

MAPPING SYSTEM AND SERVICES FOR CANAL OPERATION TECHNIQUES: THE MASSCOTE APPROACH

Daniel Renault¹
Thierry Facon²
Robina Wahaj³

ABSTRACT

On the basis of previous tools and approaches widely used in Asia by the Food and Agriculture Organization (FAO) in its modernization program (Rapid Appraisal Procedure (RAP) & Benchmarking), FAO has developed a systematic approach for canal operation improvement from the diagnosis up to the formulation of operational units and planning of a service objective agreed upon with the users.

The proposed comprehensive methodology for analyzing canal operation modernization, is based on a systematic mapping exercise: Mapping System and Services for Canal Operation TEchniques – MASSCOTE (FAO, 2007). It consists of successively mapping:

- **Performance, through a Rapid Appraisal Procedure (RAP):** to diagnose the processes and assess performance, increase knowledge about the constraints and opportunities which the system management has to consider.
- **System Capacity and Behaviour (Sensitivity) :** to assess the capacity of a canal network with regards to its various function (transport, diversion, control, etc.), as well as its behaviour through the sensitivity analysis.
- **Perturbations:** which describes the disturbances (occurrences, magnitudes) that are likely to occur along the irrigation canal systems
- **Water Networks and Water Balance:** which influence the way water resources circulate, are managed and monitored
- **Service to Users:** to determine service objective characteristics tailored to the user' needs and willingness to pay,
- **Partitioning of Sub-Management Units:** many large systems should be split into small (but not too small) manageable units. In the context of management transfer, users associations should be large enough to be able to recruit a professional to properly operate their sub-system.
- **Demand for Canal Operation,** which depends on the service requirements, the perturbations, the opportunities for water management, and the capacity and sensitivity of the irrigation structures.
- **Options for Canal Operation Improvements,** which are determined by the local conditions, availability of resources and capacity in mastering upgraded techniques

¹ Senior Officer Irrigation System Management , Land and Water Development Division (NRLW), FAO Viale delle Terme di Caracalla 00100 Rome ITALY Tel:00 39 06 570 54713 Mobile: 00 39 34 01 61 32 00 e-mail:daniel.renault@fao.org

² Senior Officer Water Management, Land and Water Development Division (NRLW),RAP FAO Bangkok e-mail:thierry.facon@fao.org

³ FAO Consultant Land and Water Development Division (NRLW), FAO Viale delle Terme di Caracalla 00100 Rome ITALY e-mail:robina.wahaj@fao.org

- **Consolidation of a System Management Plan**, with the goal to ensure consistency among the management units at the upper level.

This paper describes the MASSCOTE methodology for developing a strategy for improvements in canal operation and the lessons learned from its application in several countries of Asia.

MASSCOTE: A METHODOLOGY FOR DEVELOPING MODERNIZATION PLANS

A major part of the 250 millions hectares irrigated worldwide is served by surface canal systems. In many cases performance is low to mediocre and improvements are critically needed in (i) water resource management, (ii) service to irrigated agriculture and (iii) cost-effectiveness of infrastructure management.

The Food and Agriculture Organization of the United Nations (FAO), particularly in Asia, has concentrated its efforts in recent years on the promotion of the modernization of irrigation systems.

At a regional consultation in Bangkok, 1996 (FAO, 1997), the following definition was proposed for the modernization of irrigation systems:

“Irrigation modernization is a process of technical and managerial upgrading (as opposed to mere rehabilitation) of irrigation schemes with the objective to improve resource utilization (labor, water, economics, environmental) and water delivery service to farms.”

As part of this effort FAO has developed and field tested a comprehensive methodology which allows professionals to develop solutions for irrigation management and operation that works and serves the users better. This methodology is named MASSCOTE for MAPPING System and Services for Canal Operation TECHNIQUES.

Canal operation is at the heart of the MASSCOTE approach for two main reasons:

- In the diagnosis phase, the critical examination of the canal state and the way it is operated yields significant physical evidence on the ground of what is really happening in terms of management organization and service to users.
- In the development of the modernization plan, canal operation is critical as the intervention aims to achieve the agreed upon and/or upgraded service. Many irrigation reforms have learned how important canal operation is the hard way, by neglecting it in the design of both infrastructure and management setup. Modern design concepts are based on the definition of an operation plan to achieve specific service and performance objectives.

Users are central to this Service Oriented Management (SOM)-based approach. The way the various steps of MASSCOTE are developed aims to generate practical options and solutions for service and operations on which the users will have to decide. It is fair to say that canal operation is the focus and entry point of MASSCOTE, while its overall goal is modernization of management with the users as central actors.

Canal operation is a complex set of tasks involving many critical activities that have to be undertaken in a consistent and timely manner for good irrigation management. Among the numerous aspects of management, the following need to be considered:

- service to users;
- cost and resources dedicated for operation and maintenance (O&M);
- performance monitoring and evaluation (M&E);
- constraints on the timing and amount of water resources;
- physical constraints and opportunities relating to topography, geography, climate, etc.

There is no single answer as to how to integrate all the elements into an effective and sustainable framework for improving canal operation. However, the new MASSCOTE approach has been developed on the basis of extensive experience with irrigation modernization programs in Asia between 1998 and 2006. MASSCOTE aims to organize the development of modernization programs through a step-by-step methodology:

- mapping various system characteristics;
- delimiting institutionally and spatially manageable subunits;
- defining the objective for service and strategy for and details of operation for each subunit.

A STEP-BY-STEP FRAMEWORK

The first MASSCOTE steps [steps 1 to 6] outlined in Figure 1 are to be conducted for the entire Command Area (CA). The goal is to identify uniform managerial units for which specific options for canal operation can be designed and implemented.

Step 1: Mapping the Performance: the Rapid Appraisal Procedure (RAP)

An initial rapid but comprehensive appraisal is the essential first step of the MASSCOTE approach. The RAP is a systematic set of procedures and indicators for diagnosing the bottlenecks of performance within an irrigation system (FAO, 1999; IPTRID 2001).

The RAP internal process indicators assess quantitatively the internal processes, i.e. the inputs (resources used) and the outputs (services to downstream users), of an irrigation project. Internal indicators are related to operational procedures, management and institutional setup, hardware of the system, water delivery service, etc. They enable a comprehensive understanding of the processes that influence water delivery service and overall performance of a system. Thus, they provide insight into what could or should be done in order to improve water delivery service and overall performance (assessed by the external performance indicators).

The RAP external performance indicators compare input and output of an irrigation system and are expressions of various forms of efficiency, e.g. water-use efficiency, crop yield, and budget. They do not provide any detail on what internal processes lead to these outputs and what should be done to improve the performance. However, they could be used for comparing the performance of different irrigation projects, nationally or internationally. Once these external

indicators have been computed, they could be used as a benchmark for monitoring the impacts of modernization on improvements in overall performance.

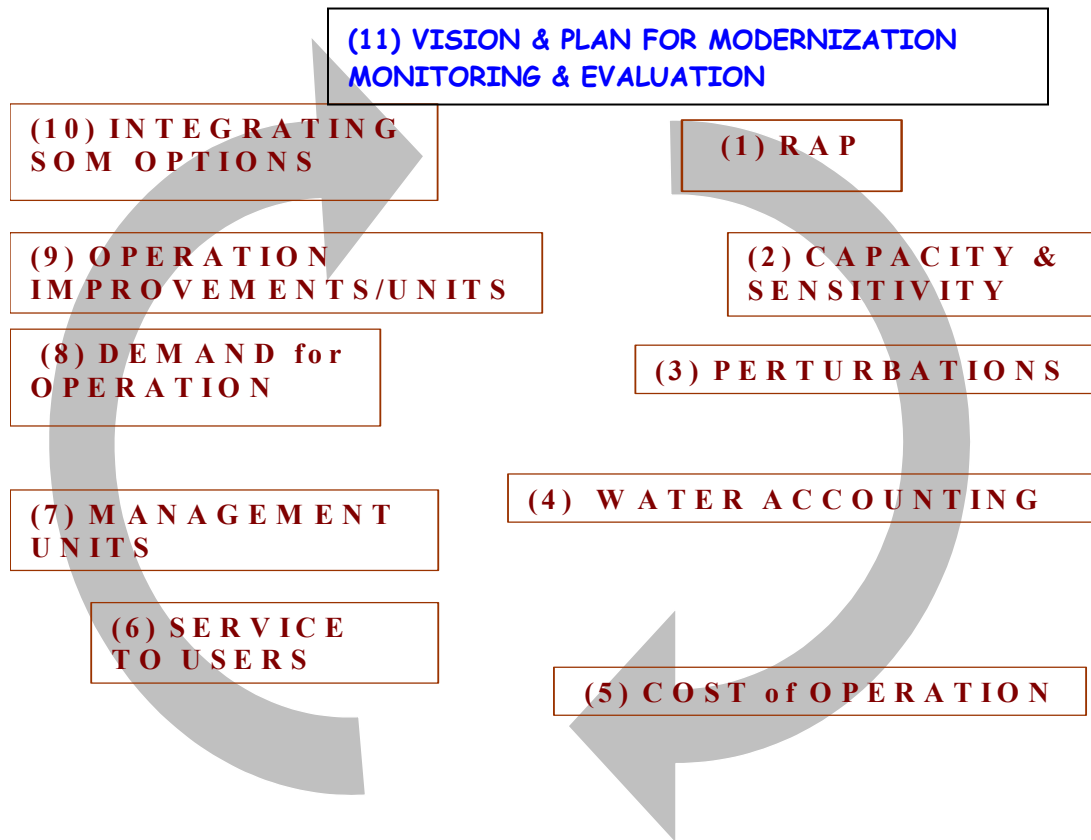


Figure 1. The 10+1 Steps in the MASSCOTE Approach

Step 2: Mapping the System Capacity and Sensitivity

Mapping the system capacity and sensitivity deals with features of the physical infrastructure including the function of structures for conveyance, water level or flow control, measurement, and safety. Irrigation structures are intended to perform a particular function. How they are designed, installed, calibrated and maintained results in specific performance characteristics – some designs are better than others depending on the situation – and actual conditions may change with time owing to various phenomena, such as erosion, siltation and rusting.

Mapping Capacity. It is important to have a reasonable assessment of the existing status of the system in performing the basic functions. Specifically, it is critical to identify any weak points, bottlenecks and/or areas with particular deficiencies. The mapping assessment of the flow capacity of infrastructure is necessary in order to compare with the design, but more importantly to ensure that the whole system is consistent with the operations plan to be developed.

Any major structural deficiencies need to be addressed as part of the planning process of modernization. Modernization improvements cannot be carried out successfully without dealing with the impacts of severely degraded or dysfunctional infrastructure.

Mapping the Sensitivity, the sensitivity of irrigation structures (offtakes and cross-regulators) is determined, along with the identification of singular points. Mapping of the sensitivity at key locations is crucial in managing perturbations.

The basic idea is to know where the sensitive offtakes and regulators are located, which subsystems propagate the perturbations and which ones absorb them. Thus, in terms of mapping:

- mapping of structures: sensitive regulators and sensitive offtakes;
- mapping of subsystems: average characteristics per subsystem – sensitive for flow control and water-level control.

This step gives rise to the following obligations and options relating to sensitive structures/subsystems:

- sensitive structures must be checked and operated more frequently or may have to be replaced with less sensitive structures;
- sensitive structures can be used to detect fluctuations (part of information management);
- sensitive subsystems can divert perturbations into subareas or through offtakes for which vulnerability is low.

Sensitivity indicator of irrigation structures: The sensitivity of an offtake refers to the function of generating an assured discharge in a dependent canal from a certain water level in the parent canal whereas for a cross regulator it refers to controlling water level in a canal. Table 1 in Appendix 1 summarizes the information about the irrigation structure sensitivity indicators (Renault, 1999).

Mapping sensitivity for irrigation structures can be achieved through: (i) direct measurement; (ii) analysis of flows records; and (iii) hydraulic formula. The last is the easiest option as it only requires knowledge of the flow type and the head on the structure. Sensitivity indicators for Offtake and Cross-regulators are estimated by the following equations:

$$S_{\text{Offtake}} = \frac{\alpha}{\text{head}} \quad (\text{unit: m}^{-1}) \quad (1)$$

$$S_{\text{Regulators}} = \frac{\text{head}}{\alpha} \quad (\text{unit: m}) \quad (2)$$

where α is the exponent in the hydraulic equation of the flow through the structure; α equals 1.5 for overshoot flow and 0.5 for undershot flow. A structure is considered low sensitive if $S \leq 1.0$; moderately sensitive if $S = 1.0$ to 2.0 ; and highly sensitive if $S > 2.0$.

Sensitivity and operational rules: one of the purposes of assessing the indicators of sensitivity is to define canal operation rules such as tolerance on water control and frequency of checking.

This is illustrated through an example taken from Sunsari Morang Irrigation Project (in the Terai of Nepal): sensitivity indicators have been assessed at main nodes (a node is composed of a cross-regulator and a major offtake to a secondary canal). Values (plotted in figure 2) are used to determine tolerance of water control and frequency of checking (see table 1) to achieve a target control of flow rates.

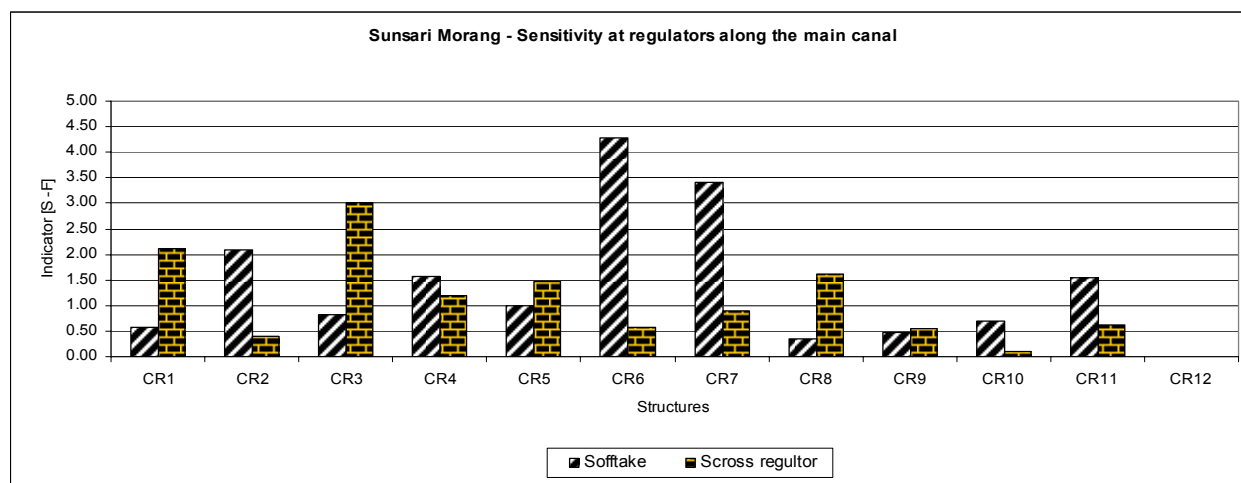


Figure 2. Measured Sensitivity Indicators at Cross Regulators of Main Canal SMIP Nepal-Terai

Table 1. Operation Rules - Tolerance and Frequency of Adjustment (Derived from Sensitivity Analysis SMIP Nepal Terai)

Cross regulator	Features	Tolerance on water level control	Frequency of adjustment of the CR
CR1	S regulator is high (2 m) S offtake low (0.6 m^{-1})	Tolerance 0.1 m acceptable	More frequent adjustment
CR 2	S regulator is low (0.4m) S offtake High (2 m^{-1})	Reduced tolerance should be sought ($\pm 5 \text{ cm}$)	low frequency enough
CR3	S regulator is very high (3m) S offtake low (0.8 m^{-1})	Tolerance 0.1m acceptable	More frequent adjustment
CR4 and CR 5	S regulator average ($<1.5\text{m}$) S offtake average ($<1.5\text{m}^{-1}$)	Tolerance 0.1m acceptable	Average frequency adjustment
CR6 and CR 7	S regulator is low ($<1\text{m}$) S offtake high ($>3.5 \text{ m}^{-1}$)	Reduced tolerance should be sought (below 5 cm) which might be difficult to achieve. Reducing the sensitivity of offtakes should be considered.	Average frequency adjustment
CR8 to CR11	S regulator is average or below S offtake is average or below	Tolerance 0.1m acceptable	Average frequency adjustment

Step 3: Mapping Perturbations

Perturbations refer to a significant change in the flows occurring along a canal network as a result of external variations in inflows or outflows, changes or adjustments in the settings of structures, or transient flow during distribution changes. Perturbations of water variables (level and discharge) along an open-channel network and unsteady state are the norm not the exception. Despite being a target for canal operation between changes in deliveries, steady state along a canal is rarely found in practice. Thus, perturbation is a permanent feature of irrigation canals caused by setting of upstream structures and compounded by intended or unpredicted changes in inflows/outflows at key nodes.

Thus, if perturbations are unavoidable, then the only option for managers is to have a reliable knowledge of their origins, and to know how to detect and manage them. Managing a canal also deals with uncertainties and instabilities.

Perturbations can be either positive or negative, representing an increase or decrease in discharge, respectively. The types and characteristics of perturbations that need to be mapped are:

- positive perturbations:
 - nature (inflow-outflow – internal),
 - magnitude (water-level fluctuation – relative discharge variation),
 - frequency;
- negative perturbations:
 - nature (inflow-outflow – internal),
 - magnitude (water-level fluctuation – relative discharge variation),
 - frequency.

With positive perturbations, the management options are:

- respond by acting on the supply;
- share the surplus proportionally among users;
- divert and store the surplus into storage capacity.

With negative perturbations, the management options are:

- compensate from storage;
- check for immediate correction;
- reduce delivery to some offtakes, with compensation later on (less sensitive/vulnerable areas, delivery points with storage facilities, with alternatives source of water).

Step 4: Mapping the Water Networks and Water Balances

In this step, the concept is to map the surface water network including irrigation and drainage layout, but also any natural channels if they interact or may interact in the future with the canal system and/or storage facilities. The objective is to know where and when all the inflow points to and outflow points from the service area occur in terms of flow rates, volumes, and timing. This mapping includes all safety structures built to evacuate surplus water to the drainage network.

The water balance of course also includes groundwater (recharges and abstractions). Although MASSCOTE focuses on canal operation, present conjunctive use within the system and conjunctive use as an option to recirculate water, improve efficiencies, or achieving a high service standard is fully considered.

Managers must have accurate knowledge about all the paths of water – where it is coming from and where it is flowing to, and in what volume. Knowing the water balance of the system is important not only for achieving high efficiencies but also for tackling environmental issues such as waterlogging and salinity buildup. It is also a good management tool for transparent water distribution within and among subareas of a system.

Estimation of inaccuracies in assessing the terms of the water balance is critical in particular with the closure of the balance (Burt, 1999, Clemmens and Burt, 1997) which is often known with high uncertainties.

Mapping of the water balance is important at each management level. Therefore the process within MASSCOTE is iterative: the first water balance should be carried out at the entire gross command areas (step 1 of the RAP in fact already includes a water balance with available information), and then at the local management agencies that result from the partitioning in step 7.

Step 5: Mapping the Cost of O&M

In this step, mapping is done of the costs for current O&M. It also involves disaggregating the elements entering into the cost and developing costing options for various levels of services with current techniques and with improved techniques.

In order to produce the service that has been decided/agreed upon with users, managers need to mobilize a set of various resources or inputs, such as water, staff, energy, office, communication, and transport. All of these entail a cost. This step aims at clarifying the issue of inputs and costs for operation as part of the overall management activities and as fundamental elements of the modernization process.

Investigating inputs and costs is important for:

- setting the service levels, in particular in exploring options for different types of services and associated costs;
- water pricing to users, in order to propose a set of charging procedures that takes into account the real cost of service production;
- improving performance and cost-effectiveness, by investigating technical options for maximizing operational effectiveness (better allocation of existing resources, automation, etc.).

Mapping the cost for operation and maintenance is usually difficult mainly because of lack of information. The figures on cost of different components (such as operation, staff, maintenance etc.) are often lumped together and disaggregating for operation and for services is not straightforward.

Step 6: Mapping the Service to Users

The services to users are today much broader than at the initial stages of irrigation development although water demands by farmers are still central. In the extended category of services within an irrigation project, the following services can be found:

- domestic supply to villages;
- recharge to groundwater;
- environmental flows;
- health;
- industrial uses;
- fishing;
- recreational areas;
- tourism.

The task of defining the service and determining the requirements for operation consists of clearly defining the service and the consequent requirements for operation.

From the previous steps, a preliminary vision of the scheme can be proposed for the near future, from which the preliminary features of the water services in the CA are derived:

- How many categories of service are considered, and how are these spatially distributed?
- How are the services evolving with time throughout the year?
- What is the service for crops with respect to the different seasons?
- What is the flexibility in defining the services with respect to the resources constraints?
- What are the features of allocation, scheduling and water deliveries that define the overall service?

Assessing all the different services provided to different users and their related costs are what need to be mapped in this step. Mapping of service is required for further analysis of modernization opportunities and economic analyses to be done in later steps.

Step 7: Mapping the Management Units – a Subunit Approach

Large canal irrigation systems serving large areas are usually divided into smaller manageable units called tracks, blocks and subsystems. In the past (and particularly for new systems), these management units have often been based on the hierarchy of the canal network (main, secondary, tertiary, etc). Today, with the increasing complexity of management and operation needed to provide higher levels of service; this partitioning might be less relevant than it was when the systems were originally constructed. There are more relevant operational criteria on which subunits should be based such as:

- Participatory management;
- Spatial variation of water services;
- Conjunctive water management and boundaries for water balance;
- Multiple users of water;

- Drainage conditions;
- Recirculation patterns and opportunities;
- Specific points along the infrastructure.

Subunits of operation/management should define an area for which a certain relatively homogeneous level of service is agreed upon and provided, and for which the water balance is to be managed as a single unit. A workable compromise has to be found between the physical/hydraulic system and the institutional/managerial resources in each subunit. Figure 3 presents an example of partitioning of a command area into sub-units.

The rationale for determining appropriate subunits takes into account multiple considerations. However, the setting up of too many units should be avoided, keeping in mind the baseline costs associated with the management of individual units and the non-viability of very small units.

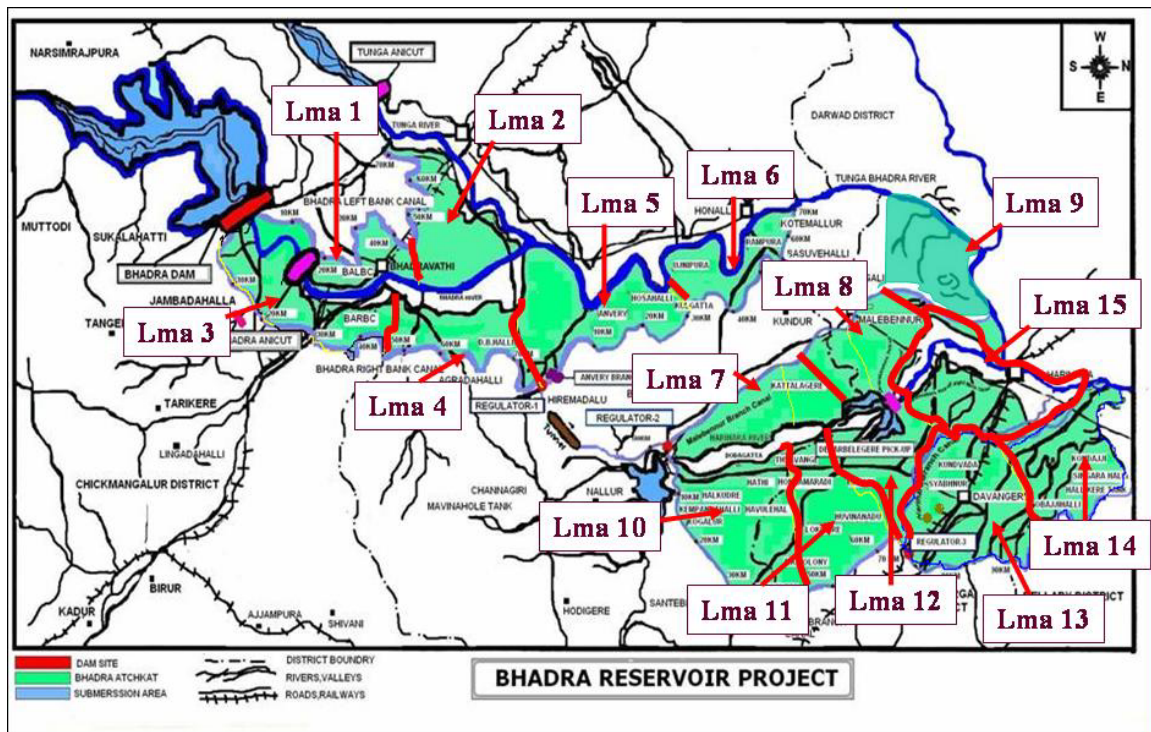


Figure 3 . Example of Partitioning with Reservoir & Main Canal into One Single Unit and CA Split into 15 Local Management Agencies (Average 7000 ha) [Bhadra Project Karnataka India]

Step 8: Mapping the demand for operation

This step involves assessing the resources, opportunity and demand for improved canal operation. It entails a spatial analysis of the entire service area, with preliminary identification of subsystem units (management, service, O&M, etc.).

Assessing the requirements for canal operation needs to be done alongside and in combination with the definition of the service by users and stakeholders. However, canal operation

requirements cannot be derived directly from service demands. The system presents opportunities and constraints that set the boundaries for possible modes of operation. In short, the requirements for operation will depend on three domains: (i) the service will specify the targets; (ii) the perturbation will specify the constraints in which the system operates; and (iii) the sensitivity will specify how fast the system reacts to changes and produces changes when left un-operated.

The rationale is straightforward: the higher the sensitivity, perturbations and service demand, the higher the demand for canal operation. This can be expressed in the relationship:

$$\text{Demand for operation} = \text{service} \times \text{perturbation} \times \text{sensitivity} \quad (3)$$

Step 9: Mapping Options for Canal Operation Improvements: Main System and Subunits

This step entails identifying options for improvements to main and secondary canal operations. Improvements should aim at specific objectives such as:

- improving water delivery services to agriculture users;
- optimizing the cost of operation;
- water conservation;
- integrating the multiple uses of water (IWRM).

Here the methodology is carried out in two complementary and converging ways or double sweeping i) at the main system serving the sub-units and ii) at each sub-unit considered initially as an autonomous system served by the main system.

Modernization improvement options are investigated for each unit (main and subunits) based on: (i) water management; (ii) water control; and (iii) canal operation (service and cost-effectiveness).

The improvements are to be sought through one or a combination of the following options:

- allocating existing resources and inputs in a more cost-effective and responsive manner;
- optimizing the organization and the operational modes;
- changing the operational strategy;
- investing in improved techniques and infrastructure.

For water management, the improvements aim to increase water use and productivity by: (i) minimizing losses; (ii) maximizing water harvest; and (iii) re-regulating storage.

For water control, the improvements concern the hydraulic configuration of the operations. This entails a sequence of: (i) fine-tuning the hydraulic heads of canal structures in relation to each other; (ii) creating a specific hydraulic property of the canal (section) so that it performs as intended; and (iii) choosing the option that will minimize manual operational interventions/regulations for a specific period.

Step 10: Integrating and Consolidating the Service-Oriented Management Options

Improvement options for the main canal system and subunits are finalized together with the associated costs for every option. The options for the sub-units are then confronted and aggregated at the main system level, and checked for consistency with the finalised improvement options at the main system level. A short-term modernization strategy is laid out with objectives and proposed achievements/improvements.

Step 11: Vision and Plan for Modernization and M&E

The carrying out of the previous steps with some reiterative cycle is the process by which, progressively, a vision of the near future for the irrigation scheme is crafted and consolidated.

This vision must then be converted into a plan that should aim at achieving the vision. A first phase of modernization improvements that meets expectations and aims at potential achievements at a realistic and practical level must be implemented in order to successfully initiate a long –term modernization process. A decision about the options to pursue is taken through extensive participation of the users. The solutions that are easiest and most cost-effective to implement are to be selected to start the process of modernization.

The establishment of long-term vision, modernization strategy, and plan for the system is outside the scope of MASSCOTE and needs to be supported by a thorough strategic planning process.

Monitoring and evaluation of the improved operations are necessary in order to ensure that achievements are maintained, and to provide a basis for comparison of the situation before and after the improvements.

IMPORTANT FEATURES OF MASSCOTE

There are four important features to bear in mind about MASSCOTE.

The first is the embedded nature of the RAP and MASSCOTE within a short-term modernization project (Figure 2) that requires a modicum of additional resources.



Figure 2. Embedded Nature of the RAP and MASSCOTE

The second feature concerns the different time frames of the interventions:

- RAP = week;
- MASSCOTE = month;
- Short-term modernization project = year;

- Medium and long term vision and modernization plan: 2-3 and 5 to 15-30 years, respectively. These may require more fundamental restructuring and mobilization of substantial additional resources.

The third feature concerns the revolving nature of MASSCOTE. This might imply iterative circles before reaching a consolidated stage of analysis and project – several rounds of MASSCOTE at different levels of the system (main supply, subunits) before integrating at the main supply and subunit level.

The fourth feature is that a major entry point of the MASSCOTE methodology is canal operation for diagnosis and for designing improvements. However, the overall objective in carrying out a MASSCOTE exercise is modernization of management. Canal operation is a critical entry point because: (i) it is the activity that puts management decisions into tangible outputs; and (ii) it is there that the current management performance is sanctioned and expressed in the most obvious manner (its symptoms). MASSCOTE evolves from canal operation to management options (institutional partitioning, organization, and SOM). A longer-term plan will address more systematically other issues related to management such as incentive structure, governance, and financing in a full-fledged asset management plan.

MASSCOTE APPLICATIONS IN CAPACITY BUILDING PROGRAMS

In 2006 and 2007 the MASSCOTE approach has been applied successfully on 10 irrigation systems. The capacity building approach was based on the following ideas: modernization should follow a holistic and step-wise approach, tailored to a detailed assessment and constraints of each individual system. To go beyond the measurement and analysis stages and on to the implementation of changes and improvement stages, there must be significant acceptance by project personnel, identification of weaknesses and potential changes, and knowledge of options for change. The carrying out of an initial appraisal with a Rapid Appraisal Procedure and a more detailed step-wise methodology with MASSCOTE are thus incorporated into the training program that integrally involves local management and operation and maintenance staff. Staff learn the concepts, are provided with a toolbox of options, evaluate their own project, and then develop a modernization strategy and detailed plans to improve operation and management for their project. This is meant to obtain support from staff, address the real issues in the system and avoid managers to be on the receiving end of standard modernization packages determined by outsiders. Modernization focuses in particular on making it easier, simpler, and more economical to achieve improved performance and is an important factor in buy-in from staff in terms of benefits that accrue to them, in addition to the core objective of improving performance and service to farmers. Those who provide funding (agencies and farmers) are also critical beneficiaries.

Immediate follow-up action requires strong leadership at agency level and at system manager level. Rigid design standards and lack of management decentralization are major factors in hindering change. However in the longer term, training does generate a shift in perceptions and concepts which may form a basis for a structured modernization program. Inputs from lower levels of operation and management, including water users associations, strengthened by

training, anchoring, and design of details of modernization policies and strategies on specific hardware and software issues arising from systematic appraisals hold the promise of achieving actual improvements.

REFERENCES

- Burt, C.M. 1999. Irrigation water balance fundamentals. Paper presented at the conference *Benchmarking irrigation system performance using water management and water balances*, pp. 1–13. ITRC Paper 99-001. Denver, USA, USCID.
- Clemmens, A.J. & Burt, C.M. 1997. Accuracy of irrigation efficiency estimates. *J. Irrig. Drain. Eng.*, 123(6).
- FAO, 1997. Modernization of irrigation schemes: past experiences and future options, FAO-RAP 1997/22, Water Report Series 12, Bangkok, 1997
- FAO. 1999. *Modern water control and management practices in irrigation: impact on performance*, by C.M. Burt & S.W. Styles. FAO Water Report No. 19. Rome. 224 pp.
- FAO 2007. Modernizing irrigation management – the MASSCOTE approach: Mapping Systems and Services for Cana; Operation Techniques
- IPTRID. 2001. *Guidelines for benchmarking performance in the irrigation and drainage sector*, by H. Malano & M. Burton. Rome.
- Renault, D. 1999. Offtake sensitivity, operation effectiveness and performance of irrigation systems. *J. Irrig. Drain. Eng.*, 125(3).

APPENDIX 1

Table 1. Summary of Sensitivity Indicators for Offtakes and Cross-Regulators

	OFFTAKE	CROSS-REGULATOR
Definition	The ratio of the relative variation in discharge through the offtake ($\Delta q/q$), to the variation in water level in the parent canal (Δh)	The ratio of the resulting variation in water level in the parent canal (Δh) when main discharge (Q) varies of (ΔQ)
Mathematical expression	$S_{Offtake} = \frac{\Delta q/q}{\Delta h} \text{ (unit: m}^{-1}\text{)}$	$S_{Regulator} = \frac{\Delta h}{\Delta Q/Q} \text{ (unit: m)}$
Assessing Estimator	Derived from the equation ⁴ of the flow through the structure. $q = M(\text{head})^\alpha$ A robust estimator ⁵ of the sensitivity indicator is: $S = \frac{\alpha}{\text{head}} \text{ (unit: m}^{-1}\text{)}$	Derived from the equation of the flow through the structure. $q = M(\text{head})^\alpha$ A robust estimator of the sensitivity indicator is inverse to that of the offtake : $S = \frac{\text{head}}{\alpha} \text{ (unit: m)}$
Use	estimating the reaction of an offtake $\frac{\Delta q}{q} = S_{Offtake} \cdot \Delta h$	for estimating the variation of water level resulting of a given discharge variation $\Delta h = \frac{\left(\frac{\Delta Q}{Q}\right)}{S_{Regulator}} \text{ (unit: m)}$
Use	for evaluating the tolerance of water control for a target of discharge variation $\Delta h_{permissible} = \frac{\left(\frac{\Delta q}{q}\right)_{set}}{S_{Offtake}} \text{ (unit: m)}$	Detecting variation of main discharge by noticing variation of water level at sensitive regulators.
Example	an offtake with a sensitivity = 2, experiences 20-percent variation in discharge when water level upstream varies by 10 cm	a cross regulator with a sensitivity = 3 will experiences a variation of upstream water level of 30 cm when main discharge varies by 10 %
Range of indicator	A structure with a sensitivity indicator $S < 1$ is considered low, medium between 1 and 2, and $S > 2$ indicates a highly sensitive structure.	

⁴ M is a value independent of the head exercised on the structure. M depends on the shape, size and hydraulic coefficients of the flow through the structure. Head is the head exercised on the structure (water level upstream minus the water level downstream if the structure is submerged, or minus a level of reference taken as the crest level for overshot structure or the orifice axis for undershot if the structure is not submerged). α is the exponent in the relevant hydraulic equation for flow; α equals 1.5 for overshot flow and 0.5 for undershot flow.

⁵ When the structure is submerged, the flow is governed by two equations and a correcting factor should be introduced. However the order of magnitude of the indicators is conserved and that is enough. Only for high sensitivity indicators correction is needed.