEEDINGS
OF THE
FIFTH INTERNATIONAL ITIS NETWORK MEETING

AURANGABAD, MAHARASHTRA, INDIA
28/30 OCTOBER 1998

MODERNIZATION
Of
IRRIGATION SYSTEM OPERATIONS

Food and Agriculture
Organization
of the United Nations

International Water
Management Institute

Research Centre for Agriculture
& Environmental Engineering

Water and Land
Management Institute
Maharashtra

For copies, contact:
Thierry Facon
Regional Water Management Officer
FAO Regional Office for Asia and the Pacific
Maliwan Mansion, 39 Phra Athit Road
Bangkok 10200, Thailand
Tel: (662) 281 78 44
Fax: (662) 280 04 45
E-mail: Thierry.Facon@fao.org

FOREWORD

The ITIS network of about 500 professionals in irrigation (managers, designers, researchers) is an informal forum to share and exchange experiences. The focus of the ITIS network has enlarged with time, from the application of information techniques in irrigation systems to the modern management of those systems. Originally supported by the International Water Management Institute (IWMI) of Sri Lanka and Cemagref, the Research Centre for Agriculture and Environmental Engineering of France, the network now also enjoys the support of the Food and Agriculture Organization of the United Nations (FAO).

The fifth international ITIS network meeting was held from 28 to 30 October 1998 in Aurangabad, Maharashtra, India, with modernization of irrigation system operations as its theme. The meeting was jointly organized by IWMI, Cemagref, FAO and the Water & Land Management Institute (WALMI) in Maharashtra, India, and was sponsored by IWMI, Cemagref, FAO and the International Programme for Technology & Research on Irrigation & Drainage (IPTRID).

The proceedings of the meeting were originally edited by Daniel Renault, ITIS co-ordinator at IWMI, and published by the ITIS network in June 1999. The meeting confirmed the necessity to modernize irrigation system operations in the region and added to the knowledge and understanding of experiences and of the impact of modernization accrued since the FAO expert consultation on “modernization of irrigation schemes: past experiences and future options” held in Bangkok on 26-29 November 1996 (published as FAO Water Report 12).

The conclusions and recommendations made by the irrigation professionals gathered at the meeting represent a significant advance in outlining strategies for successful and appropriate irrigation modernization by focusing on the critical areas of project and programme monitoring and evaluation, understanding of capacity-building requirements and of the interaction between the technical, organizational and institutional changes implied by the modernization of irrigation schemes.

The meeting made an important contribution to the promotion of irrigation modernization. The publication of the proceedings by FAO is to make the results available to a wider audience, particularly to the concerned decision-makers, organizations and professionals of the Asian region for undertaking irrigation modernization programmes in their own countries.

PREM NATH
ASSISTANT-DIRECTOR GENERAL
AND REGIONAL REPRESENTATIVE
OF THE FAO REGIONAL OFFICE FOR ASIA AND THE PACIFIC

+

Table of contents

INTRODUCTION

BENCHMARK STUDIES ON MODERNIZATION

EXPERIENCES IN MODERNIZATION

FUTURE PERSPECTIVES ON MODERNIZATION

ANNEX

The meeting in brief

Fifty irrigation professionals gathered in Aurangabad, Maharashtra State, India, between 28 and 30 October 1998 to discuss and exchange ideas concerning the modernization of irrigation system operations. Twelve countries, and seven Indian states, were represented along with several international institutes.

This gathering was the fifth international meeting of the ITIS network, the main objective of which is to disseminate information techniques for the improvement of irrigation performance through an exchange of ideas between managers, researchers and decision-makers. The network is supported by the International Water Management Institute (IWMI), headquartered in Sri Lanka, Cemagref, the French research centre for agricultural & environmental engineering, and FAO, the Food and Agricultural Organization of the United Nations, headquartered in Rome.

The fifth ITIS meeting was hosted by the Government of Maharashtra and organized by the ITIS network and the Water and Land Management Institute (WALMI) of Maharashtra. The previous meetings were held in Sri Lanka in 1993, Pakistan in 1994, Malaysia in 1996 and Morocco in 1997.

The basic assumption underlying this meeting is that the modernization of irrigation system operations is the key to success in increasing yield and productivity in agriculture and in improving the management of limited natural resources such as water.

Aspects of modernization in India and all over the world were examined. Participants visited the Majalgaon Pilot Project of Dynamic Regulation, Maharashtra, where different forms of infrastructural modernization were recently adopted, including a remote-control system for the main canal and hydraulically controlled fixed structures for the branch canals and minors. In this project, the emphasis on flow management through more rigorous flow control substantially improved the reliability of water supply to the farmers. The project demonstrates how modernization can usefully combine high technology and simple, locally made structures.

The meeting was a great success – the participation of high-level professionals led to lively and thorough exchanges of ideas and experiences. Important recent studies concerning modernization were presented and discussed in the plenary sessions. These studies help define the directions in which the irrigation community should move to promote effective modernization.

During the debate, the discussions avoided emphasizing the technical details of modernization, which tend to be site-specific, and focused instead on generic and strategic actions that should be implemented to accompany modernization efforts and therefore increase their chances of success.

Four points were investigated in group discussions which led to the following statements:

- There is a need for a re-engineering process to rethink the operation of irrigation systems within a more global framework including a clear redefinition of the service of water, the elaboration of a consistent water management strategy at scheme level, the identification of current constraints and a vision for the future development of the scheme.
- There is a need for in-depth methods of evaluation and monitoring of the performance of pilot projects in terms of costs and benefits to increase the general awareness on modernization. There is also a need for rapid evaluation methods mixing diagnosis and the identification of a strategy for modernization at project level.
- There is a need to consider modernization without limiting it to the introduction of modern hardware and software techniques, but rather as a fundamental transformation of the management of water resources. This transformation can include changing rules and institutional structures related to water rights, water delivery services, accountability mechanisms and incentives in addition to the physical structures. The institutional dimension of the modernization should be well understood for the appropriate design of physical transformation as well as for the water management strategy.
- There is a strong need to include training and capacity-building to enhance the ability of irrigation professionals to initiate, design, organize and implement modernization measures. Training is essential to improve the skill of all professionals. In the irrigation agencies a new culture of engineers-managers should partly replace the mono-culture of engineers-builders. Consulting firms should also be strongly involved in the capacity-building programme for modern techniques in order to be able to provide appropriate services, maintenance and timely repairs in case of emergency.

The final conclusion of the meeting was that a strategy for modernization should be defined consistently at state level: the goal is to establish a framework for the best institutional arrangement, increase awareness in modernization, upgrade the knowledge of the irrigation professionals, and define methodologies for diagnosis and the selection of appropriate strategies of modernization at project level.

Summary report & conclusions of the ITIS 5 Meeting

Preamble

Irrigated agriculture already contributes more than one third of the food supply of the world population. In future this contribution will further increase in order to meet the demand of a growing population during the next millennium.

As competition with other uses of water increases dramatically, the challenge for irrigation is to produce more with less water. This goal can only be the result of a high level of performance. It will not be possible without considerable changes in the way water is managed throughout the basin, from the resources down to the end-users. The increase of water productivity in the agricultural sector and the cost-effectiveness of irrigation require changes (or adaptation) of the institutional set-up as well as of the physical infrastructure. In many situations the first crucial improvement is to enhance the reliability of the water supply to the farmers. In other situations where the reliability is already high, further improvement will result in increased flexibility of delivery.

The modernization of irrigation systems is, without doubt, one of the most promising strategies to meet these challenges and targets.

The previous ITIS meeting, held in Morocco in 1997, focussed on modern techniques for canal control. The discussions illustrated how diverse experience in canal control can be. One conclusion of the debate was that the ITIS network should do more on modernization by looking in particular at experiences in developing countries. This motivated the choice of convening the ITIS 5 meeting in Aurangabad, Maharashtra.

Modernization is not a new issue in irrigation; many forums and meetings already have focussed on it. Therefore, to avoid, as much as possible, an overlap with previous meetings, it was decided to address the general theme of modernization of irrigation system operations, with an emphasis on consistent and reliable strategies to accompany modernization interventions.

Thus the emphasis of the meeting was not on the content of modernization techniques, but on the accompanying actions which have been shown to be crucial for its success. In that regard, four more specific aspects were proposed for discussion:

- re-engineering operations;
- evaluation and monitoring of performance;
- institutional approaches; and
- training and capacity-building.

The venue and programme of the meeting

The meeting was hosted by the Government of Maharashtra and held at WALMI Aurangabad, from 28 to 30 October 1998. The meeting was honoured by the presence of Mr Deokule, former Secretary of Irrigation of the Government of Maharashtra. The concluding session was chaired by Dr Chitale, High Commissioner of Water and Irrigation of the Government of Maharashtra and former General Secretary of ICID.

Close to fifty irrigation professionals attended the meeting: 12 countries, and 7 Indian states, were represented, along with several national and international institutes. (A list of participants is given in Annex.)

Plenary sessions were organized for the first day of the meeting and keynote speakers presented benchmark studies on modernization. These were followed by debates organized with the participation of panel members.

The second day was devoted to a visit of the Pilot Project of Dynamic Control of Majalgaon. The irrigation system in Majalgoan was recently modernized with a remote control system on the main canal and fixed regulated structures (duckbill weir and baffles) on some branches and minors. This physical modernization was accompanied by institutional reforms, the creation of water user associations and the introduction of a volumetric tariff.

The third day was spent in group discussions focussing on the four themes mentioned above. In addition, special interventions were delivered by experts on the evolution of the role of funding agencies in modernization and on strategies for training and capacity-building in the field of modernization.

Highlights of the inaugural session

In his inaugural message, *Er* R.G. Kulkarni, Secretary of Irrigation of the Government of Maharashtra and President of WALMI, welcomed the holding of the meeting in Maharashtra and the high-profile professionals gathered. He expressed the wish that the meeting would identify practical solutions for modernization interventions that should culminate in the economical and more effective allocation of water to any form of end use.

In his welcoming message to the participants, Mr Pendse, Secretary of CADA, Government of Maharashtra, underlined the Maharashtra Irrigation Department's pleasure at co-hosting this important event through WALMI and suggested that these three days of deliberations would open up new possibilities, compatible with different Indian local conditions, enabling the integration of the latest information techniques for the most efficient management of irrigation systems.

Following the opening words of welcome by *Er* Suresh Shirke, Director of WALMI, Mr Ian Makin, Programme Leader on Design and Operations at IWMI, recalled to the audience that the ITIS network has recently shifted from a narrow focus on information techniques to the broader issues of modernization. This evolution is natural as the challenges faced by irrigation are not confined to the technical domain but lie within a broader managerial domain, with the goal of coping with an increasing competition for water, funds, labour and food.

In his opening statement, Thierry Facon, of FAO, stated that the modernization of irrigation system operations has become a priority for FAO and that ITIS 5 provided a timely opportunity to move in that direction. In this regard FAO would focus on developing performance methodologies enabling sound strategic choices for modernization, for evaluation of decision support systems in their daily operation and management, and for the transfer of modern control concepts. Lack of appropriate knowledge on modernization and modern techniques is considered as one of the major hurdles. Therefore, FAO has developed a concept for training and capacity-building on modernization. FAO wished to take the opportunity of the ITIS 5 meeting to present, for the first time, and discuss proposals with the irrigation community.

Thierry Rieu, of Cemagref, highlighted three main aspects which make the ITIS network original compared with others. The first is experience-sharing between managers, researchers and decision-makers. The second is the willingness (or opportunity) to undertake irrigation management, which implies considering two systems: a water system and an agricultural production system. The third lies in the assumption that irrigation systems are heterogeneous, and this is becoming more and more true as the influence of the market becomes greater on irrigation systems.

Finally, in the inaugural address of the meeting, *Er* S.T. Deokule, former Secretary of Irrigation of the Government of Maharashtra and the Chief Guest at the ITIS 5th Meeting, welcomed all the participants and delivered a vibrant plea for modernization. He recalled some of the major steps taken in the state during the last decades in this direction (see the inaugural intervention).

Summary of the plenary sessions

Modernization in India

The first plenary session focussed on modernization in India. The first presentation was made by A.B. Mandavia on the status of canal automation in India, with insights on existing or planned projects. The second presentation, by Dr Sakthivadivel, reported the results of an in-depth evaluation study of the Bhadra project in Karnataka, before, during and after rehabilitation. Papers related to these presentations are included in the Benchmark Studies section of the proceedings.

These papers were then discussed by panel members, which led to a general discussion with the audience. Dr Jesda, from Thailand, stated that it is now well understood that modernization should combine hardware, software and human-ware. He further underlined that human-ware is a key factor for success, as shown by the results from the Bhadra project. Concerning the human-ware, Mr Khalaj, from Iran, highlighted that the goal of modern delivery systems, i.e. providing the right amount of water at the right place at the right time, is becoming more and more difficult as the task becomes more complex. Therefore automation, as discussed by A.B. Mandavia, is also a means to minimize human error and to be more efficient with the help of information techniques (MIS, DSS, models, etc). The main question then is how far can we go with automation and in particular when consideration is made of the role of water user associations. The difficult issue of the transfer of high technology in less favourable environments was then identified by Dr Shirke, from India, as one major problem which has to be properly addressed.

The general debate focussed first on how to set some strategic levels of intervention with two concerns: what is the optimal size of a water user association and at what level in the network do high-tech solutions become less effective than other solutions?

One of the difficulties mentioned during the discussion was how to properly anticipate the behaviour of the end-users after modernization, when the service of water has been changed. The Bhadra project shows that a gap may exist between expected and actual behaviour. The involvement of farmers in the system operation has to be carefully discussed and planned to avoid failure.

The question of homogeneity or heterogeneity of irrigation systems is also a matter of concern. Projects based on the concept of a structured system are appropriate for homogeneous conditions but might run into problems where the environment is heterogeneous. This is certainly one of the lessons from the Bhadra study.

Another important question debated was: on what grounds should modernization be based and promoted by decision-makers? A consensus may be easily obtained on the need to document modernization experiences so as to increase the general knowledge and improve technical as well as institutional choices, but this means that at least some projects have to be initially encouraged to generate sufficient experience. This reflects the present situation in India, where very limited data from modernized projects is available. As a consequence, for some time it will be necessary for modernization to get the support of decision-makers who are aware of their long-term advantages. It is hoped that in the long term, more modernized systems will generate sufficient positive feedback to make the decision to modernize motivated by observable success rather than encouraged by outsiders.

One of the main conclusions of this session was that in-depth evaluations of the very few existing projects of modernization are crucial to start building a strategy for the planning and design of future interventions and to increase their chances of success.

Experiences in other countries

The second session focussed on experiences in other countries, with a presentation made by Professor Skogerboe on modernization in the Indus Basin, followed by a survey of modernization in 16 projects world-wide presented by Dr Charles Burt. Related papers are also included in the Benchmark Studies section.

Afterwards, Mr Alexander Reuyan, from the Philipines, raised his concern that modernization of water management should be accompanied by agricultural improvements in the use of other resources to increase yields. He also expressed his interest in seeing the rapid appraisal methodology proposed by C. Burt applied in his country for the diagnosis of irrigation systems and a better organization of modernization interventions. This point was also underlined by Dr Goddalyadda, from Sri Lanka, who reported his own experience of irrigation system classification and of diagnosis for improved methods of operation. Mr J. Plantey, of ICID, insisted on the need to have a continuing approach to modernization to cope with the ever evolving society and agricultural sector. He suggested that modernization should redefine the mission of the manager who is responsible for the service of common interest.

There was an agreement on the fact that information is a fundamental basis for modern management, and that sometimes modernization is nothing but going back to the basic activities of managers. At the other end of the spectrum of modernization, the question of high technology should be analysed less in terms of sophistication than in terms of profitability.

The question of how the movement toward modernization should be initiated was largely addressed during the discussion. Some believed that farmer organizations should be created first to provide the major thrust for modernization. Some argued that organizing farmers is not obviously a good route, especially when the service is poor, and that improvement in the service should take place while or before creating water user associations in order to generate a win-win dynamic situation. Everyone agreed that the water user associations and the service provider should be directly accountable to each other. Successful water user associations are often business-oriented and rely heavily on proper legislation, well-established water rights, and efficient law enforcement. Furthermore, local management is often successful in situations where there is a long history of rural organizations, as in Nepal for example. It was also felt that it is not so much the size of an irrigation system which matters but more its complexity. Large irrigation systems can always be split into subsystems and properly analysed at that level. Obviously this is a requirement for Pakistan, which has the largest continuous irrigated agriculture in the world.

Key interventions were also made during the meeting by Hervé Plusquellec, who presented the point of view of a funding agency and particularly the evolution of the role of the World Bank (details are given in a paper of the author in the proceedings). The policy of the Bank for modernization and irrigation has evolved from a site-specific project approach in the 1960s to a comprehensive-package approach in the 1970s aiming at simultaneously addressing many infrastructural elements (water, roads, schooling, health, etc) and on to a water-resources management policy in the 1990s. Modernization is now seen, discussed, planned and supported by the Bank at state (national) level. Therefore it is crucial for professionals to define consistent state strategies for modernization before addressing site-specific projects.

Group discussion output

Working group 1: re-engineering

CHAIRMAN: P.W. VEHMEYER – CO-CHAIRMAN: K.V.G.K. RAO

Statement proposed to the group: *Before being thought in terms of hardware and software, the re-engineering of irrigation system operations needs to be thought within a more global framework, including a clear redefinition of the service of water, the elaboration of a consistent water management strategy at scheme level, the identification of current constraints and a vision for the future development of the scheme.*

The group agreed with this statement, but added that the clear redefinition of the service of water needed to be done keeping in mind local circumstances and that not only current constraints, but also future constraints should be taken into account. Furthermore, both the group and the plenary session agreed that re-engineering itself is not only a question of putting hardware and software in place, but also consists in providing for an adequate institutional set-up to manage the operations.

The group started its discussion by addressing the question of the circumstances in which an irrigation system needs to be re-engineered. Generally there is a need to re-engineer when either the present system of operations is malfunctioning or a change in policy is affecting the operation of the irrigation system.

A change of policy is the result of a change in the perspectives policymakers have on how the irrigation system would be able to function in the most appropriate way. It comes forth from a change in the socio-political and economical environment.

A particular policy brings with it certain targets for the operation of the irrigation system. Performance indicators illustrate the way an irrigation system meets defined targets. In the case of a change in policy, the targets will also change. Accordingly the performance of the irrigation system will fall short of the newly defined targets, necessitating a re-engineering of the irrigation system operation.

As the statement says, the re-engineering of irrigation system operations needs to be thought of within a global framework. Part of that global framework is an understanding of the process, which led to the requirement for re-engineering in the first place.

One should also be aware of the different parties involved in the operations of an irrigation system and of their respective interests. In general terms the involved parties are the policymakers, the water users and the service providers. The point was made that re-engineering is a process, which is initiated by a change of policy coming from the policymakers. However, it might well be that this new policy is not in the interest of the individual water users. This needs to be recognized in the re-engineering process.

The working group elaborated on the main constraints which should be taken into account when re-engineering an irrigation system. The first point made was that, as a result of broadening the scope of things taken into account in re-engineering, the number of constraints also increases. The types of constraints include:

- limited availability of data;
- physical constraints related to the infrastructure already in place;
- financial constraints for changes;
- local circumstances; and
- future constraints, such as salinization, water-logging and excess sediment entry into the canal system.

Finally there was some discussion about the need for the use of appropriate technology, i.e. technology which meets the skills of the local staff. Although this is an important point for consideration, it should not be separated from an analysis of the general interest in implementation of more modern hardware and software for the irrigation system operations.

Working group 2: evaluation

CHAIRMAN: A.K. CHAKRABOTI – CO-CHAIRMAN: T. RIEU

Statement proposed to the group: *The required efforts of modernization of irrigation are huge in terms of the command area and of the required financial resources. It is therefore crucial to identify, for each project, the most appropriate alternative, i.e. the best cost-effective solution. To reach this stage it is essential that awareness of the on-going modernization efforts should be increased and disseminated at the proper scale (state, national, regional). This awareness should be based on reliable procedures of performance evaluation and on trustworthy diagnosis.*

Regarding the performance evaluation, three points were identified as important:

- On a project scale it is necessary to carry out pre-, mid-term and post-evaluation of the project.
- On a larger scale it is necessary to prioritize the projects for modernization and for evaluation.
- To monitor performance it is necessary to start from the objectives of the modernization and focus on the specific performance indicators that monitor the progress made in achieving these objectives:

- crop productivity indicators,
- water use efficiency,
- hydraulic system,
- financial performance and
- process indicators (social, economic, management, institutionalised).

To assess irrigation systems and modernization procedures, the group felt that two main types of methods are complementary:

- Rapid Appraisal of Performance, which focuses more on the process, on system performance indicators, and on how the overall management is organized. The method is useful in identifying the key points of the performance that should be improved, the constraints that should be relaxed and finally the strategy that should be pursued to modernize that particular system. It is an essential method for the design of interventions.
- In-Depth Study, which, in the particular case of modernization, aims at documenting the gains achieved after the intervention and identifying the causes of success and failure in all processes. In-depth study is fundamental for increasing the general knowledge concerning the modernization of irrigation systems at the state level, and for identifying obstacles to be overcome to increase the chances of success.

In both cases the issues of accuracy and reliability of data are fundamental to the effectiveness, though not very simple to handle.

Rapid appraisal of performance and in-depth study should not be used at too large a scale, for many reasons. Primarily these procedures assume a homogeneous system, and as the scale increases, an irrigation system tends to be more heterogeneous. They have therefore to be undertaken on a small-scale basis: in-depth study on representative areas and on a pilot-project basis and rapid appraisal of performance on each project proposed for modernization.

These methods are complementary in the sense that rapid appraisal can be more easily duplicated within a large project and can be related to each in-depth study to produce a good understanding of the complete project in all its complexity and heterogeneity.

The technique for evaluation should be based on:
- database creation of a selective/core/representative canal system,
- adoption of information technology tools (remote sensing , geographic information survey, models) and
- concurrent evaluation (interaction with project authority).

It is essential that a global strategy emerges from the monitoring of pilot projects.

Clear objectives of modernization are required for a clear identification of the end-users' current constraints and potentialities, and of the obstacles to be overcome.

The critical issue of the cost-effectiveness of modernization was debated in the following terms: Modernization should increase the water productivity and sometimes generate water savings. Water savings can be used within the irrigation sector (extension of cultivated areas, more water-demanding crops) or transferred to other sectors. In the latter case, the question is then who will pay for the water transferred and how can the irrigation sector get support from other sectors to fund the modernization programmes. A cost-benefit analysis should be made for any modernization project to assess the real costs as well as the real benefits.

Working group 3: institutional approach

CHAIRMAN: GW. SKOGERBOE – CO-CHAIRMAN: J. PLANTEY

Statement proposed to the group: *Modernization is not only limited to the introduction of modern hardware and software techniques, but is rather a fundamental transformation of the management of water resources. This transformation can include changing rules and institutional structures related to water rights, water delivery services, accountability mechanisms and incentives in addition to the physical structures. The institutional dimension of modernization should be well understood for the appropriate design of physical transformations as well as for the water management strategy.*

Given the diversity of situations and national contexts, the group felt that the first step in a modernization design should be a situation analysis. The objective of this is to try to understand the real needs of farmers at project level as well as to enlarge the scope to a higher level conciliating all water uses in the watershed, in accordance with national priorities.

Strong political and legal support is required for success in modernizing irrigation schemes and systems and in sustaining water rights in the irrigation sector. Water rights for irrigation are contested because of a perceived low efficiency of schemes, therefore one target of modernization should be to consolidate the water rights demonstrating an increased performance and thereby justifying the allocations to agriculture.

At scheme level, situations may be diverse depending on size; a large scheme may require some involvement of the state, whereas a small scheme can be managed purely by the local users.

Two principles were put forward to underpin modern management of irrigation schemes: compatibility between the collective organization and the water resource, and consolidation of water rights on the basis of a quantum.

Volumetric delivery is therefore essential. By ensuring that the deliveries are well controlled for discharge, a simple measure of the opening duration of a gate allows for volume accounting. This might be seen as a good alternative to, and a less cumbersome procedure than, discharge measurement.

A water tariff also motivates efficient use of water. Examples were discussed which show that farmers are motivated where they feel responsible and assume the cost of operation and maintenance.

One strong point in an institutional approach is to clarify the concepts of price, tariff, cost and value of water.

The group unanimously agreed that it is necessary to make the physical organization compatible with the institutional organization.

Working group 4: training and capacity-building

CHAIRMAN: T. FACON – CO-CHAIRMAN: A. BENHAMOU

Statement proposed to the group: *Capacity-building is fundamental to enhance the ability of irrigation professionals to initiate, design, organize and implement modernization interventions. Training is essential to improve the skills of all professionals. In the public sector a new culture of engineers-managers should partly replace the mono-culture of engineers-builders. The private sector should focus on modern techniques to ensure appropriate service and maintenance, timely repairs and emergency interventions.*

The participants in the working group fully supported the statement submitted by the meeting organizers. They added that capacity-building for an irrigation modernization programme should also include the training of officials of water user associations, of top-level, mid-level and field technicians and, last but not least, of farmers. However, in view of the time available, the working group decided to limit the discussion to the training of engineers and irrigation managers. Training of professionals from other sub-sectors might also be required when irrigation modernization is implemented in the context of improved water resources management, which is typically the case in a situation of water scarcity when recycling, transfer among users in a river basin and such are required.

A large-scale modernization programme would typically require retraining of a large number of professionals and technicians. The effectiveness of such programmes, however, may be hampered by systematic staff rotation policies (usually three years).

A training programme for professionals should include both technical and non-technical (management, etc) disciplines.

Dr Charles Burt, Director of the Irrigation Training & Research Centre at CalPoly, made a presentation to the working group of the FAO proposal for an irrigation modernization training programme. FAO estimates that a very ambitious large-scale retraining programme for engineers and managers is required now to build up internationally the capacity to implement the needed revolution in the operation of irrigation systems. Irrigation engineers and operators need to understand the new concepts of modernization and be trained in the required skills to implement them practically in the field. The document presenting this programme is included in this report. The programme is structured as a prestigious certification training-of-trainers programme expanded into national upgrading programmes in selected regional and local training centres. It is based on active, pragmatic methods and teaches what we already know works. An important aspect would be the teaching of a rapid appraisal process to diagnose scheme operations, design a locally suitable modernization strategy and identify proven workable technical and management options that can be applied locally to solve identified problems.

The working group unanimously endorsed this programme concept proposal and felt it addressed a real need. Modernization programmes are too often associated only with automation and meet resistance. Even when funding for training is available (in certain countries, as a rule one percent of total costs of all projects is allocated to training), adequate pragmatic training for field staff is not available. The proposed certification system would help create a better recognition of expertise in the modernization of irrigation systems and irrigation management.

WALMI Aurangabad proposed itself as the training centre where the first training-of-trainers programmes could be launched. It was suggested that other WALMI institutes in India could serve as state-level training centres.

It was emphasized that a prerequisite for the launching of such programmes would be a genuine commitment by governments, which should be willing to make qualified staff available for trainers. The modernization concepts need therefore to be accepted first by top-level decision-makers and managers. To this effect, the benefits for developing countries of implementing modernization programmes should be better documented (including in terms of improving water use efficiency, which is typically very low). FAO should also address some design issues in the programme:

- selection criteria for trainers of trainers;
- association with other international bodies such as the International Commission for Irrigation and Drainage or Global Water Partnership;
- adaptation of the curriculum to regional specific circumstances and needs in regional focal institutions (Marrakech university was suggested as a regional focal centre for North Africa and West Africa);
- training of professionals in the private sector: consulting firms, manufacturers, construction companies; and
- involvement of private companies (resource persons, equipment) in the programme.

It was noted that in certain countries such as the United States, private firms were very forthcoming in responding to requests from training or research centres to supply them with sample equipment or materials.

The role of on-site research in modernization programmes is extremely important. Such sites could enhance dissemination of new techniques and concepts outside of the classroom. Implemented as a small fraction of a large programme, they could be instrumental in steering problem-solving action-oriented practical research by research institutes and in building the capacity to implement the programmes through the targeted training of associated staff.

Diagnostic analysis and performance evaluation methods should be used to identify the problems and orient the design of the research and training programmes.

It was noted that, by necessity, training and research centres which depend on their customers (the irrigation scheme managers) for the funding of their research programmes have to provide a real service to them and have therefore developed rapid intervention methods such as rapid appraisal processes, an outgoing attitude, and carry out in essence on-site research programmes. Centres such as WALMI in Aurangabad and IWMI in Sri Lanka also stated that they felt that the on-site research programmes they were implementing for irrigation agencies and projects were very helpful in gaining a knowledge of the real problems they should address.

Finally, the group noted that the number of irrigation professionals and managers who have access to e-mail and the Internet, including in developing countries, is expanding at an increasing pace and that local and national institutions are developing their Web sites. It was felt therefore that the time was ripe to consider realistically modern networking methods such as e-mail and the World Wide Web as very powerful means of disseminating knowledge and exchanging experience on irrigation modernization among the professional community to increase the capacity for modernization and promote the transfer of technology.

It was noted that a specific discussion mailing list on modernization does not exist yet. Existing non-moderated mailing lists such as TRICKLE-L and IRRIGATION-L are very useful to irrigation practitioners.

FAO announced that it was considering developing a Web site on modernization in 1999 to serve as a platform of exchange of experiences in irrigation modernization and added that it would also consider creating an electronic mailing list as suggested by the group.

Main conclusions

The central message which emerges from this meeting was that modernization is above all an issue of human-ware. It is quite noteworthy to see that, although most participants to the meeting were engineers, almost every paper and almost all questions and points of discussion dealt with institutional, development and sociological issues and were not focussed on techniques. The issue of human-ware can be further expanded into complementary directions.

A further message is that service-oriented management is an essential first step in modernization. This service-oriented management requires in turn an adapted infrastructure and an appropriate strategy for operation. Finally, modern management and operation range from refocus on traditional activities (information) to high techniques as the situation requires.

The third important message is that modernization requires a consistent strategy at state or national level to cope with the cost of interventions, to organize and prepare the irrigation community to overcome the challenges of modernization, to implement the necessary institutional changes and to define and ensure the enforcement of water rights or service rights.

These messages can be further expanded into more practical recommendations which have been fully debated during the meeting:

- build management-oriented strategies based on the service of irrigation to the agricultural production users and to the other users;
- develop strategies and techniques adapted to developing countries for the operation of irrigation systems that will overcome the new challenges for water and heterogeneity in the delivered service;
- test and disseminate methodologies for the assessment of performance and diagnosis for modernization schemes;
- create an era of re-engineering of the irrigation process to allow most engineers to move from a purely construction skill base to one including operation and management skills; and
- develop a strategy for training and capacity-building in modernization strategies, design of projects, diagnosis and evaluation.

Introduction

Development and modernization of irrigation in Maharashtra

Er **Shri S.T. Deokule**

Former Secretary of Irrigation
of the Government of Maharashtra

Respected personalities on the dais, honourable guests, distinguished delegates, ladies and gentlemen,

I am very happy to have this opportunity of participating in the inauguration ceremony of the Fifth International Network meeting on Information Techniques for Irrigation Systems focusing on the modernization of irrigation system operations. It is heartening to note that a large number of experts of international repute are participating in this meeting in addition to top irrigation professionals from all over India, including a large contingent of the cream of irrigation functionaries from Maharashtra. With such a participating body of top experts, I am sure the presentations and the discussions on the topic will result in a thorough compilation of experiences on the theme of modernization of irrigation systems and that guidelines for reference in the matter will be formulated for use by the world irrigation community.

I was also fortunate in attending the inauguration ceremony of WALMI, Aurangabad, in 1980 under the aegis of the World Bank. In the last eighteen years, this institute has grown to international status, primarily due to its faculty and facilities and also to contributions received by various visiting professors and experts from all over the world. You will find the atmosphere here to be very congenial for deliberations in this network meeting.

In this vast country, irrigation in various forms has been practised for ages and a large number of various types of old irrigation systems are still in operation with their own well-established irrigation practices evolved out of experience. Furthermore, during the various five-year plans, from the first to now the ninth, a large programme of construction of various types of irrigation systems has been undertaken and phenomenal progress has been achieved. The ultimate potential of about 120 million hectares of irrigation, as currently assessed by various sources in this country, is likely to be achieved in the second decade of the next century.

In each state, and even in parts of each state, there is tremendous variation in the basic environmental factors such as rainfall pattern and intensity, ground profiles, soil types and depths, spread of rural population, and agricultural practices, and obviously irrigation policies and practices have to be developed keeping in mind these basic factors. The salient features of the irrigation schemes taken up for execution in the past were primarily and obviously based on the experience of existing similar schemes in each state. However, at the beginning of operations in these new irrigation projects, a number of problems were faced for which specific solutions were found over time. In this continuous process of learning, in addition to the phenomenal work done by the irrigation fraternity in this country, the contribution received from the international community has also to be acknowledged.

Maharashtra is the leading industrialized state in India, but its current development of only 13 percent of its irrigation potential is far below the national average of about 33 percent. The land developed so far in the state by the large and medium-sized irrigation projects is only about 56 percent of the currently identified ultimate potential of 4.1 million hectares. The state has a rugged terrain, and a large number of rivers originate here, resulting in many comparatively small irrigation projects. However, the total number of dams of more than 15 metres in height built in Maharashtra is about 900, compared to 2 900 countrywide, so the state can claim to be the leading dam builder in the country. Irrigation is a state subject and the state has a force of about 15 000 engineers and more than 120 000 men working in investigation, planning, design, construction, maintenance and operation of the irrigation systems. The state spends Rs10 to 12 billion every year to manage some 3 million hectares of surface irrigation. This gives an indication of the amount of work which is being done here on irrigation development and management. The current strategy is to optimize irrigation efforts so as to provide irrigation facilities to larger areas and to a greater number of farmers. This needs to be done at the cheapest possible rate and refinements will have to come later. Despite all these efforts, a large percentage of the area will remain rain-fed and subjected to the vagaries of nature.

Similarly, current efforts in the country as a whole are primarily aimed at creating additional irrigation potential through the launching of new projects and maintenance of existing irrigation schemes. As maintenance grants have been meagre, the accumulated effect of inadequate maintenance has been a substantial reduction in project benefits for some of the older systems. Hence, for some older projects in the state as in the country, renovation or rehabilitation was carried out to restore the original capabilities and in some projects extensions were made.

The modernization of irrigation systems does not mean merely an improvement of the engineering parameters such as lining of canals or improvement and modification of structures, but also the application of a complex combination of field disciplines to irrigated agriculture. As such, modernization has to cover not only the engineering but also the agronomic and management aspects. The modernization of existing projects has hence to be taken along with their restoration and rehabilitation. Detailed diagnostic analysis or performance evaluation needs to be carried out to identify, quantify and execute the required measures.

Several individual efforts have also been made to modernize existing irrigation systems so as to achieve better water use, after studying and thoroughly analysing the irrigation systems concerned. The Central Water Commission of the government of India has formulated guidelines for the modernization of existing irrigation projects. According to these guidelines, a review of such factors as hydrology, land potential, cropping patterns, crop water requirements, physical features of the canal system, groundwater, drainage, water management and environmental management, and economic evaluation has to be made. Required modifications have to be identified and provided for in the modernization projects. In addition, participatory irrigation management and operation plans for improved use of the canal system also need to be included. We propose to achieve the synthesis of all these requirements through this workshop by the documentation and dissemination of experiences of modernization.

For the control of canal and distribution systems, the traditional means of communication in Maharashtra consisted of telegraph and telephone facilities installed at critical locations along the canal alignment. This system, simple in operation, was in use for a very long period and it is only in the last decade or so that the wireless system is progressively replacing it. Although the wireless communication system, along with centralized control, has been used for a fairly long time for flood control, as well as for other purposes such as police or military communications, its use for irrigation management was permitted only recently, after the relaxation of restrictions on the use of wireless systems for civil purposes. So far, 1096 wireless network stations have been installed all over the state and the main centres connected through satellite.

Thus an effective system for flood control and irrigation management is now available in this state.

A very ambitious programme to introduce a computerized management information system for the Maharashtra Krishna Valley Development Corporation of the irrigation department of the government of Maharashtra has been undertaken so that all the executives of the corporation are connected to headquarters, in order to ensure a prompt flow of information and its analysis for use by the corporation. The hardware is in position and the software modules for items such as project and contract management, land acquisition and personnel, financial and water management are installed.

The western part of our state, known as the Kokan area, consists of very rugged terrain and the heavy rainfall there during the four monsoon months allows the growing of only one rice crop, by field-to-field irrigation. A pilot project has been started to develop a water control system in order to diversify cropping patterns in the coastal areas of Maharashtra. This will be achieved notably through piped water distribution, right down to individual fields.

For the existing Khadakwasla irrigation project, a canal automation project has been undertaken in collaboration with the Department of Electronics of the central government. Once it is fully implemented, the use of computerized information technology in irrigation water management should expand progressively.

Tomorrow you will visit the Jayakwadi Project, which is one of the largest irrigation projects in this state, with about 400 000 hectares of irrigation potential. The project has been carried out in phases and fraught with a number of construction and irrigation problems. Since 1970, it has been assisted by the World Bank, both financially and through guidance in the form of expert advice and the use of various types of pilot projects, including the pilot dynamic regulation project which will be discussed in detail in this meeting.

I have just recounted the various advances made by the progressive and dynamic irrigation department of Maharashtra, as the state is entering an era of use of modern techniques in irrigation management. As such, this is the most appropriate time for holding this fifth ITIS meeting here so that this innovative state and the irrigation community as a whole may benefit immensely from the dialogue and discussions regarding the application of information techniques in the modernization of irrigation system operations.

I wish the seminar success and thus conclude my inaugural address. Thank you.

Modernization of irrigation systems: a continuing process

Daniel Renault
ITIS Co-ordinator, IWMI

Improving irrigation water management, in order to increase productivity and minimize adverse effects such as salinization, is one of the main contemporary issues in the agricultural sector. A considerable effort is being made to improve irrigation operations and to reduce costs. Society in general and water user associations, particularly where they have to bear the cost of irrigation, are demanding that irrigation become more cost-effective. Hence water services have to be better matched with the cost of operation and maintenance.

Improving irrigation water management

Improved performance in irrigation water management can usually be achieved through three types of interventions:

- Rehabilitation, which consists of re-engineering a deficient infrastructure to return it to the original design. Although rehabilitation usually applies to the physical infrastructure, it can also concern institutional arrangements.
- Process improvement, which consists of intervening in the process without changing the rules of the water management. For instance, the introduction of modern techniques is a process improvement.
- Modernization, which is a more complex intervention implying fundamental changes in the rules governing water resource management. It may include interventions in the physical infrastructure as well as in its management.

Defining modernization

For many decades, modernization has been central to the concerns of the irrigation community, but the concepts behind it have evolved. It is now well understood that modernization is not limited to the introduction of modern hardware and software techniques, but is rather a fundamental transformation of the management of water resources. This transformation can include changing rules and institutional structures related to water rights, water delivery services, accountability mechanisms and incentives, in addition to the physical structures.

A definition of modernization that captures the current general understanding was put forward during a recent FAO consultation on modernization (Bangkok 1996):

> *Irrigation modernization is a process of technical and managerial upgrading (as opposed to mere rehabilitation) of irrigation schemes combined with institutional reforms, with the*

objective to improve resource utilization (labour, water, economic, environmental) and water delivery service to farms.

The need for a consistent framework for modernization

We hypothesize that success in modernization relies on internal consistency among key elements of water rights, institutions and infrastructure, and external consistency with the multiple uses of water within the basin. Consistency needs also to be found between the many objectives that might be assigned to modernization, such as:

- Increasing water productivity (in the context of strong competition between different types of users). In most countries, irrigation is the largest water user, therefore an improvement of water use efficiency is expected from the irrigation sector and a small percentage improvement releases large quantities of water for other users.
- Increasing the cost-effectiveness as funds for irrigation from national budgets dwindle and as the cost of irrigation is increasingly borne by the end-users.
- Increasing the reliability in irrigation deliveries. Farmers require a reliable water supply, i.e. as initially planned or expected, in order to properly plan their cropping pattern, to maximize the use of other inputs and to intervene in time with the appropriate practices. Wherever reliability is low, modernization should first focus on how to (re)establish a reliable irrigation service to farmers.
- Increasing the flexibility of deliveries. Flexibility is an important property of irrigation deliveries. With a flexible service users can intervene and supply water to crops whenever they think it is required. An improved level of flexibility is increasingly required as cropping patterns become more and more diversified.
- Consideration of other uses of water. Competition for water is increasing and the modernization of irrigation cannot be undertaken without taking into account the other uses of water in the catchment in terms of quantity as well as of quality. For example, many domestic supplies rely entirely on irrigation water, either directly through canal supply or indirectly through groundwater recharge.
- Increasing knowledge and human resources development. Managers require reliable methodologies to analyse the main relevant features of an irrigation system for water management and for canal operation. Therefore they need appropriate professional training and also links with applied research institutes which explore and test alternative solutions for water management and canal operation.

Obstacles in the way of modernization

Successful modernization is not straightforward, and failure to achieve targeted performance objectives, in some instances, requires further investigation of the underlying causes. As far as the technology is concerned, significant hardware and software progress has been made in irrigation system operations in the past decade, including computer facilities, information techniques, measurements, and canal control concepts. However, the adoption of these techniques in the fields has, in general, been slower than expected. In developing countries, irrigation managers face many constraints that may explain the gap between the available and the applied technology, including:

- Technical gaps between the requirements needed to implement the improved method (availability of expertise, technical maintenance of equipment) and available local resources.
- Financial constraints resulting from the gap between the cost of equipment for the improved method and the gain in water savings and improved services, as water is generally not priced or charges are low.
- Social constraints. Human resources are relatively less expensive in developing economies than alternative technological solutions. An irrigation agency, often a large employer in the area, has some obligation to maintain local staff.
- Institutional constraints. Bureaucratic centralized irrigation administrations are not well suited to service-oriented activities.

Above all, one major bottleneck is often the lack of knowledge of possible choices for technical as well as other modernization measures. Their respective advantages and disadvantages and their ability to fit site-specific contexts must be further investigated and the results disseminated. This is one of the problems faced by designers and managers when confronted with the need for modernization. This may explain poor choices in the past which have led to disappointing results or a failure of modernization programmes.

What model for the modern irrigation enterprise?

It is clear for many that the irrigation sector in general has not reached the same level of effectiveness as other sectors, such as the industrial and service sectors. Hence modernization can be seen as a means to create and favour modern irrigation enterprises by introducing methodologies which have proved successful in other sectors.

There is a debate as to whether the irrigation industry would better benefit from an analogy with the industrial production sector or with the service sector.

Those in favour of service argue that irrigation agencies have often been deficient in defining and monitoring an appropriate service to their customers, and that this should be corrected to give more flexibility to water users in the management of the agricultural inputs. Furthermore, the introduction of intermediate-level partners (water user associations) between the irrigation agencies and the downstream users, highly increases the need for clarification of the service provided at each interface and of the responsibility at each level (delivery point, operation, maintenance, etc). Taking into account the management of the multiple uses of water within an irrigation scheme requires clarification concerning each specific service. Lastly, the notion of service becomes very important as soon as the water pricing policy is modified or merely introduced, where water was previously delivered free.

All these arguments, and many others in favour of emphasizing service in a modern irrigation enterprise, are fully valid. It does not mean, however, that we should forget about the industrial production analogy. In fact, the product delivered to users within a water delivery system is tangible, i.e. timely inputs of water. This product is the result of an industrial process from the source of water down to the delivery point. The quality of the delivered service fundamentally depends on the efficiency of the industrial process. We advocate here that both metaphors are valid. In both domains the irrigation enterprise can, and must, be improved to cope with modern agriculture as well as with the challenges resulting from water competition and environmental protection.

The role of the engineer in irrigation system performance is interesting. The huge development of irrigation projects in the 1960s and 1970s was made possible by the development of a strong engineering capacity. Later on, in many irrigation departments, administration completely disregarded engineering resources, and water management received little attention. State agencies are now often too bureaucratic rather than suffering from too many engineers. The phase of builders-engineers, which is receding, has not always given way to managers-engineers.

We advocate that modern enterprises in irrigation require a reengineering of their processes in order to cope with the new challenges faced by irrigation.

Reengineering irrigation system operations

The reengineering of the irrigation operation should consist of designing the most cost-effective answer to the redefined water service within the scheme. It should consider:

- The spatial distribution of the effective demand for the water service. The service might differ significantly with user demand, e.g. cash-crop farmers might ask for a high quality and costly service whereas farmers with an alternative source (wells) might be satisfied with a low and cheap service. The service might also differ because of other considerations such as hydrological hazards (salinization, water-logging) and opportunities (recycling of water).
- The spatial distribution of the physical infrastructure characteristics. The sensitivity of the canal delivery structures, the efficiency in controlling water depth, the ease of monitoring and implementing operation – these are some of the important features that should be considered when designing an appropriate answer to meet the demand.

It is hypothesized here that the reengineering process should be spatially differentiated to lead to the best cost-effective solutions possible and to cope with the effective demand. This places the concept of flexibility of water service at the heart of modernization.

Flexibility in modernization

The concept of flexibility has long been discussed and advocated in the field of irrigation modernization. So far it has encompassed the notion of flexibility in water deliveries as opposed to rotational and fixed deliveries. Flexible deliveries can be proposed to users in different forms (on request, free access, etc) at a cost compared to a strict rotational distribution.

The flexibility in water service advocated here is broad in the sense that it encompasses the spatial variability of the service within an irrigation system. This means that the level of service might vary from one subsystem to another, e.g. some subsystems might choose strict rotation while others might ask for a more flexible access to water. The coexistence of different levels of service in a single system represents a technical challenge for the managing agencies which requires a strong reengineering of the whole process of operation.

This concept of flexibility leads to abandoning the homogeneous approach of irrigation systems that has so far prevailed. Instead, a heterogeneous approach of the demand and of the efforts (inputs) to operate irrigation systems is sought for a closer match of water availability to demand requirements.

These thoughts on modernization are meant only to introduce some of the rapidly changing challenges faced by the irrigation sector and to illustrate how the debate on modernization is still rich and lively. Although modernization of irrigation systems has been the subject of many large international meetings during recent decades – to name but a few, the 11th Congress of ICID in Grenoble in 1981, the 13th Congress of ICID in Casablanca in 1987 and the FAO international consultations on modernization held in Bangkok in 1996 – still the debate and discussions are continuing, e.g. the next ICID Congress in Granada in 1999 will focus partly on modernization.

Finally what matters is to realize that modernization is a never-ending process of adapting activities to current constraints and objectives. The agricultural and economic contexts are permanently evolving and so are the demands from society. What was modern and up to date some decades ago might now appear to be incompatible with current needs, and this is not only true of the technical aspects of irrigation. What might be considered new now is the increase of the speed of adaptation required to match a society which is evolving at an ever faster pace. Modernization is therefore a permanent and relentless process.

Modern management implies that the physical and institutional structures of management are adapted to the current environment, respond to the needs of society and are sufficiently flexible to cope with short-term evolutions.

We do hope that this ITIS 5 meeting in India will have contributed effectively to the debate on modern irrigation processes and modernization of irrigation systems operation, and we also hope that we made progress on some practical recommendations on important related matters such as: reengineering operations, evaluation and monitoring of performance, institutional approaches, and training and capacity-building.

The role of the World Bank & new opportunities

Hervé Plusquellec

Former World Bank Irrigation Adviser

The irrigation sector has been one of the largest recipients of public investments in the developing world. Seven percent of the World Bank lending, amounting to about 35 billion in constant US dollars, has been for irrigation. Lending for irrigation is now in decline: the annual lending for the sub-sector and the number of irrigation projects are about half what they were during the peak period 1975-85. Despite this decline, however, the World Bank and the regional development banks as well have largely contributed to the expansion of irrigation and to the share of irrigated agriculture in meeting the food needs of a rapidly increasing population during the last half-century. However, the role of the World Bank in the modernization of irrigation has not been as valuable as one would expect. This paper discusses the reasons for the slow progress in modernization in Bank-financed irrigation projects and explores some new perspectives for modernization by combining institutional reforms and physical improvements.

The evolving role of the Bank in irrigation

The world has changed tremendously over the past fifty years, and so has the Bank, in its membership, organizational structure, operation scope and development agenda. Projects financed by the Bank are now radically different from those financed in the 1950s, when there was little concern for policy frameworks, poverty alleviation, environmental protection or the privatization of inputs and services. The World Bank started lending for agriculture through large irrigation projects, in keeping with the prevailing emphasis on large infrastructure. In the 1950s and the 1960s, the Bank did not finance rehabilitation works of existing irrigation systems. Rehabilitation was considered the responsibility of the borrowing governments. Similarly, the Bank limited its contribution to the construction of the main and distribution systems, assuming that the farmers would contribute in constructing themselves the tertiary systems in addition to the on-farm development works. Experience invalidates that hypothesis.

The food crisis in India in the mid-1960s focused attention on the need to improve food-grain productivity and new technologies. The Bank began lending for agricultural research and extension, rural credit and the production of high-yielding varieties and fertilizers, either directly through specific agricultural projects or as components of irrigation projects. In the 1970s, under the presidency of Robert MacNamara, the Bank turned its energies to alleviating poverty. Irrigation projects became overloaded with rural development programmes, such as construction of rural roads, schools and health centres. Irrigation projects became very difficult to prepare and implement because of the number of sub-components and agencies involved. Since 1976, the Bank's internal regulations require that project preparation be upgraded to completion of detailed design and bidding documents for presentation to the Board to avoid delay in implementation and to reduce the risks of cost overruns. Post evaluations showed that many irrigation projects did not comply with this requirement and if they did, emphasis was on the structural design of infrastructure, not on canal operation and delivery of water to the users.

By the 1980s, it became evident that faulty policies seriously affected production in many countries. It also became apparent that competition for water was acute in many countries, water quality was seriously affected and water-related issues could no longer be treated separately by each sub-sector. In 1993, the Board of Directors of the Bank approved its Water Resources Management Policy, which encourages the adoption of institutional reforms, analytical frameworks for managing water resources, water conserving technology, decentralization of responsibilities to local governments, user participation and environmental protection. The water policy marked a turning point in the formulation of irrigation projects, which progressively shifted from the agricultural sector to the water sector.

In the early decades of lending for irrigation, the Bank financed specific individual projects or a group of subprojects which were all well identified. The attention now given to the recommendations of the water policy has contributed to shift the Bank-supported irrigation programmes to projects national or regional in scope. For example, some projects cover the entire irrigated area of a state in India or a province in Pakistan or even the entire multiple-year plan of a country, such as in Mexico. A "new-style" project typically includes two major components: an institutional component supporting the creation or strengthening of water user associations and reforms of irrigation and water agencies, and a physical component for rehabilitation or differed maintenance work. Depending on the needs of the project, financing of environmental studies, agricultural research or support services or creation of basin agencies are also included. The main focus is on the software recommendations of the water policy such as the participation of users or the legal framework enabling the setting up of water rights and water markets.

The scope and concept of modernization

The modernization of irrigation systems has different meanings depending on the background of irrigation experts. Modernization is not necessarily the conversion of an irrigation system to the state of the art in technology and management. It should be understood as any physical or institutional change which would contribute to an improved service to users, to a reduced deterioration of water quality, and to a reduction of government intervention in management.

The scope of modernization could therefore include a large range of activities:

- operation of the main and distribution system through advanced water control structures and modern operation tools;
- water application at farm level through the adoption of water saving techniques;
- construction technology, such as the use of geo-membranes for canal lining, use of canal lining machinery, and prefabrication;
- user participation either through transfer of management responsibilities or any other consultative approach; and
- administration and accounting.

This paper focuses on proper water control and water delivery, which are prerequisites to getting full benefit from water saving techniques at farm level and from the implementation of institutional and policy reforms. Application of volumetric water charges and quotas, implementation of water rights and active water markets, and demand management are reform tools which require confidence from the users in the water delivery service, and proper water control to provide that service.

The World Bank experience in irrigation modernization

Most of the irrigation projects supported by the Bank are gravity irrigation projects. This simply reflects the regional distribution of projects. Most irrigation lending – 50 percent of the projects and 69 percent of the money loaned – has occurred in Asia, where rice cultivation predominates. However, the Bank has financed sprinkler irrigation projects in water-scarce countries such as Morocco, Jordan and Romania and in Northeast Brazil and, on a smaller scale, drip irrigation in Cyprus and Turkey for example. The Bank has financed and continues to finance investments for water conservation at farm level consisting of lining of tertiary canals or conversion to low-pressure systems, for example in China, India, Chile and Mexico.

The World Bank has successfully financed irrigation projects in countries where modern design standards are the norm, such as in North Africa. Successful transfer of water control technology in individual projects has also been achieved in some countries which have not yet standardized their design. The Kemubu and Muda projects in Malaysia and the Lower Klalis project in Iraq are a few examples. However, some modern water control pilot projects have failed for various reasons:

- implementation agencies should be committed at the highest level to the success of pilot projects; pilot projects should be integrated in a long-term modernization strategy;
- training should not be limited to a small project design team; training should include staff involved in controlling the quality of the construction of pilot projects and those who will manage these projects;
- water control equipment should be manufactured according to the technical norms of the original designer; locally modified control equipment to avoid patent issues rarely works: as usual, one gets what one pays for; and
- continuity in staff of the implementation agencies as well as of the lending agencies is needed to avoid loss of interest or change of focus.

Besides a number of modern projects mostly in water-scarce countries and a few isolated cases in other countries, the majority of projects are based on simplistic hydraulic design standards. The complexity of unsteady flows which are common in the operation of irrigation canals, the interaction between control structures, the impact of rigid or unreliable water delivery on farmer behaviour, the operation of canals at less than full supply are not always understood. The reasons for the slow adoption of modernization are extensively discussed in the World Bank Technical Paper 246 (see its chapter 8: The debate on modernization).

The fundamental cause for the slow rate of technology transfer identified in that paper was a lack of knowledge of available technologies and a misunderstanding of the nature of irrigation. The recent research funded by the World Bank on the performance of irrigation systems strongly confirmed that hypothesis. There is an immediate need for major training in the concepts and details of the modernization of irrigation.

Adverse administrative and behavioural reasons for the adoption of modern designs are more difficult to address. The pressure from the World Bank management to reduce the time of preparation has further increased during the last years. The trend toward low cost rehabilitation and maintenance programmes is also not in favour of modernization. Economic pressures on the irrigation agencies responsible for the management of irrigation systems and contractual motivation for their consultants are still missing. Irrigation managers, engineers and others are still adhering to outdated designs and resisting to change in many countries.

The Bank-funded research study referred to above provides well-documented evidence of the benefits of modernization and should be a milestone in the dissemination of the advantages of modernization. That study should widely contribute to the rejection of some unfounded myths against modernization. Modern design, defined as a concept and not by the technology and equipment used, is not too sophisticated for developing countries. A number of low-cost changes can be gradually introduced without affecting the economic viability of a project. In many cases, the first step in modernization may be shifting from inadequate to rational design based on the understanding of simple but sound hydraulic principles, for example adopting the right combination of control structures at cross regulators and off-takes to limit the hydraulic sensitivity to inflow fluctuations.

The slow adoption of modern designs and the failure of some pilot projects should not overlook the progress which has been made in the dissemination of knowledge about modern irrigation. The World Bank has largely contributed to the transfer process through training courses, study tours, audio-visual programmes, conferences and workshops. It is encouraging that some countries located in the humid tropics, an environment considered by some experts not suitable for the adoption of arid irrigation technology, are now experimenting with new concepts: the Magat project in the Philippines, the Majalgaon project in Maharashtra and the High Level Pehur Canal project in Pakistan are encouraging examples of transfer of technology in countries with strong adherence to old design manuals in the past.

A comprehensive approach to modernization: the case of Mexico

The best example of comprehensive approach to the modernization of irrigation is found in Mexico. The Mexican government implemented a policy reform programme, including decentralization and price liberalization of its entire economy, in the late 1980s. To date, the management of over 3.2 million hectares in 80 irrigation districts has been transferred to 410 water user associations, and to 11 federations for the main systems. The national irrigation agency, CNA, implemented a massive training programme of the professional, technical and administrative staff of the water user associations and of the members of the boards of these associations. CNA also retrained its own reduced staff to its new role of advising and supervising the associations.

The reform of the Mexican irrigation sector was not limited to the institutional aspects. With the assistance of an international consulting firm, the CNA-designed standards were upgraded to address the problems of unsteady flow conditions in irrigation canals and operation at less than full supply. A training programme was implemented for CNA staff and private local consulting firms. Most remarkably, irrigation modernization was incorporated in the curriculum of Mexico universities to prepare the next generations of irrigation engineers.

Once the management transfer in Mexico was well advanced, CNA focused on the modernization of maintenance through the adoption of weeding chemical and biological treatment methods and the purchase of specialized maintenance equipment.

A project currently under preparation in Mexico will break new grounds in the process of modernization of irrigation systems with a bottom-up approach. Modernization is to be carried out at the initiative of water user associations, which are to contribute 50 percent of the investment costs.

The success of Mexico in transfer management, widely popularized by the World Bank, has encouraged the Turkish irrigation agency, DSI, to embark on a similar programme. As of the end of 1997, the management of about 1.2 million hectares had been transferred to 222 associations. The World Bank is providing financial assistance for the purchase of specialized maintenance equipment and, at pilot scale, for the conversion to drip irrigation of about 1200 hectares at the demand of two associations which would contribute 70 percent of the costs.

Possible scenarios for modernization

As discussed above, the formulation of irrigation projects has much evolved over the last decades. On the one hand, there is a risk that the importance now given to overall water resource management, institutional and regulatory systems, poverty alleviation, environmental protection and other issues during project preparation might overshadow the technical aspects for improving canal operations and water service to users. Dealing with all the policy issues with the challenge of currently decreasing financial resources for project preparation does not provide an environment favourable to the modernization of irrigation systems, which require an in-depth diagnosis of their functioning by well-trained experts as well as detailed studies of alternative solutions.

On the other hand, the "new-style" projects, which are now national or regional in scope, offer the opportunity to shift from the project-by-project approach to a global approach to modernization through training programmes, revision of design standards, involvement of the users in the decision process and financing of investment costs. The World Bank strategy to promote irrigation management transfer may also give a new impulsion to the modernization of irrigation systems. The user associations have a real interest in improving the physical infrastructure to provide better water service to the members and to reach financial sustainability. Large business-type associations with real decision powers on investments and water allocation policies may succeed if properly advised on the alternative solutions for modernization.

Institutional and policy reforms should be combined with a programme of modernization of the irrigation infrastructure. Irrigation management transfer is not an end-objective, but should be the beginning of a new era for irrigation. Irrigation management transfer programmes should be designed with that long-term vision.

Benchmark studies on modernization

Modernization of irrigation system operational management by way of canal automation in India

Anil B. Mandavia

Chief Engineer, Management Information Systems
Sardar Saroar Narmada Nigam Limited, Gandhinagar, Gujarat, India

Synopsis

A scientific management culture should enter the field of our irrigation system operational management: only then the irrigation systems set up with enormous investments through the various five-year plans can be sustained to ensure reasonable returns. In India, the introduction of systems based on information technology for monitoring and controlling canal operations is necessary to improve water management not only at the operational level but also at the farm level. As the farmers are the end-users, when new technology is applied, they have to be informed during implementation of the improvements planned and of the anticipated benefits which they may gain. Upgrading existing canal system operations needs to be done in stages as a rehabilitation programme. It can be done in small areas which are easily and economically assessable for improvement. If information technology is brought to an existing water resource project, restoration of the existing control structures, canal sizing, canal lining and other related command area development activities must be completed before taking up the automation project. The cost of canal automation on an existing irrigation project and that on a new project cannot be compared, as the built-in constraints in the existing project not only limit the degree of automation but also increase the cost by way of remodelling the existing canal systems. In Indian conditions the cost of automation on the main canals can vary from Rs1 500 to Rs2 000 per hectare and that on the secondary canals from Rs3 000 to Rs4 000 per hectare. New techniques such as on-farm irrigation scheduling are available to predict the time and volume of water needed for the most effective irrigation. Specific amounts of water required for crop irrigation at particular times can be derived using the soil-water plant relationship. Soil characteristics such as infiltration rate and water-holding capacity are used in the calculation. By using soil characteristics, moisture content and estimated evapotranspiration, the timing and quantity of water needed to replenish the depleted soil moisture available to plants can be calculated and used to forecast the next irrigation. These schedules are then provided to the computer centre controlling the canal conveyance and delivery system to update the weekly and daily schedules of irrigation, which are set at the start of the season based on the available data. Thus the requirement of the release of water into a main canal can be predicted on a scientific basis and this will allow for a more flexible operation of the canal system. The linkage of real-time data collection and monitoring of climate crop-soil relation parameters with the canal automation of the conveyance and distribution system is the ultimate goal, and the use of information technology below outlet level must be given an equal priority. The socio-economic conditions of the farmers and the scientific use of water to satisfy crop requirements will determine the degree of success of the complete approach of implementing automation from headwork to farm level.

Introduction

As we approach a new millennium, there are growing concerns and periodic warnings that we are moving into an era of water scarcity. With increasing demand for food and competing use within the water sector, the pressure is on irrigation professionals to manage water efficiently. The rallying cry is "more crop per drop". In response to this, strategic decisions and interventions need to be made on a continuous basis. These decisions should cover the full spectrum of the irrigation water supply system, from diversion and distribution to on-farm application down to the crop root zone.

Agriculture is the mainstay of the Indian economy; almost three quarters of the country's working population are engaged in agriculture and about half of the gross national product is generated by agricultural production. Agricultural growth largely depends on water, which is the prime input. Rainfall is not quite dependable or helpful to agricultural development in India. The Indian monsoon is known for its vagaries. Almost 85 percent of the rainfall is provided by the Southwest monsoon (June to September) and some parts of Southern India receive rain from the Northeast monsoon (November to December) as well. Rainfall distribution is uneven with respect to time as well as space, and frequently erratic. The mismatching of rainfall and crop-water requirements is quite common. A large part of the country is arid and semiarid as rainfall is not sufficient to ensure even a single crop. Furthermore, the low-rainfall areas of the country have a fairly high coefficient of variation. Droughts are experienced quite often in one part of the country or another. Irrigation is, therefore, an inseparable part of the welfare of Indian agriculture.

The country's population, which is now about 950 million, is expected to reach the billion mark by the turn of the century. The production of food grains, which was around 50 million tons in the pre-plan period, has reached about 195 million tons now and will have to be raised to 220 million tons by the year 2000. Boosting irrigated agriculture is the only way to achieve this target.

The management of irrigation in India differs conceptually from that practised in those developed countries where limited water is not a constraint. Good management, efficient operation and well-executed maintenance of irrigation systems are essential to the success and sustainability of irrigated agriculture. They result in better performance, better crop yields and sustained production. One of the key objectives in the management of an irrigation system is to provide levels of service as agreed with the relevant government authorities and the consumers at the minimum achievable cost.

In many parts of the world, irrigation systems are performing well below their potential. The problem of poor irrigation performance has stimulated the interest of a whole range of development professionals. There is unanimous agreement among them for the need to improve the operation of irrigation systems in order to increase productivity. In most countries great importance is now placed on programmes for rehabilitation, operation and maintenance of existing projects. However, works included in these programmes are often limited to canal lining, land levelling, construction of additional control structures, rehabilitation of existing control structures, improvement of access roads and to non-physical components such as staff training, improvement of cost recovery systems and so on. Too often, not enough attention is paid to alternative approaches to irrigation management, system operation and design.

History of irrigation in India

The history of irrigation in India can be traced back to prehistoric times, when agriculture was first practised by mankind. The Vedas and other ancient Indian texts make frequent references to wells, tanks, canals and dams and to the responsibility of the community for their efficient operation and maintenance. The entire landscape in southern and central India is studded with tanks and wells, some of which were built many centuries before the beginning of the Christian era. In North India there are equally old small canals in the upper valleys of rivers. The character of these works was largely conditioned by the natural features of the area. In the arid and semiarid plains of the perennial rivers of the north like the Ganges and the Indus, flood flows were diverted through inundation canals for irrigation, while in the rain-challenged south, water had to be stored in large tanks for domestic and agricultural use. Since the majority of the rural population subsisted on agriculture, irrigation had to be developed for growing crops in view of the vagaries of rainfall. While the use of groundwater from shallow wells was largely the result of individual private efforts, the surface water development for irrigation has traditionally been the result of community or state efforts.

Irrigation development in India gained momentum after Independence. The net irrigated area in 1950-51 was 20.85 million ha, with 1.71 million ha irrigated during more than one crop season. The gross irrigated area was 22.6 million ha. The planners assigned a very high priority to irrigation in the five-year plans. As a result, giant multipurpose and irrigation projects such as the Bhakra Nangal in Punjab, Damodar Valley in Bihar and Hirakund in Orissa were taken up.

By the end of the seventh five-year plan, the country had an irrigation potential of 29.9 million ha under large and medium-sized irrigation projects and 46.6 million hectares under smaller projects. By 1993-94, the irrigation potential created under the bigger irrigation projects was 31.2 million ha, 27.1 million ha of which were in use. In the case of the smaller irrigation projects, the potential created was 51.7 million ha, with 47.7 million ha used.

The target now is to achieve by the year 2010 the ultimate irrigation potential of 113.5 million ha from all sources of water – 58.5 million under large and medium-sized projects and 55 million under smaller projects. This means adding some 1.7 million ha a year to the larger irrigation projects.

With the rapid expansion of the irrigation programme since the beginning of the planned economy in the early 1950s, there was significant growth in irrigation potential. It was soon realized that the potential created was not being fully used as farmers failed to distribute the water equitably and efficiently and to synchronize field activities with the creation of irrigation potential at the outlet. Thus a gap developed between potential and use, as can be seen from the table below.

Period	Cumulative potential (million ha)	Cumulative use (million ha)	Gap in use of potential (million ha)
1950-51	22.50	22.50	–
1979-80	56.50	52.60	4.00
1984-85	67.90	60.40	7.50
1989-90	79.50	71.00	8.50
1993-94	82.90	74.80	8.10

Efforts to minimize the gap were initiated early in the Fifth Plan, i.e. in 1974-75, by initiating a command area development programme, with the following features:

- Modernization and efficient operation of the irrigation system as well as of drainage systems beyond the outlet serving 40ha blocks.
- Construction and lining of field channels and water courses.
- Land levelling and shaping.
- Construction of field drains.
- Conjunctive use of surface water and groundwater.
- Adoption and enforcement of a suitable cropping pattern.
- Introduction and enforcement of *warabandi* (see below).
- Preparation of plans for the supply of inputs, viz. credit, seeds, fertilizers and pesticides.
- Strengthening the existing extension, training and demonstration organizations.

Canal system operation in India

The canal system transfers water from its source(s) to one or more points of diversion downstream. Operation deals with the movement and behaviour of water in a canal system, and relies on the principle of open channel hydraulics. The primary function of operation is to manage the changes in flow and depth throughout the canal system. The term 'operation' refers to the hydraulic reaction in the canal pools which results from control actions. Several methods are available which can be used to convey water downstream through a series of canal pools. The method of operation determines how the water level varies in canal pools to satisfy the operational concept. A canal's recovery characteristics – the speed and manner in which the canal recovers to a steady state flow after a flow change – depend on the method of pool operation.

Conventional operation

The majority of canal systems in India are operated in a manner which is referred to as conventional operation. A conventional operation consists of a scheduled delivery, an upstream operational concept and a constant downstream depth operational method.

Conventional operation evolved as a practical method of satisfying irrigation needs within traditional canal system limitations. By using delivery schedules, it essentially combines demand-based needs with supply-based operation. The purpose of conventionally operated canals is demand-oriented, since the primary goal is to satisfy the needs of the water users. The downstream demand for water is assessed in advance so as to schedule the supply of water entering the canal through the headwork. Although the headwork flow is based on this schedule of anticipated demand, the actual operation of the canal is based on the supply. Check structures are operated to respond to upstream conditions, and the outflow from a pool reacts to the inflow.

One weakness of conventional operation is the inevitable discrepancy between forecast and actual delivery flows. In addition, there will be always inaccuracies in checking the flow and the amount of water stored in the canal pools. Since the canal system is not operated to react to actual demand, any such errors are transferred downstream. The sum of all operational errors will accumulate at the far end of the canal. Tail-end water users will often suffer from too much or too little water. To prevent shortages of water at the downstream end, excess water must be supplied at the headwork. Most of the time, this excess ends up being wasted near the downstream end of the system. The typical wastage in a conventionally operated canal system is about 5 to 10 percent of the total flow.

Conventional operation involves the following basic procedure :

(1) orders are submitted by the water users;
(2) a water schedule is formulated;
(3) flow changes are made at the head of the canal to meet the water schedule; and
(4) the canal is operated manually to transfer these changes downstream, making adjustments at the canal-side turnouts and canal check structures en route.

Water delivery practices in India

Depending on the type of schemes the water distribution system for irrigation can be different for surface irrigation and groundwater projects. The important models of distribution of water below outlets in surface irrigation commands developed over time in India on the basis of requirements and experience are:

1. the *warabandi* or *osrabandi* system of Punjab, Haryana, Rajasthan and Uttar Pradesh;
2. the *shejpali* and block systems of Maharashtra and Gujarat and *satta* system of Bihar; and
3. the localised system for paddy areas in the southern states of Andhra Pradesh, Karnataka, Tamil Nadu, etc.

Warabandi or *osrabandi*

The word *warabandi* originated from two vernacular words, *wara* and *bandi*, meaning 'turn' and 'fixation' respectively. As such, *warabandi* literally means 'fixation of turn' for supply of water to the farmers. *Osrabandi* is a synonym of *warabandi*. Under this system of management, the available water, whatever its volume, is equitably allocated to all farmers in the command irrespective of location of their holdings. The share of water is proportional to the holding area in the outlet command and allocated in terms of time interval as a fraction of the total hours of the week. Whereas the term *warabandi* is commonly used in Haryana, Punjab and Rajasthan, this system of water distribution is usually referred to as *osrabandi* in Uttar Pradesh.

Shejpali, block and *satta* systems

The main feature of these systems is that the government enters into some sort of agreement with the farmers for supplying water to them. The farmers file applications and the government issues permits for the supply of water and the two together constitute the agreement. The *shejpali* and the block systems are practised in Maharashtra, Gujarat and parts of Karnataka, whereas the *satta* system was evolved and is still in use in the Sone command area in Bihar, which is one of the oldest irrigation systems of the country. The word *satta* means agreement. The *satta* system includes the features of both the *shejpali* and the block systems.

Under the *shejpali* system the water is distributed according to a predetermined date in each rotation. A preliminary programme is drawn up every year depending on the availability of water. Farmers submit applications for supply of water indicating the crops they wish to grow and the areas under them. Water is then apportioned on the basis of the crops and the overall demand. Proportionate reductions in the irrigated area proposed by the farmers are made if the demand is found to be higher than the water available. A schedule, known as *shejpali*, fixing the turns to different farmers for the sanctioned crop area is prepared for each rotation. The farmers at the tail-end of the command are served first, those at the head of the watercourse are served last. The irrigation interval depends on the rate of water consumption by the crops, i.e. high water consuming crops may be supplied water in each rotation, whereas the lighter crops on the same outlet may get irrigation on alternate rotations. The schedule so made is notified in advance and every farmer of the command has prior information about his turn of supply. The system is called 'rigid *shejpali*' if the duration of supplying water to the various fields along with the date is also recorded on the permits issued to the farmers for sanctioned areas. This checks the tendency of the farmers to overdraw water.

Under the block system, a long-term arrangement for supply of water is done particularly on perennial crops, but irrigation from season to season proceeds through *shejpali*. One third of each block is to have sugarcane and the remaining two thirds is to be used for seasonal crops. The blocks are sanctioned for six to twelve years. There is assured supply of water for a long period under this system and farmers therefore can go for land development and plan their cultivation well.

The localised system for paddy areas

In most of the irrigation projects of southern and north-eastern states as well as in the states of West Bengal, Orissa, Bihar and Jammu & Kashmir, where paddy is the main crop, the irrigation below the outlets proceeds from one field to the other through surface flooding. The individual holdings are thus irrigated one after the other or even more than one field is irrigated at a time. Such a method of water distribution is prevalent in many of the outlet commands (where *warabandi* has not been introduced) in the Chambel Irrigation Project of Rajasthan. However, in Tamil Nadu and some other states, the farmers have a rotational system of water distribution in the outlet commands of some irrigation projects on one and a half days to four days basis for paddy crop and a longer interval for other crops. In this case, the water allocation is for a specified crop in a season and penalty is levied for deviation.

The modernization needs of irrigation system operational management in India

Although in India the major consumer of water is irrigated agriculture, the demands for various other competing and conflicting purposes are ever increasing. Ensuring water supplies in sufficient quantity and desired quality, properly distributed in time and space, has become a complex task. Water resource planning and management has become multidisciplinary in nature, requiring co-ordination among various government and non-government agencies. Making optimum use of water resources has long engaged human effort but it is only in recent times that it has taken the form of integrated water resources development and management. Pressure on the available water resources for conflicting uses has become so great that individual water resources projects, whether single purpose or multipurpose, cannot be undertaken or managed with optimum benefit unless there is a broad plan for the entire drainage area. Integrated development and management thus involves a co-ordinated and harmonious development of the various works (existing and new) in relation to all reasonable possibilities. This may include irrigation and drainage, generation of electrical energy, navigation, flood control, watershed management, industrial and domestic use of water, recreation and conservation of wildlife.

Water resources development planning has traditionally been attempted at state level, as in the case of other sectors, although it is well known that water does not obey political or administrative boundaries. Yet a river basin or a sub-basin should be the basic hydrological unit for water resource planning. In the early stages of water resource development, projects were formulated to serve mainly irrigation requirements or irrigation combined with hydropower generation and some other incidental purposes. As projects were relatively few, inter-project considerations were more or less absent and each project was considered and planned as an independent entity.

In spite of substantial growth in irrigated agriculture and consequent agricultural productivity over the years, irrigation systems in India are still facing many problems. The root cause of the poor performance of our irrigation systems may be the lack of scientific approach to their management. On most command areas served by a canal, water is poorly distributed over area and time. A common shortcoming is that tail-end users are not getting water or are getting insufficient and unreliable water. Conversely, head-end users often get too much water, either because they have no choice or deliberately, taking water when they can and often more than needed. Low irrigation efficiency is also attributed to changes in cropping patterns. In many cases, the cropping pattern actually adopted by the farmers is very different from the designed cropping pattern because it is mostly influenced by market forces, farmers' preferences, reliability of water supply and other factors. The on-farm irrigation practice prevailing in the country also results in wastage leading to low irrigation efficiency. Most farmers still irrigate the way their forefathers did thousands of years ago by flooding or channelling water through parallel furrows. This gravity system, typically least expensive to install, fails to distribute water evenly. Farmers are forced to apply an excessive amount of water to ensure that enough reaches the plants situated on higher ground or on the far side of a field. The adoption of field-to-field irrigation adds to the problem, as does poorly conceived irrigation scheduling.

Modernization of irrigation system operational management by way of canal automation

The overall water use efficiency of a manually operated system, exclusive of the use of any return flow, seldom exceeds 40 percent. It is reasonable to expect an increase of the overall efficiency of about 10 percent or more for a system with some automation. The advantages of automation are not limited to savings in operation cost and in water. It also alleviates the risk of waterlogging and salinization. A further advantage is that it increases the reliability and accuracy of water distribution. This contributes to the establishment of a climate of confidence between the operating authority and the farmers, which in turn contributes to the effective organization of water user groups and their participation in operation and maintenance activities. With automation, it may also be possible to accurately know the volume of water delivered to individuals or groups of farmers. This makes possible the introduction of volumetric water charges, combined or not with a system of annual volumetric allocation. This approach is a useful tool for encouraging farmers to optimize the use of limited water allocations and to increase productivity.

Improvements in automatic control equipment have greatly expanded the field of canal operation and control. Automation has become a common term when discussing modern canal systems. 'Automation' is defined as *A procedure or control method used to operate a water system by mechanical or electronic equipment that takes the place of human observation, effort and decision; the condition of being automatically controlled or operated.*

Automating a canal system is therefore implementing a control system that includes automatic monitoring or the control equipment that upgrades the conventional method of canal system operation. Automation is used to simplify and reduce or replace the decision-making process of the operators and to implement a decision. It is increasingly used to improve the effectiveness and to reduce the cost of water supply system operations.

Automation of distribution canals becomes essential for optimum conditions. The process must not be dismissed out of hand as too expensive. Its economics must be studied, keeping in mind that reduced on-farm costs and water requirements, and increased yields and management capabilities, provide savings that usually will more than make up for increased project costs. Reduction of project operation costs and water loss is also a benefit of automation and is usually the only one considered.

Automation of a canal system should not be thought of as an end in itself, but rather as a means to better operate that system. The true goal should be to achieve the most efficient and beneficial operation possible. Expanding control system capabilities is one way of economically reaching this goal.

Automation can be obtained in many ways, some extremely simple, others very complex. A long crested weir (also called duckbill or folded weir) by its very existence maintains a nearly constant water level in a canal under variable flows. A closed pipe line system connected to a variable source such as a canal carrying excess water to local needs, will automatically convey the exact amount of water that is withdrawn at the turnout valves.

Float-actuated mechanical devices such as the Neyrtec constant level and the improved controlled leak canal gates are self-contained but can obtain a constant canal water level. These systems easily adjust to variable flow rates. If they are desired to control down to the no-flow regime rather than just regulate the flow, they need to be installed in top-level canals. They are sluggish in reaction as they receive input in sequence from each adjacent reach to transmit a change over the whole canal length.

The objective of building and operating a canal system is to serve the farmlands, supply municipal and industrial needs, carry storm runoff to natural drainage channels, collect water from several independent sources into a single supply, convey water used for the generation of electrical power and supply water to fish and wildlife and for recreation. In order to serve the above purposes as efficiently and economically as practicable, canal operations should be tailored to meet the specific requirements of the systems.

The flexible, high-quality operation of a canal system will yield many benefits, some of which are:

- increased crop production,
- reduced water use,
- better service to the water users,
- increased power generation,
- decreased power consumption,
- labour savings,

- less water wasted,
- easier management of the water system,
- improved protection of the conveyance facilities,
- reduced maintenance requirements,
- more accurate and equitable distribution of water,
- fish and wildlife enhancement,
- decreased flood damage,
- less need for subsurface drainage,
- better response to emergencies,
- social benefits (user's satisfaction, less conflict),
- environmental protection, and
- improved co-ordination with power operations.

Most of these benefits result in obvious economic savings and some of them represent intangible benefits to which it is difficult to assign a monetary value. Regardless, they all result in a better and more cost-effective water resource project.

Present status of canal automation in India

To improve irrigation efficiency in general and to assure a reliable supply of water to users in particular, many water resource projects in India, whether existing or new, have taken up the challenge to improve water management by way of remote monitoring and controlling of various physical structures and parameters. In most of the projects, it has been planned to select a segment of the existing canal system for a pilot project which will study and analyse the benefits of improved water management systems and which can cover a larger area later on.

To describe the present status of canal automation in India, we will discuss the case studies of canal automation on the following water resources projects:

1. the Chambal project in Madhya Pradesh,
2. the Khadakwasla project in Maharashtra,
3. the Majalgaon project in Maharashtra,
4. the RAJAD project in Rajasthan,
5. the Sardar Sarovar project in Gujarat and
6. the Tungabhadra project in Karnataka.

The Chambal project in Madhya Pradesh

The Chambal project is a multipurpose project, a joint venture of the states of Madhya Pradesh and Rajasthan. It is comprised of a cascade of reservoirs, i.e. the Gandhisagar reservoir in Madhya Pradesh, the Ranapratapsagar reservoir in Rajasthan and the Jawaharsagar reservoir in Rajasthan, (with a powerhouse at the foot of each of the reservoirs), and of a terminal barrage at Kota in Rajasthan, which has two main canals for irrigation purpose. Total installed capacity of hydropower generation at the three dams is 386 MW. The state of Madhya Pradesh is served by the Right Main Canal (RMC), which cuts across Rajasthan for about 130 km, then crosses over the Parvati river and enters Madhya Pradesh with a design discharge of 110.4 cubic meters per second (cumecs) at the Parvati aqueduct. The entire Chambal command area has been divided into seven administrative divisions, namely Sheopur, Sabalgarh, Joura, Morena, Ambah, Gohad and Bhind.

The Chambal project was commissioned in 1961-62 with a projected irrigated area of 283 500 ha annually (85 050 ha for *kharif* and 198 450 ha for *rabi* crops). The maximum irrigation achieved so far was 188 307 hectares in 1977-78, and the minimum 124 016 ha in 1982-83. The average area under irrigation over the last fifteen years is of 148 000 ha. Large areas at the tail-ends of the Ambah Branch, Morena Branch, Bhind Main canal and Mau Branch canal have not received the benefit of canal irrigation since the commissioning of the project.

In the present system of operation of the Chambal canal network, the availability of water at the beginning of the *rabi* season, i.e. on 15 September, is assessed. In the Chambal command area, water is allocated from crop season to crop season, through an announcement called 'Sinchai Ghosna', which is issued before or on the eve of the crop season and contains figures of areas to be provided with water at the subdivision, block, *tehsil*, assembly and branch-distributary levels. The names of the villages to be irrigated, and in each village of the channel and the reduced distance from the heads up to which water will be provided, are also indicated. During the first fortnight, the Right Main canal with all distributaries under its direct command, the Lower Main canal, the Morena Branch, the Bhind Main and the Mau Branch canals are supplied with water. During the second fortnight, while they continue to get water, the Ambah Branch canal in turn is supplied but all the direct command distributaries on the Right Main canal are closed. During the third fortnight, the Right Main and Ambah Branch canals with all their direct distributaries are supplied with water. The minors, sub-minors and fields get their water by adjustments. Although the announcement is made at the start of the *rabi* season, it has not been possible, so far, to really supply the allocated water and the tail-end users have always suffered. An analysis of pattern of deliveries at the Parvati aqueduct indicates that the supplies have wide fluctuations daily, monthly and yearly, and also vary according to the crops. Due to the unreliability of flows, many farmers are left guessing as to the quantity and timing of the supplies they will receive.

A part of the Chambal canal system in Madhya Pradesh has been selected for a UNDP-funded pilot project, in the Sabalgarh administrative division, and in association with the local Central Water & Power Research Station.

The Khadakwasla project in Maharashtra

The Khadakwasla irrigation project consists of three dams, viz. the Tanaji Sagar dam (Panshet dam) on the Ambi river, the Veer Pasalkar (Warasgaon) dam on the Mose river and the Khadakwasla dam on the Mutha river. The Khadakwasla dam is located downstream of the confluence of the Ambi and Mutha rivers, some 17 km west of Pune city, near the village of Khadakwasla. The New Mutha Right Bank canal is a contour canal, with a design discharge capacity of 58 cumecs. It is planned to irrigate 97 100 ha of gross command area, with 62 146 ha of irrigated area over the district of Pune. The command is covered by 60 distributaries off-taking either directly from the canal or from the Bhigvan branch (located about midway along the canal) and the Indapur branch in which the New Mutha Right Bank canal tails.

The New Murtha Right Bank is a long canal, and the effect of a change made in the release of water at its head will take time to be felt at the distributary heads downstream. A rough estimate is that it will take about 24 hours for a change made at the head to get transmitted down to the tail. When a canal has to be run with requirements down the line changing from day to day, operation becomes complicated for the following reasons:

1. Changes have to be made in the releases at the head of the canal in anticipation of the change of demand (closing of running distributaries and opening of new ones) and associated travel time to the various distributary off-takes.
2. When level changes occur down the main canal as a consequence of a change in release at its head, the discharge into the distributaries will change. Therefore, unless close watch is kept on distributary off-takes and gate settings are adjusted, deliveries into distributaries

will not match what is planned. The operating staff will tend to play safe and ensure that their distributaries are drawing more than what is strictly required.

3. Gate settings at cross regulators will need to be adjusted to reduce fluctuation in water levels in the different sections of the canal. The frequency of adjustment will depend on how releases into the canal change to satisfy the changed demands at distributary off-takes.

The decision on the release of water into the New Mutha Right Bank canal from the reservoir is taken at the main administrative headquarters, i.e. in Pune, which must decide whether it is appropriate to release the entire amount of water determined based on the requirements arrived at from the operational schedule received from the field, or to cut down on the requirements. The decision will be made in the light of the current storage available in the reservoir and of an assessment of the likely demand and inflows in the reservoir for the rest of the season, and of the storage that is desirable at the beginning of the next season.

The water delivery system as practised in the state of Maharashtra is known as the *shejpali* system. In this system, at the beginning of the season the farmers make applications in prescribed forms for the irrigation of specific areas. The Department of Irrigation accedes to the requests depending on the availability of water and other relevant factors. In the *shejpali* irrigation delivery system, the distributary is considered as a unit, i.e. with all minors and sub-minors if any is running for the same number of days as the distributary. The irrigation schedules are prepared taking into account more or less uniform characteristics of the command, as it is very difficult in practice to calculate the demand based on the condition of the various fields in the command. In the *shejpali* system, the Department of Irrigation commits itself to providing adequate water at the outlet to meet the irrigation requirement of a crop till maturity. What is adequate for the standing crop in the field is decided by the farmer and the effectiveness of irrigation is judged by the degree to which the irrigation department is able to fulfil its commitment to the farmer. For the success of this system, it is necessary to have reliable irrigation supplies at least at the head of the distributaries.

The pilot project is conceived as one unit, integrating telemetry, communication, computers and decision support software to improve system operations. It covers the operation of the New Mutha Right Bank canal and its distributaries. Three agencies, i.e. the Department of

Electronics of the central government, the Department of Irrigation of the government of Maharashtra and CMC Ltd. are associated in the project.

The Majalgaon project in Maharashtra

The Majalgaon irrigation project is located in the Marathawada region of Maharashtra, south-east of Aurangabad, in the valley of the Godavari river. It constitutes the downstream part of the Jayakwadi project, which is planned to irrigate about 350 000 ha of cultivable command area. In this region, the Paithan dam on the Godavari has a gross storage capacity of 2 950 Mcm, supplying water to the Paithan left bank and right bank canals, and the Majalgaon dam on the Sindhphana river, with a gross storage capacity of 450 Mcm, is supplying water to the Majalgaon right bank canal. The runoff of the Sindhphana basin is insufficient to meet the water requirements of the Majalgaon project, and shortages are to be supplemented by additional releases from the Paithan dam.

Compared to other Indian states, Maharashtra is poorly endowed in water resources. Even with full exploitation of the available water resources, the total area that could be brought under irrigation, including well irrigation, would be about 34 percent of the total cultivable area. The water delivery schedule popularly known as the *shejpali* system has been in practice in the state for over fifty years. In its present form, any change made at the head of a canal to suit the changing demands down below takes a long time to be felt at the distributary. If there are frequent changes in the demands on the distributary, the releases at the head reach must be changed accordingly, and unless a very close watch is kept on the distributary off-takes and there are frequent gate settings adjustments, the deliveries in the distributaries will not match what is anticipated.

To overcome the problem, the government of Maharashtra has implemented a system of volumetric water distribution to the farmers' association on the Majalgaon project. This requires that the volumes, flows and levels in the main and branch canals be controlled to suit the operational philosophy. Improved water control with the help of constant water level gates, baffle distributors and remote monitoring and real-time computer-assisted management control has been executed on the Majalgaon project.

The government of Maharashtra has introduced a pilot project to improve water control management on the Majalgaon Right Bank canal from Km0 to Km165 in two successive phases. The first phase has covered the entire 100km length of the canal and the entire length of its Ganga Masla branch. Technically it consists of a combination of control and regulation techniques associated with remotely monitored computer-assisted control on the main canal and local control using float gates, long crested weirs, baffle distributors and self-regulated outlets on GMBC distributaries and minors.

The Majalgaon Right Bank canal has a design discharge capacity of 83 cumecs at its main head regulator. Ten cross regulators are planned over its 100 km. The Ganga Mala branches off at about 8 km on the Majalgaon Right Bank canal and has a designed discharge capacity of 9 cumecs. Upstream control with AVIO gates and baffle distributors at the head gate of the Ganga Mala branch, along which nine duckbill weirs have been installed over a 13km stretch for improved water control. The length of weir is about 50 m for a discharge of 9 cumecs.

The constant volume concept of operation will be used on the Majalgaon Right Bank canal. When it will be extended beyond Km100 and the demand of irrigation water at main-head regulators will increase beyond 60 cumecs (as against a designed discharge of 83 cumecs), the canal will be operated on the concept of controlled volume.

At each remote location, remote terminal units will be installed. Sensors will measure water level upstream and downstream of the gate and at the centre of the pool. The gate position sensor will sense the position of each gate in the control structure. Data will be transmitted by radio. The main control centre will be located at the Majalgaon dam site and will have the usual hardware and software necessary for remote monitoring and control functions.

Water will be supplied by volumetric allocation with a rotational water delivery system. User associations, covering an area of about 200-300 ha, will receive water from the canal system and will distribute it to their members on a rotation basis.

The second phase will be implemented on the remaining part of the Majalgaon Right Bank canal and its distribution system, based on experience gained in the first phase. The pilot project is carried out under an Indo-French co-operation programme in water resource management. The government of Maharashtra, in consultation with the French consulting firm GERSAR, has implemented the first phase of the project at a cost of Rs136.7 million.

*The Rajasthan agricultural drainage (*Rajad*) project*

The Chambal command area, in the south-eastern part of Rajasthan, serves an irrigated area of 229 000 ha from storage facilities on the Chambal river and a diversion dam at Kota. The Left Main canal serves about 102 000 ha of irrigated land and the Right Main canal 127 000 ha of irrigated land. In addition, the Right Main canal carries water to irrigate an area in the adjacent state of Madhya Pradesh. The latter, which thus shares the water of the Chambal river with Rajasthan, has installed a wireless radio network along the Right Main canal to monitor its share of the water. This has proven to be a valuable tool in tracking flows along the initial 130 km of the Right Main canal, which are in Rajasthan.

The Command Area Development (CAD) authorities of the Chambal and Indira Gandhi Naher projects aim to have an improved sub-surface drainage and water management in the command area. An important part of water management is the automation and remote monitoring system on the canal. The Chambal CAD authorities recognize the value of canal automation and have initiated steps to install a voice communication radio network that would put all parts of the command area within 20 km of a base station. The voice communication network will consist of ten field base stations located at CAD offices throughout the command area. In addition there will be 11 mobile units for senior staff to allow them to keep in contact with all stations when they are away from their offices. A data communication network is also planned on the canal system to collect data related to water levels and flow rates.

In a pilot project, four remote monitoring sites have been selected. From these, data will be transmitted to the CAD office for monitoring and control. A head regulator gate on one of the distributaries which was of the slide type and manually operated has been replaced by an automatic gate. To maintain constant water level in the distributaries, duckbill weirs are planned to be installed at the location of an existing fall-cum-village road bridge structure. The pilot project comes under an Indo-Canadian co-operative aid project and is being implemented by the CAD authorities of the Chambal and Indira Gandhi Naher projects in consultation with Canadian experts.

The Sardar Sarovar project in Gujarat

The Sardar Sarovar (Narmada) project, currently under construction, is one of the largest multipurpose water resource development projects in India. It will consist of a large concrete gravity dam on the Narmada river in the state of Gujarat, a riverbed powerhouse (underground, with an installed capacity of 1200 MW), a canal-head powerhouse (surface, with an installed capacity of 250 MW) and a widespread network of canals and drainage channels as required to irrigate about 1.792 million ha of land out of the 3.428 million ha of the gross command area. The command area of the project spreads over 12 districts and 62 *tehsils* (partially or fully) of the Gujarat state. The canal water released from the Sardar Sarovar reservoir will pass through the 250MW canal-head powerhouse located below the Vadgam saddle dam on the right rim of the reservoir near the Sardar Sarovar dam. The water will then flow through four secondary ponds created by a series of rock-filled dams, which are interconnected by open channels. These ponds provide diurnal balancing storage of the flows released through the canal-head powerhouse to provide hydroelectric peak capacity. The 458km-long concrete-lined Narmada Main canal will be one of the world's largest multipurpose water supply canals. It extends on the northern side from the dam site up to the Gujarat-Rajasthan state border. The Narmada Main canal will have a design discharge capacity of 1 134 cumecs at its head and it will taper down to 71 cumecs at the border. The canal is extended further to irrigate parts of the Barmer and Jhalore districts of Rajasthan and also to provide domestic, municipal and irrigation water supply. Its head regulator will control water deliveries through five 12.2 x 13.5 m radial gates. The cross section of NMC at its head has a 73.1 m bottom width and a water depth of 7.6 m with a 2:1 inner slope on either side. The flow velocity at the head of the canal with a designed discharge of 1 134 cumecs will be 1.69 metres per second.

The Narmada Main canal will supply water to a vast conveyance and delivery network comprised of branch canals, distributaries, minors and sub-minors of a total length of more than 47 000 km. The canal system has been designed to operate on the 'controlled volume' concept for timely deliveries. A real-time computer-based monitoring system and a state-of-the-art communication network will allow remote control operation of the canal conveyance system to provide reliable and equitable distribution of water. In a 75-percent dependable year, under full development, there will be approximately 9 million acre feet (Maf) of water delivered through this system in Gujarat from the reservoir formed by the Sardar Sarovar dam.

From the Narmada Main, two major branch canals branch off, at Km264 and Km386, to convey water for irrigation, domestic and municipal needs and for industrial uses. The Saurashtra Branch, which branches off at Km264, is 104km-long and has a difference of 40 m over that length. This means that water needs to be lifted by about 70 m to cover the command area and the entire Saurashtra region for the supply of drinking water. At three fall sites, hydropower will be generated and used to lift water at five pumping sites. Similarly, on the Kutchchh Branch canal, which branches off at Km386, there will be a series of falls and pumping plants to serve the command area in Kutchchh and to cover the entire Kutchchh region for the supply of drinking water.

In a 75-percent dependable year and under full development, the Gujarat state will have approximately 9 Maf of water to use from the Sardar Sarovar reservoir. Priority is to be given to the supply of drinking water and of municipal water followed by industrial water and irrigation. Thus, about 1.06 Maf of water will be used for the drinking and municipal water supply and for industrial use; 8 215 villages and 135 urban centres will receive water for drinking purposes. About 7.94 Maf of water will be available for irrigation to cover a widespread command area. It is planned to irrigate about 1.79 million ha of land, which means that water availability per unit area, at the head of the main canal head regulator, will be about 55 m^3.

The command area covered by the Kutchchh branch canal lies at a distance of about 800 km from the Sardar Sarovar reservoir. The effect of change made in the release of water at the head of the Narmada Main canal will take time to be felt downstream. A rough estimate is that it will take about 7 days for a change made at the head to get transmitted down to a tail located 800 km away. The operation of the canal system becomes complicated if operated in a conventional way, for the following reasons:

1. The canal water released from the Sardar Sarovar reservoir will pass through the 250 MW canal-head powerhouse located below the Vadgam saddle dam on the right rim of the reservoir. As this powerhouse is provided for hydroelectric peak requirements, it will be operated for about 8 to 10 hours a day. To provide diurnal balancing storage of flows released through the powerhouse and water drawn into the canal system, a balancing

reservoir is created upstream of the main canal head regulator. A diurnal variation of about 3 m will be there in this reservoir, thus to control the discharge into the main canal, the gates of the main canal head regulator will have to be operated more frequently to take care of changes in water levels in the balancing reservoir.

2. Changes have to be made in the release not only at the head of the Narmada Main but also at the head of the other main canals branching off it, in anticipation of changes in demand. This requires a very close monitoring at all locations of the control structures.
3. When level changes occur down the Narmada Main canal as a consequence of a change in release at its head, the discharge into the branch canals and hence the distribution system will change. Therefore, unless close watch is kept on branch canal off-takes and gate settings are adjusted, deliveries into the branch canals will not match what is planned.
4. Settings at cross regulators will need to reduce fluctuation in water levels in sections of the Narmada Main and its branch canals. The frequency of adjustments will depend on how releases into the main canal satisfy the changed demand downstream.
5. Pumping stations on the Saurashtra and Kutchchh branch canals can create emergency conditions when they fail to draw their designed discharge due to either power failure or some mechanical fault at the pumping plants. The design discharge of the Saurashtra Branch canal is 319 cumecs. When such a heavy discharge is rejected, the water already released from the reservoir must be handled so that it is not wasted and the main canal and respective branch canals are not overtopped. Simultaneous gate operations of various control structures become essential in such a situation.

To overcome the above problems, the conveyance and delivery system is planned to be operated with a design discharge capacity of up to and above 8.5 cumecs under the ‘controlled volume’ concept. The operational plan is designed to provide efficient, reliable and equitable water supplies to the users. The primary objectives are to:

- respond quickly to changes in delivery requirements throughout the system;
- minimize adverse hydraulic transients during flow changes;
- provide fast response in unusual or emergency operation conditions by shortening the time between detection, rectification and return to service;
- operate the delivery system on an almost full-time basis;

- make reliable deliveries of predetermined amounts of water to every service point in the command area (a rotational water delivery system will result in not all supply points operating simultaneously); and
- achieve optimum irrigation efficiency commensurate with high agricultural production.

Operation of the Narmada canal system

Canal operation in general centres on the pivot point of the canal pool's water surface. The pivot point is the location within a canal pool at which the depth remains constant while the water surface slope varies. The Narmada canal system is planned to be operated on a controlled-volume basis by managing the volume of water contained in each canal pool. There is no well-defined pivot point. The volume can be made to change to satisfy operational criteria, allowing the pivot point to move within the pool. The water surface may sometimes rise or fall without a pivot point, like a reservoir. Since the operation is based on volume, either flow or depth may be used as the measured quantity. The Narmada canal system is also planned to work on the upstream operational concept. The upstream operational concept is used when the upstream conditions or supply dictate how the system is to be operated. As the availability of water for irrigation is limited to the availability of water in the Sardar Sarovar reservoir, the upstream operational concept is used.

The operation of a canal system is accomplished primarily by controlling the flow through the check structure. Flow charges which are initiated by gate movements create the translatory wave phenomenon. The Narmada canal system is planned to be operated by the simultaneous control structure operating technique. Adjusting all the canal check structures simultaneously can establish the new steady state flow condition in the canal system in the shortest possible time.

The Narmada canal system is planned to be operated using the supervisory automatic control method. The supervisory control method involves monitoring and control of the control structures from a central location referred to as the main control centre. Monitoring is the collection of data from various sites on the canal system and the presentation of this information for use in determining control actions. Data such as water level, gate positions, flow and pump status are collected at each remote location, including check gate structures and pumping plants. The information collected at all remote locations is transmitted to the control centre, where it is analysed and presented in a suitable format. Control commands are then transmitted back to the remote sites, creating control actions such as gate movements. Supervisory control enables control decisions to be based on comprehensive information. A change in any portion of the system can be recognized promptly and the appropriate control action taken. This capability maximizes the operational flexibility of a canal system.

The system is also planned to be operated on the upstream control concept. The control concept in general is defined by the location of the information needed for control relative to the control structure. This information can include the flow, depth or volume at one or more points in the canal system. In the case of the upstream control concept, the control structure adjustments are based on information from upstream. The required information could be measured by a sensor located upstream or based upon the upstream water schedule established by the irrigation management authorities. Upstream control transfers the upstream water supply (or inflow) downstream to points of diversion or to the end of the canal and is compatible with the upstream operational concept.

The Narmada canal system is thus planned to be operated on the controlled volume method with an upstream operational concept. The control action is initiated with an upstream control concept and with the supervisory automatic control method. The simultaneous control structure operating technique will enhance the canal operation. Based on these, for the purpose of irrigation management it is proposed to divide the 3.428 million ha of gross command area into blocks of approximately 26 000 ha. The irrigation management data for each of the blocks will be collected by a data collection centre, using very high frequency radio. One hundred thirty-two such centres are planned. They will communicate data required for the regulation of branch canals to divisional operational centres, which will be in charge of branch canals. Taking into account the limitations imposed from a hydraulic and canal operation point of view, 15 divisional operational centres are planned. They, in turn, will report to the main control centre, which will be in charge of the overall operation of the Narmada canal and will be located near Gandhinagar.

The Narmada canal conveyance and delivery system of up to 8.5 cumecs designed discharge capacity has been planned and designed to be operated on the controlled volume operational method with remote monitoring and control system for its operation. The construction of the canal conveyance and delivery system in Phases I and II of the project area is in full swing. The work in Phase I is about to be completed. One divisional operational centre in Phase I of the command area will be selected to carry out the pilot project. It will cover about 100 km in length over the canal system with some 120 flow control gates and about 0.15 million ha of irrigated area. The Sardar Sarovar Narmada Nigam Co Ltd, in consultation with experienced consultants, will take up the task of implementing the pilot project in the near future.

The Tungabhadra project in Karnataka

The Tungabhadra project was conceived and executed to serve the chronically drought-prone districts of Raichur and Bellary of Karnataka, and the Anantpur and Kurnool districts of Andhra Pradesh. To manage this project the Tungabhadra Board was constituted by the Government of India in 1955. From the 2 300 Mm^3 of water expected to be developed by the project on average over the long term, Karnataka receives 1 515 Mm^3 and Andhra Pradesh 785 Mm^3.

The Tungabhadra project involves three main canal systems, viz. on the right side (both a low-level unlined and a high-level lined canal systems) and on left side (lined canal system), running for a total length of 750 km and covering an irrigated area of more than 0.5 million ha.

The present canal operational procedure is based on the following principles:

1. Canal capacities are designed for average duties. If a canal serves areas of mixed crops, its capacity is sufficient to provide authorized discharge for the seasons with the maximum requirement. In other seasons it is operated at a reduced discharge.
2. Continuous flow is provided to the outlets so that, in principle, canals run continuously to provide a specified discharge to the controlled outlets. If a full supply is not required, then its discharge can be reduced.
3. Variable supply and flexibility are important operational objectives since variable discharge may be required at any level, either to serve different localised areas in different seasons or to meet different crop requirements within a season.

The flexibility provided in the present distribution system requires that gates at every control structure be adjusted to respond to variable flows in the parent canal. For the system to work, it is necessary that the gate operators perform their duties correctly and on time, and that there be no interference in the gate setting or in the flow regime of the parent canal.

The pilot project has been executed in the state of Karnataka on the right bank high-level canal up to the Karnataka-Andhra Pradesh state border. In this task, four agencies are associated. The Central Water Commission of the government of India, the Tungabhadra Board, and Bharat Electronics Co Ltd, in consultation with USAID experts, have executed the pilot project.

From the above case studies it can be noted that the Central Water Commission and the Department of Electronics of the central government, various state governments and public- and private-sector companies have entered programmes to improve water management on existing water resource projects by involving engineers and scientists from various disciplines, all of them with the goal to satisfy the desire of end-users for reliable and timely delivery of irrigation water. With the improvement in water management now being planned, it will be possible to improve the irrigation efficiency at farm level and operational ease and flexibility at project level.

Cost aspect of canal automation in India, based on case studies

The financial and economic analysis of plans to automate irrigation canal systems implies complex technical exercises that require the expertise of professional economists and financial analysts as well as engineers, agronomists, land classifiers, soil scientists and other irrigation specialists. The financing of such plans, in most cases, requires programmes and financial resources beyond the capability of water users. Financial and economic considerations are therefore the key to the successful implementation of plans to automate irrigation canal systems.

While financial and economic analyses are closely related, a distinction between the two is necessary. Economic analysis is used to estimate total return on investment to society as a whole, without regard to who contributes the resources and who obtain the benefits. The state government or the central government is interested in the economic analysis of a canal automation project to justify disbursements. Financial analysis, on the other hand, is used to determine the inflows and outflows of funds of project entities and of the farmers and other water users. While economic analysis and justification may or may not be needed for a given canal automation project, its financial feasibility is required for the successful implementation of the automation project.

Economic and financial analyses should not be limited to only the costs and benefits associated with operating the project facilities. Improved irrigation systems and better water management by way of automated irrigation canal systems provide each farmer with the ability to improve his on-farm management through flexible scheduling. Cost savings to the farmer and benefits from increased crop yields, better quality of products and ability to diversify crops must also be considered in the analysis.

The computation of the benefits of an automation project is quite complex. An automation project is undertaken to improve irrigation systems so that they can meet enhanced operating criteria. Usually this implies increased water volumes and improvements in conveyance, distribution and application efficiency. These, in turn, may require the re-dimensioning of some structures and, if enough water is expected to be saved and additional land is available nearby, may lead to an expansion of existing irrigation projects by increasing their command areas.

The decision to implement a control system should not be justified solely on tangible benefits. Intangible benefits are significant on most canal projects. Estimating tangible benefits and properly describing intangible benefits related to the need to upgrade a canal operation is essential when one examines the feasibility of a proposed automation system.

Implementing automation on new projects is a comparatively simpler task than on existing projects. Built-in constraints and limitations in existing projects must be identified, evaluated and answered on a project-by-project basis. As these constraints are different in each project, their economic evaluation will also differ. It is not possible to assess the cost of automation on existing projects by rule of thumb. In the case of a new project, one can estimate a two-to-three percent cost for automation. In reality, the cost of civil, mechanical and electrical engineering structures and components in water resources projects increases during the execution of the project, the cost of electronic components either remains at the same level or decreases; thus, cost figures may come down when the cost of the completed project is considered.

Improving the operation of the Mahi right bank canal

The feasibility study undertaken in March 1982 by the French consulting firm GERSAR on improving the operation of the Mahi right bank canal concluded that it would be possible to improve the efficiency of the system with automation. According to the study, the efficiency of the network at the time was 23 percent. The irrigation authority proposed to introduce *warabandi* in the command area without any improvement in regulation. This would increase efficiency to 28 percent. The study recommended to have "dynamic regulation" on the canal system implemented in two stages. At the end of the first stage the efficiency of the system would increase to 34 percent and to 44 percent by the end of the second stage. The pilot project was selected to cover 100 km of the main canal and 4 400 ha of the distribution network. The cost of automation was estimated at Rs500 per ha on the main canal and Rs1 700 per ha on the distribution network, as of 1982.

Canal automation on the Sardar Sarovar project

The feasibility study presented in April 1990 by the Gujarat Communications & Electronics Co Ltd on a control and communication network for the Narmada canal proposed a supervisory control system based on the controlled volume concept. The Narmada main canal has a designed discharge capacity of 1 134 cumecs at its head tapering down to 71 cumecs at the Gujarat-Rajasthan border and it would be operated on the automation concept. The main canal has 42 branch canals. Most of them would have a designed discharge capacity of more than 8.5 cumecs. Optical fibre would be the communication medium. A canal network with a designed discharge capacity of less than 8.5 cumecs would be operated by local manual control. Information on irrigation water demand would be sent to a data collection centre through very high frequency radio. The data collection centre would be the terminal point at which the design discharge capacity of the canal system would be of 8.5 cumecs. The cost of the control system, which includes the cost of the communication system up to the village service areas, was estimated at Rs1 970 million, for a total project cost of Rs64 800 million.

As the command area of the project covers 1.863 million ha, the cost per hectare works out at Rs1057. This figure can go up if the project authority decides to extend the canal automation to the grid with a discharging capacity below 8.5 cumecs. It is difficult to come out with a realistic figure of the cost of canal automation until automation has been implemented. Also, in the case of this project, the cost of civil, mechanical and electric works incurred for the control structures is not included in the cost of canal automation, as it is a component of the overall project cost.

The breakdown of the cost estimate of Rs1970 million is as follows:

Sr. No	Description	Cost (Rs million)	Remark
1	Control system (computer system, remote terminal units sensors and controllers)	746.0	Up to 8.5 cumecs discharge capacity canal system
2	Fibre optic communication network	964.0	Up to 8.5 cumecs discharge capacity canal system
3	VHF Communication Network	186.0	Below 8.5 cumecs discharge capacity canal system
4	Time division multiplexing network	74.0	Up to 8.5 cumecs discharge capacity canal system
	Total	1 970.0	

Dynamic regulation on the Majalgaon right bank canal

A pilot project of "dynamic regulation" has been selected for the Majalgaon right bank canal, covering 100 km in length for the main canal, 18 km for the Ganga Massla branch canal and its distribution systems.

The initial cost estimate of the pilot project, at the 1992-93 price level, was Rs30 million plus 7.3 million French Francs. At the conversion rate of FF1 = Rs7.5, the total estimated cost of the pilot project was Rs84.75 million.

The detail of expenditure incurred on the various components of the pilot project is as follows: Rs17.8 million for civil engineering works, Rs28.7 million for mechanical engineering works, Rs90.1 million for electrical and electronic components. This means a total expenditure of Rs136.6 million. The cost of dynamic regulation works out at Rs1 663 per ha on the Majalgaon canal, Rs2 961 per ha on the Ganga Massla branch canal and Rs3 755 per ha on the Minor branch canal.

The cost of canal automation on an existing irrigation project and on a new project cannot be compared, as the built-in constraints in an existing irrigation project will not only limit the degree of automation but also increase the cost by way of remodelling the existing canal systems. It can be concluded that the cost of automation on a main canal can vary from Rs1 500 to Rs2 000 per ha and that on a secondary canal from Rs3 000 to Rs4 000 per ha.

The cost of improved water control methods depends on the degree of automation desired. Even though supervisory control may amount to about one and a half percent of the project cost, it is not desirable to directly employ the said technique. When new technology is applied, one must keep in mind that high technology by itself has not been found to be very effective. It has to be matched by a proper environment and by proper user response. A farmer can receive the maximum possible benefits if there is flexibility in water distribution in terms of frequency, rate and duration. But this may not be practicable in our irrigation canal systems, as water has become a scarce commodity. If we are in a position to offer reliable water supplies to the farmers for irrigation, the goal to improve our water management plan can be considered as achieved. Water management is now viewed as a scientific art. If, by way of automation, the irrigation management authority is in a position to offer reliable water supplies and thereby boost the credibility of an organization, what monetary value can we assign to credibility?

Conclusion

The management of irrigation systems has gained importance over the last five decades due to a tremendous increase in irrigated area in India, primarily as a result of massive investments in new and existing surface irrigation projects. There has been a growing realization of possible improvement in water management for a more efficient use of available water resources. The potential of information technology applications for improved irrigation system management was realized long ago, but concerted efforts on this front have only been made in the last ten years. The use of computers, communication and information to control irrigation systems will yield many benefits, resulting in obvious economic savings and in intangible benefits whose value cannot be measured in monetary terms.

Rehabilitation and modernization of the existing water resource projects can be carried out under three main headings, engineering, agronomy and administration.

The engineering side includes modernization and rehabilitation of all headwork and their replacement where they have outlived their usefulness, and modernization of canals, canal structures, in particular the regulating devices, provision of additional cross regulators, permanent outlets and on-farm development works such as field channels, field drainage and land levelling.

The agronomic side includes the review of current cropping patterns, scientific assessment of crop water requirements to upgrade the system to meet the new demand, adoption of high-yielding varieties, propagation of proper cultural practices and so on.

The administrative side includes the consolidation of land, volumetric supply of irrigation water, changes in water rate policy and the like.

All of this can be achieved by improved water management at farm level, keeping in mind the existing constraints of the physical system and its operational constraints.

It is easier to plan and design a new project to be operated on the canal automation concept than to implement that concept in existing water resource projects. Physical and operational constraints must be evaluated and based on the impact of each constraint, the dynamic system design approach will have to be formulated to produce an economical technical solution.

With the exception of Sardar Sarovar, on all projects where canal automation is either planned or being implemented, it is done basically with a view to carry out the remote monitoring of the system through either manual control or local automatic control to achieve reliability in water flows. As the systems have their own constraints, the first step cannot be better than the one planned and it should not be treated as the final step, as we have to achieve an irrigation efficiency of about 60 percent in times to come.

Water is no longer defined as a natural resource but as a commodity, the value of which has been recognised both at administrative and farm levels. Unless reliability in irrigation is achieved, all other efforts to boost the irrigated agricultural sector will not reach the required goal. With limited water resources, it is now the responsibility of the engineers to create water which can be used on farm by reducing the operational and conveyance losses in the system.

Inadequate water in quantity, time and space is the primary constraint on agricultural production. However, when water reaches an outlet in an irrigation system, we cannot afford to remain despondent or indifferent to its proper distribution. Experience teaches us that inefficient water management below outlets not only results in lag of use, but also leads to serious legal complications due to inequity in water distribution. Normally, tail-end users are those who do not get their legitimate share of water. Furthermore, the farmers generally irrigate their farms with as much water as possible and as frequently as possible whenever water is available. This practice cannot be continued when water for irrigation is insufficient. Application of more water to crops does not necessarily mean better yields; on the contrary, it may lead to problems of waterlogging and thereby adversely affect crop yields.

There is considerable interest among farmers in technologically and economically advanced countries over the use of personal computers to implement their own irrigation scheduling programmes. Data collection equipment gathers necessary details about evapotranspiration, rainfall and irrigation. The irrigator selects the parameters of allowable soil water depletion and application depth. Irrigation scheduling forecasts the date and amount of the next irrigation, but does not check the ability of the distribution system to supply the required flow.

Though the below-par performance of an irrigation system is primarily attributed to inefficiency in water distribution below the outlet, it is not the only factor. Problems also lie in the main system operation, and reliable supply of water to the outlet is indeed a prior requirement for success of any management scheme below outlet. Water conveyance could be readily made automatic from the main canal headwork for the scheduling of irrigation at farm level. It requires linkage of the actual requirements of the irrigated crop or plant to the farm outlet as well as to the source of supply.

Recent advances in irrigation have related irrigation scheduling to the complex climate-crop-soil relationship. Increased knowledge of soil and plant characteristics combined with better methods of measuring soil moisture content and estimating soil moisture depletion are available to predict with greater accuracy the time and actual quantity of water needed for the next irrigation. The sensor element for measuring the prevailing soil moisture content could be a commercially available instrument or even a trained technician. The information could then be fed into an automatic data-processing digital computer which has available in its memory the information concerning the characteristics of the soil such as its moisture-holding capacity, the type of plant and its maturity, an estimate of evapotranspiration and many other parameters which may affect the quantity and timing of the next irrigation. A digital computer using many reference inputs determines the irrigation schedule, which is then provided to the computer centre controlling the canal conveyance and delivery system to update the weekly and daily schedule of irrigation as set up at the start of the season, based on the data available then. Thus the assessment of water needed to be released into the main canal can be forecast on a scientific basis, and this will allow a more flexible operation of the canal system. Linkage of real-time data collection and monitoring of the climate-, crop- and soil-related parameters with the canal automation of the conveyance and distribution system is the ultimate goal, and use of information technology below outlet level will be assigned equal priority. The socio-economic conditions of the farmers and the scientific use of water to satisfy crop water requirements will determine the success of the complete approach of implementing automation from headwork to farm level.

Intervention analysis of an irrigation system using a structured system concept

R. Sakthivadivel[1], S. Thiruvengadachari[2] and Upali A. Amarasinghe[1]

[1] IWMI – [2] IWMI Consultant (former NRSA)

Abstract

Modernization with a structured system concept is increasingly adopted in irrigation improvement programmes in the Indian subcontinent and elsewhere to alleviate the burden of operating the system. This paper evaluates the performance of the Bhadra reservoir project in India – before, during and after the introduction of modernization with such a concept. The performance analysis, supported by data generated by remote-sensing techniques, office records, field visits and farmer surveys, focused on water management, agricultural productivity and farmer participation and perceptions. The analysis of IRS IC satellite wide field sensor data on 20 overpass dates during the rice growth cycle of the most recent *rabi* season proved particularly valuable to evaluate water distribution between the distributary commands.

The concept of a structured system and equitable supply-based technology, central to the National Water Management Project intervention in the Bhadra project, did not succeed for various reasons analysed in this paper. The analysis indicates among other factors that water use since then has increased as a result of the cropping pattern being dominated by water-intensive crops such as rice during the *rabi* season. Preferential allocation to head end of command continues and inequity sets in within the distributary commands. The tail-end water supply deprivation is partially offset by farmers practising deficit irrigation. The *kharif* and *rabi* seasons did not come early, so there was water saving. Farmers' organization and participation in decision-making at scheme level and water distribution at distributary level and below are very low. However, agricultural productivity has not registered a significant decline since before the intervention of the National Water Management Project.

The absence of continuing support mechanisms by way of institutional arrangements and effective farmer participation and involvement in implementing the operation plan has been the major cause of the decline in water management, which has slid back to quasi demand-based supply, and in productivity per unit of water. Strong farmer involvement thus holds the key to sustainable performance.

Introduction

The structured system concept in irrigation projects is about maintaining control of the water flow through the use of proportional devices without human intervention, intermittent water supply in the distributary canals and a systematic operation plan. The concept advocated by the World Bank (Shanan, 1992) is being increasingly adopted in the Indian subcontinent in the rehabilitation and modernization of irrigation projects, some of which have been under operation for more than five years after withdrawal of external aid. A holistic performance evaluation of such systems, especially of how well they have been sustained after closure of external credit, is of great significance not only to India but also to other developing countries, given dwindling financial allocations for irrigation operations, maintenance and management, increasing competition for water and interference by vested interests.

The structured system concept is central to the World Bank-funded National Water Management (NWM) project, which covered some 80 schemes in 11 states in India during 1988-1995. Subsequent to the NWM project, the concept was extended to the ongoing Water Resources Consolidation project in the states of Tamil Nadu, Orissa and others. In view of its widespread adoption there is a pressing need to evaluate the adoption of the structured system concept in improving irrigated agricultural performance. This paper attempts to evaluate the Bhadra reservoir project in the state of Karnataka, which was one of the earliest to adopt the structured system concept under the NWM project. The main objective of this paper is to carry out a comparative analysis of the project before, during and after the NWM project. While the main focus will be on water distribution and agricultural productivity, the analysis will also briefly cover other relevant issues such as farmer participation, monitoring and evaluation, and training. The lessons learned could be of use for future implementation of such projects.

The paper builds upon the 1995 evaluation by the International Irrigation Management Institute (IIMI), which focused on water distribution, agricultural productivity, training and farmer participation up to the 1993-94 *rabi* season. That study found that farmer participation had shown no significant progress and planned farmer organizations had not been created, water distribution along the distributaries had improved, and significant improvements in agricultural output and in the value of that output occurred after NWMP was introduced. IIMI has now revisited the project to evaluate the lingering impact of NWMP two years after external aid stopped in 1995.

The analysis will address the following questions:

- Has there been a decline in irrigated area, change in cropping pattern or in land and water productivity of rice, particularly in the tail-end areas in recent years since external inputs stopped?
- Has water management deteriorated in terms of more water being used, head-to-tail

preferential allotment or use, irrigation seasons and crop calendar changed, and the canal operation schedule being different?

- What is the current status of water user associations?

A noteworthy feature of the comparative analysis is the application of satellite remote-sensing techniques to generate objective and de-aggregated information on agricultural productivity during the *rabi* season, particularly on rice productivity per unit of land. Multiple-date data from the recently launched IRS IC satellite during the 1997 *rabi* season also provided indications of equity and reliability of the water distribution between the distributary commands. Ground data were obtained from office records, field visits and farmer surveys.

The comparative study argues that the successful operation of a structured system, particularly in a water-rich environment, is complex and requires realistic planning, rigorous implementation (involving the wholehearted participation of farmers) and a mechanism for sustaining the benefits of intervention after cessation of external aid. The conclusions are supported by a critical analysis of proposed NWM interventions for improved water management and analysis of actual water distribution and agricultural productivity across the command area and through the years during the implementation of the NWM project and since the cessation of aid.

The Bhadra reservoir project

The Bhadra reservoir project (Fig 1) was built between 1946 and 1966. The reservoir has a gross storage capacity of 2 025 Mm^3, a live storage of 1 608 Mm^3 and a surface area of 11 200 ha. An annual withdrawal of 1 747 Mm^3 (61.7 TMC), including reservoir evaporation losses, was awarded to the project by the Krishna River Tribunal, with 1 400 Mm^3 specific to the right bank canal, whose command is covered under the NWM project. The NWM project was implemented during 1987-89 and most of the physical rehabilitation work was completed by that time. The estimated cost of the project is Rs5 500 per ha (US$160/ha) at 1994 prices. However, external funding for operation, maintenance and management was continued up to 1995. Three periods – pre-intervention up to 1988, intervention from 1989 to 1995 and post-intervention thereafter – are considered for analysis of the performance.

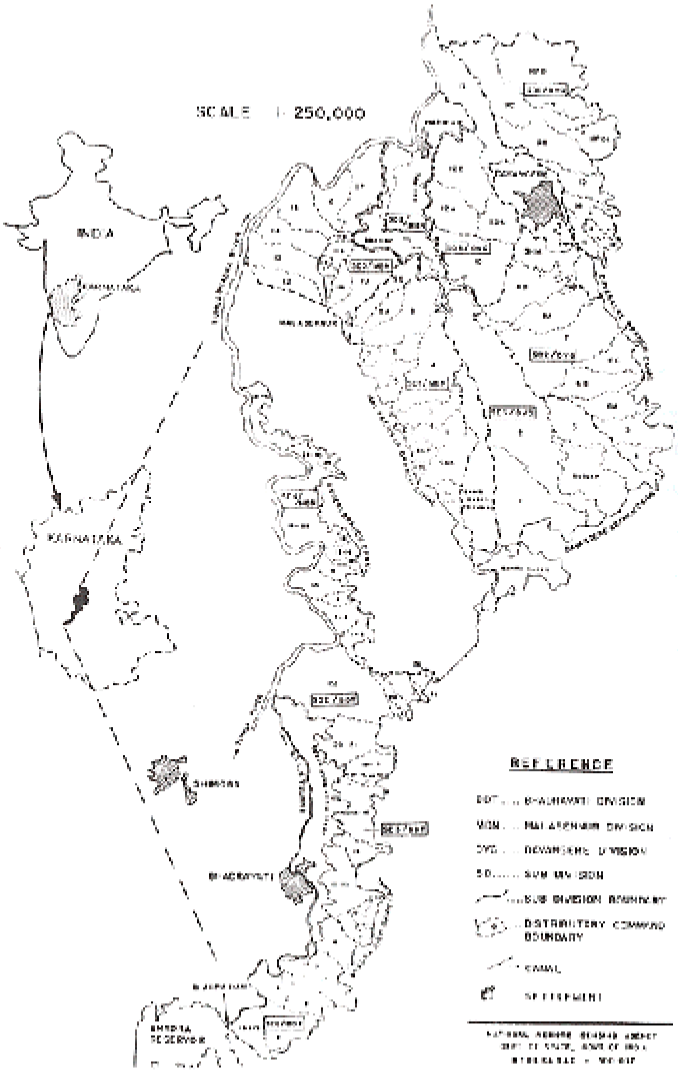

Figure 1. Location of the Bhadra project command area

The right bank canal, with a full supply discharge of 75 cumecs, commands an area of 92 360 ha and has 29 direct distributaries, which irrigate 17 050 ha. The Anvery Branch canal, watering 6 320 ha, branches off at Km76.4 of the right bank canal. Further along, at Km103, the right bank canal bifurcates into the Malebennur Branch, benefiting 23 710 ha, and the Davangere Branch, which waters 45 280 ha. Administratively the whole right bank canal command area is divided into three divisions: Bhadravathi, with three subdivisions; Malebennur, with four subdivisions; and Davangere, with four subdivisions.

The annual rainfall in the command area is about 800 mm and decreases toward the tail end. Most of the rainfall is concentrated during the south-west monsoon period of June to September. The mean monthly evapotranspiration is equal to or below rainfall during July to October, but is substantially above it during the rest of the year. Even during the south-west monsoon period, breaks in the monsoon are frequent, necessitating supplemental irrigation. The command area gently rolls with moderate slopes. Red soil covers 60 percent of the command area. The majority of the holdings are less than 1 ha and are generally split into 2 or 3 segments.

The National Water Management project

The main objective of the National Water Management project was to increase productivity and farm income in the existing irrigation scheme through a more reliable, predictable and equitable irrigation service. This would be achieved by developing the institutional capacity to plan, implement and monitor improved operation and maintenance practices and providing low-cost infrastructure improvements to support the proposed operational plan. The improved water management would come from more systematic canal operation, best use of available rainfall, reduction of irrigation wastage and optimization of the cropping season particularly during the *rabi* season, and reduction of crops with high irrigation demands by manipulating the frequency of irrigation.

Before the introduction of the NWM project, rice was grown wherever possible. Water availability was good in the distributaries directly branching off the right bank canal and in the head reaches of the branch canals. Irrigation supply was very unreliable in tail reach areas, leading to cultivation of mainly semidry crops. The cropping seasons were *kharif* from July to November and *rabi* from January to May. The NWM project aimed at a better use of water resources by providing irrigation supply starting from May, which would enable a better use of rainfall by the *kharif* crops and would lower the irrigation requirement for the *rabi* crop, which it would be possible to sow in November. This plan required a carryover storage of 250 Mm^3 in the reservoir for irrigation supply in May and part of June. The seasonal calendar proposed under the NWM project was *kharif* extending from 15 May to 15 October (153 days) and *rabi* between 15 November and 15 April (121 days).

The assumed cropping plan of the right bank canal command envisaged 100 percent cropping intensity in the *kharif* season. In the *rabi* season, rice was to be excluded by releasing water to the canal intermittently during the first two months. But even with 90 percent of the area under semi-dry crops, peak irrigation requirements in the dry season were so high that within the capacity limitations of the canal, only 75-percent intensity could be achieved. The distribution policy, as incorporated in the staff appraisal report, envisaged that the command would be divided into four zones and every year one zone, selected in rotation, would be left out of *rabi* irrigation.

Under the NWM concept, the available water resources were allocated proportionally within the command area. In principle, each farmer received his share based on the acreage he either owned or rented, irrespective of the crops grown and irrespective of farm location.

In order to prevent the upper parts of the command from monopolizing the water withdrawal to the disadvantage of the lower command, distributaries and lower level channels were to be so sized with proportional outlets that they would not draw more than an equitable share of the capacity of the main canal. The NWM project proposed the establishment of a structured distribution system below the turnout from the right bank canal and branch canals in the distributaries and minors and installation of a network of flow measurement structures at strategic locations. In Bhadra, the level of structuring was restricted to distributary, i.e. branch canal outlets leading to distributaries were operated as non-structured (manual) systems. A scheme-level committee, with the participation of the Irrigation Department, Command Area Development authorities, the Agriculture Department and farmers, would meet before each irrigation season to approve the operational plan and define the rules for implementation, and again meet after each season to evaluate the operation.

Systematic linkages were to be developed between the operation-and-maintenance agency, other government agencies and farmers. Operation and maintenance were to be strengthened by setting up a main canal operating unit with computer facilities.

The operational plan at the scheme level would be the basis for monitoring system operations. Regular reports would be submitted to the project committee on the seasonal and annual operations (water delivery, irrigation efficiency, cropped area, farmer satisfaction) in order to evaluate performance. The subsequent seasonal operation plan would be modified using this feedback. Thus the scheme level monitoring and evaluation would be an essential element of NWMP intervention.

Training would cover orientation training for senior officers, training in planning for the staff of operation and maintenance units, training in design for engineers, and implementation and operation training for scheme-level officers and field workers. Farmers would be trained to understand NWM concepts to lead to their acceptance and create awareness of their own responsibilities. The NWM project considered farmer participation very important to the success of a scheme operation. Effective participation was to be achieved by holding meetings with farmers to discuss NWM plans and to modify the plans to suit specific situations, organizing a farmer committee at each outlet and higher level committees for each minor and distributary canal, and through farmer training.

Basic data

Historic and current-season data on reservoir release and distribution in branch and distributary canals has been collected from the Bhadra Reservoir Project offices. Agricultural productivity data in terms of total irrigated area, area under rice and other crops and rice productivity per unit of land were obtained through the digital analysis of satellite data of the 1986-87 and subsequent *rabi* seasons. A satellite inventory for the 1994-95 and 1996-97 *rabi* seasons which was not available at the time of the 1995 IIMI evaluation has been used in the study. This data available at pixel level can be aggregated for any desired aerial unit such as distributary command or at branch canal level. Since crop-cutting experiment data for the 1996-97 *rabi* season for sample rice plots was not available during the study, a satellite-based rice yield model was developed by normalizing the rice yield model of the 1992-93 *rabi* season to the current season (Appendix 1). An additional feature of the satellite inventory of the 1996-97 season is the analysis of 20 IRS IC satellite wide-field sensor data sets (with a repeatability of five days compared to 22 days for IRS-2A and IB) between February and June 1997. The average wide-field sensor-based normalized difference vegetation index for each distributary command plotted against time represents the rice growth profile during the *rabi* season and enables comparative analysis of rice conditions through the season and between distributary commands.

A farmer survey covering 105 farmers in seven distributaries (one each in the head and tail end of the Right Bank Canal direct command, one each in the head and tail end of the Malebennur Branch and one each in the head, middle and tail end of the Davangere Branch) was conducted in April 1997 (Figure 1). Typically, in each distributary three villages were selected, one each in the head, middle and tail reaches; the selection of five farmers in each village was based on village records and distributed between small and large farmers. A structured questionnaire was given to the farmers to fill in, and the data organized in a data base for further analysis. Interaction with the water user associations has made it possible to evaluate their current status and effectiveness.

Application of satellite remote-sensing techniques

The earliest satellite remote-sensing application for de-aggregated irrigation inventory in India was in the Bhadra project (Thiruvengadachari and Sakthivadivel, 1997). The methodology, developed and refined since 1992, has been applied in the Bhadra project to generate de-aggregated information on the cropping pattern and rice productivity per unit of land right up to the reach of a distributary for the *rabi* seasons from 1987 to 1997. An important application is the development of a rice yield model linking the satellite-derived normalized difference vegetation index to the harvested rice yield in sample plots. A further development is the extension of such spectral yield relationship from one year to another through radiometric normalization of satellite data (appended). In addition to area and yield data, the spatial variability in the rice transplantation calendar could be captured through the analysis of multiple-date satellite data through the season. Satellite remote-sensing data supported by ancillary information have been applied in a geographic information system environment to analyse system performance and to conduct diagnostic analysis of the Bhadra irrigation project.

An important recent development is the improved capability for through-the-season analysis with wide-field sensor data of 180 m spatial resolution and five-day revisit period since December 1995 from IRS IC and since September 1997 from IRS ID satellites. During the 1996-97 *rabi* season, 19 rounds of cloud-free coverage were obtained and the normalized difference vegetation index profiles were generated and analysed for spatial homogeneity in rice growth and health status.

The NWMP planning process: a critical analysis

The project report ventures that optimum water use would be achieved through more systematic canal operation making the best possible use of the available rainfall and reducing irrigation wastage, optimization of the cropping season, particularly *rabi*, and reduction of the crop area with high irrigation demand by manipulating irrigation frequency. This has not been completely or adequately addressed under NWMP proposals for intervention in the Bhadra project. Significant deficiencies including unrealistic assumptions and incomplete attention to details have vitiated the planning process and led to unsatisfactory impact during and after implementation. While equity is ensured when the water supply is proportional to the area irrespective of the crops grown, the assumed cropping pattern helped in the determination of expected water requirements and sizing of canal capacities. The catch here is that the assumed cropping pattern was unrealistic.

The high rainfall in the upper command (an annual rainfall of 950 mm is normal in Bhadravathi compared to 650 mm in tail-end Davangere) makes rice the preferred crop but it leads to spatial variability in cropping pattern during the *rabi* season. The assumption of excluding *rabi* rice is doomed to fail without strict adherence to the operational schedule of this traditional rice-growing area. Thus the more realistic assumption of a spatially varying cropping pattern and an alternate definition of equity by changing priorities for assured water supply in the two seasons would have had better implementation potential. A careful analysis of past cropping responses to irrigation supplies and rainfall pattern, and consultation with farmer groups, would have resulted in a more realistic cropping pattern. The steps for achieving the farmer consensus and participation necessary for effective supply management have not been sufficiently detailed, nor have specific funds been provided.

In order to use rainfall effectively, the canal supply needs to be variable and capable of adjustment. The NWM project, in contrast, proposed that the branch canals be designed with a capacity equal to the sum of the capacities of off-taking distributaries (with allowance for losses), and be operated at constant maximum flow. This would mean that if a distributary under a branch canal is closed due to lesser demand, the excess flow would just get redistributed among other distributaries or run downstream. In either case no saving would result.

When the main canal is operated at varying flows, closing a distributary can result in saving only if there is a corresponding change in the release at the right bank canal head regulator or by opening a closed distributary of similar capacity. This requires a tightly operated system with excellent communication facilities and an effective decision-making system. The NWM project did not propose to develop such support mechanisms. Thus the assumption of water saving under the project was defeated at the planning stage itself.

Effective use of rainfall and consequent reduced reservoir withdrawals were also to be achieved by advancing the *kharif* sowing to mid-May by providing irrigation from storage carried over from the previous water year. This was corroborated by a simulation study showing that the carryover storage of 250 Mm^3, including storage required to meet all the evaporation losses from the reservoir, was available every year during the 1974-1984 period. The *rabi* sowing correspondingly would be advanced to November, reducing crop water requirements in that season.

The operational plan proposed running the right bank canal continuously during the advanced *kharif* season. This would result in the withdrawal of 985 Mm^3 from the reservoir. The withdrawal in the *rabi* season with three initial cycles of on-off operations is computed at 674 Mm^3. The annual withdrawal would thus be 1 659 Mm^3, and with 175 Mm^3 allocated to the canal and reservoir evaporation of 172 Mm^3, the total withdrawal works out at 2 006 Mm^3 against an allocation of 1 747 Mm^3 by the Krishna River Tribunal. Any saving would be only by operating the main canal with a varying flow and, as mentioned earlier, this was not an effective proposition.

Comparative analysis of performance: before, during and after intervention

This section will attempt to compare the performance during and after implementation against what prevailed before 1988. The main focus will be on water management, agricultural productivity and farmer perceptions, with lesser attention to other NWMP elements. The collapse of the guide wall at the entrance of the right bank canal in September 1991 marks a change from the prevailing 75 percent zoning to the irrigation of the whole area in the *rabi* season. Therefore the performance during the period from 1992 to 1995 is taken to represent the impact during implementation, unless otherwise specified. The post-implementation period is considered to be after 1995.

Water management

The start of the canal operation was always delayed during the pre-intervention period; it was in time as planned during the intervention period and up to the 1995 *rabi* season and advanced beyond *kharif* 1995 (Table 1). The actual number of days the canal was operated – as against the actual number of days planned – also varies, especially during the post-intervention period. Substantial deviations from NWM postulates against the actual planned and operated water distribution schedule are seen for all the three periods investigated. The advancing of the *kharif* season to 15 May, and consequently of the *rabi* season to 15 November, as contemplated in the original proposal, was not achieved, and the seasonal calendar highly varied from year to year, more so in the *kharif* season. The start of the *kharif* season has been delayed particularly since 1994-95 because of monsoon vagaries. The gap between the planned and actual withdrawal from the reservoir is shown in Figure 2. Water use during the *rabi* season became more critical when the 25 percent zoning policy under the NWM project was abandoned in 1992-93, and the whole right bank canal command was provided irrigation supplies. The excess water use in the *rabi* season thus increased, against the computed *rabi* allocation of 674 Mm^3, from 19 percent in 1992-93 to more than 30 percent after 1994-95, compared to 35 percent in the pre-NWM years (Table 2). Although withdrawals during *kharif* were less than those stipulated in the NWM project proposals, the annual withdrawals steadily increased between 1992-93 and 1996-97 (0 to 5 percent). The marginal decrease in excess withdrawal in 1996-97 was due to poor rainfall in the Bhadra catchment area (the area received 1 245 mm in 1996 compared to the 1 569 mm normal rainfall), which resulted in lower reservoir storage levels in that year. Thus the NWM objective of restricting water use within the tribunal allocation was not achieved, as water use increased as of 1992-93. The rather significant increase in water use since 1994-95 is perhaps the result of the physical deterioration of the system due to inadequate maintenance, with more water needed to push supplies to the whole command.