Diagnostic analysis and some approaches for improving water delivery performance in the Bhakra canal command

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Abstract

The modernization of an irrigation system generally aims at removing or relaxing the constraints that undermine the performance of the system in respect of the designed objectives. It involves cost and has to be undertaken after establishing the nature and degree of improvement required and its technical and economic feasibility. Evaluation of the hydraulic performance of the irrigation system at the watercourse and farm levels was undertaken in the command area of a branch canal, the Fatehabad branch of the Bhakra canal system in Haryana. Equity (in terms of uniformity coefficient and modified inter-quartile ratio), adequacy (in terms of relative water supply) and water productivity, which reflected both adequacy and timeliness, were evaluated.

The equity of water distribution decreased with the size of the watercourse (flow rate), and the average value of the modified inter-quartile ratio was 1.85. With an average relative water supply value of 0.64 across watercourses and the seasons, the system had highly deficient supply. Water productivity value was only 0.51 across watercourses and seasons. Lower values of water productivity as compared to seasonal adequacy reflected a time mismatch between supply and demand. Equity in water distribution along the watercourse and irrigation efficiencies on the farm can be substantially improved through the proper design of the unit command area size using the procedure that has been developed for this purpose. Variable time warabandi and provision of tube wells in tail reaches would also minimize inequity. Intra-seasonal modifications in the existing water delivery schedule, based on the simulation model, indicated a substantial improvement in water productivity. Further improvements were possible through the provision of auxiliary storage at the head of watercourses.

Introduction

During the last few decades there has been very a rapid expansion of irrigation facilities all over the world. In India, which has chosen irrigation development as a vehicle for time-targeted progress, the rate of irrigation development has been the highest. At present, an area of some 51 million ha is irrigated by different sources. Through large and medium-sized projects in several states, including Tamil Nadu, Punjab, Haryana and Rajasthan, the irrigation potential has grown by 70 percent or more.

Provision of irrigation facilities has raised agricultural production, has improved productivity and has brought some sort of stability to Indian agriculture. In spite of these substantial gains, there is a growing perception that the performance of the irrigation system has been less than satisfactory. The shortcomings that are frequently mentioned include:
• smaller than expected increase in productivity;
• low irrigation intensities;
• higher than anticipated costs of construction and maintenance;
• inequity in water distribution; and
• environmental degradation in the form of waterlogging, salinity, erosion, spread of disease, etc.

The scope for further increase in irrigation potential at a reasonable cost is not very high. Also, allowing the present state of affairs to continue for long may have bearing on the long-term sustainability of irrigation in many regions. The conviction is spreading that a major breakthrough in irrigated agriculture is possible only through the modification of existing practices after diagnosing the causes through performance analysis (Government of India, Ministry of Water Resources, 1987). Meaningful performance appraisal is possible only if there is a clear understanding of how we define the irrigation system, its management and the objectives for which it has been created. The vastness of the subject also makes it necessary to define the boundaries of the proposed exercise along with anticipated outputs and future beneficiaries.

Physically, an irrigation system may include (1) capture and storage, (2) conveyance, (3) bulk distribution, (4) delivery, (5) application and (6) removal of water from agricultural land. These physical entities, which are distinct hydraulic levels fall under different management domains (Kellar et al, 1988). The management at hydraulic levels 1 and 2 is exclusively dealt with by irrigation project authorities such as irrigation departments or management boards, whereas the management at hydraulic levels 5 and 6 is in the domain of farmers or of the officials of the agriculture department. Hydraulic levels 3 and 4 fall in the intermediate zone where both irrigation department and command area development authorities interact.

Scope of the study
This study aims at determining the scope of improving the performance of an irrigation system at hydraulic levels 4 and 5 (watercourse and farm) through structural and operational changes in the system. The need for improvement will be established through a diagnostic analysis of the system performance. The type and nature of the interventions will be decided on the basis of an analysis of the strengths and weaknesses of the system.
Project area

The project area is a part of the Bhakra canal system in Haryana and it covers about 0.28 million ha between the latitudes 29° 00’ to 30° 55’ N and longitudes 73° 02’ to 77° 28’ E in the Ghaggar river basin, which is a part of the Indus basin.

The Fatehabad Branch canal, which branches off the Bhakra Main Branch canal, was selected for the study. Four pairs of watercourses (one lined and the other unlined) branching off the Gorakhpur and Khajuri distributaries in the head reach, Adampur in the middle reach and Kutiyana and Sheranwali in the tail reach, were selected for investigation. In addition, two watercourses on the Fatehabad distributary in the tail reach near Fatehabad were also chosen.

The salient hydraulic data for these watercourses are given in Table 1. In this irrigation command, a three-stage water distribution system is in use. The first stage consists of main and branch canals and the second stage has the network of distributaries and minors. The distribution network in the first two stages is owned and operated by the state irrigation authorities. Watercourses which distribute water beyond the canal outlet constitute the third stage, and these are owned and managed by groups of farmers. The watercourse draws water through an adjusted proportionable module.

<table>
<thead>
<tr>
<th>Distributary</th>
<th>Watercourse No CCA</th>
<th>Lined/unlined</th>
<th>Length (m)</th>
<th>Design discharge (l/s)</th>
<th>GCA (ha)</th>
<th>(ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gorakhpur</td>
<td>5000L Lined</td>
<td>1 811</td>
<td>45.0</td>
<td>330</td>
<td>282</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3275L Unlined</td>
<td>1 980</td>
<td>45.0</td>
<td>296</td>
<td>288</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8758L Lined</td>
<td>2 010</td>
<td>46.4</td>
<td>305</td>
<td>288</td>
<td></td>
</tr>
<tr>
<td>Khajuri</td>
<td>9400L Unlined</td>
<td>1 440</td>
<td>28.0</td>
<td>177</td>
<td>169</td>
<td></td>
</tr>
<tr>
<td></td>
<td>11260L Unlined</td>
<td>1 125</td>
<td>19.5</td>
<td>139</td>
<td>114</td>
<td></td>
</tr>
<tr>
<td>Fatehabad</td>
<td>179415L Lined</td>
<td>3 800</td>
<td>68.0</td>
<td>462</td>
<td>408</td>
<td></td>
</tr>
<tr>
<td></td>
<td>204200L Unlined</td>
<td>3 300</td>
<td>45.6</td>
<td>392</td>
<td>273</td>
<td></td>
</tr>
<tr>
<td>Adampur</td>
<td>44000L Lined</td>
<td>1 500</td>
<td>29.7</td>
<td>178</td>
<td>185</td>
<td></td>
</tr>
<tr>
<td>Kutiyana</td>
<td>780L Lined</td>
<td>3 020</td>
<td>45.5</td>
<td>456</td>
<td>274</td>
<td></td>
</tr>
<tr>
<td>Sheranwali</td>
<td>2000R Unlined</td>
<td>2 850</td>
<td>34.6</td>
<td>290</td>
<td>195</td>
<td></td>
</tr>
</tbody>
</table>

The capacity factor (actual discharge/designed discharge) during the winter season is only 0.72 and is indicative of inadequate supply in general.
The problems
The problems of distribution and application in the Fatehabad branch canal are representative of similar problems on other projects in the region. Appraisal of the relevant documents, a walk through the system and discussions with the farmers and officials of the irrigation department indicated the following problems:

- Rigid irrigation water delivery schedules with almost the same frequency throughout the growing season cannot meet crop demands.
- The water supplied is scarce and the effects of scarcity are more severe in areas with highly saline/sodic groundwater.
- In unlined watercourses about one third of the area toward the tail does not get any water; this leads to the unauthorized practice of sale of canal water.
- The command areas of watercourses seem to have been fixed entirely on the basis of topography without much consideration for the soil infiltration rate.

Diagnostic analysis of irrigation performance
Chambers (1984) has listed some of the perceptions of good performance by different disciplines and sections of the society. An in-depth criterion of the objectives is given in Small and Svendsen (1990). Since we are limiting our scope of performance evaluation at the hydraulic level of watercourses and farms, success can be measured in terms of equity, adequacy and timeliness, and efficiency in application, distribution and storage on the farm.

On-farm irrigation system performance
In the present study only hydraulic performance of the field irrigation was evaluated. Graded borders are the most common way of applying water to crops. The test borders were specified along the entire length of the Fatehabad branch canal, in the command of selected watercourses. In general, three borders on each watercourse with location in head, middle and tail reaches were selected. The detailed procedure prescribed by Meriam (1978) was adopted. The application efficiency in most cases is quite high, whereas storage efficiency is low (Table 2). Because of higher stream size, the water spreads quickly and the irrigation is terminated before the required quantity has been diverted into the border. The distribution uniformity is also poor (less than 60 percent) in the majority of cases. Thus there is scope for improvement in the design of water application practices.
Table 2. Field irrigation efficiency in head, middle and tail reaches of watercourses

<table>
<thead>
<tr>
<th>Water Location</th>
<th>Inflow rate (l/s)</th>
<th>Stream size (l/s/m)</th>
<th>Irrigation required (cm)</th>
<th>Land slope (%)</th>
<th>AE (%)</th>
<th>SE (%)</th>
<th>DU (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5000L Gorkahpur distributary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head</td>
<td>50.8</td>
<td>4.064</td>
<td>5.9</td>
<td>0.15</td>
<td>85</td>
<td>49</td>
<td>70</td>
</tr>
<tr>
<td>Middle</td>
<td>40.3</td>
<td>4.112</td>
<td>6.1</td>
<td>0.15</td>
<td>82</td>
<td>50</td>
<td>65</td>
</tr>
<tr>
<td>Tail</td>
<td>29.6</td>
<td>2.846</td>
<td>6.5</td>
<td>0.15</td>
<td>87</td>
<td>57</td>
<td>68</td>
</tr>
<tr>
<td>3275L Gorkahpur distributary</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>6.7</td>
<td>0.20</td>
<td>78</td>
<td>52</td>
<td>67</td>
</tr>
<tr>
<td>Middle</td>
<td>23.1</td>
<td>2.852</td>
<td>7.4</td>
<td>0.16</td>
<td>75</td>
<td>56</td>
<td>72</td>
</tr>
<tr>
<td>Tail</td>
<td>15.6</td>
<td>1.835</td>
<td>8.0</td>
<td>0.15</td>
<td>62</td>
<td>61</td>
<td>64</td>
</tr>
<tr>
<td>8738L Fatheabad distributary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head</td>
<td>36.1</td>
<td>3.539</td>
<td>5.6</td>
<td>0.20</td>
<td>65</td>
<td>52</td>
<td>36</td>
</tr>
<tr>
<td>Middle</td>
<td>29.0</td>
<td>2.990</td>
<td>6.8</td>
<td>0.12</td>
<td>79</td>
<td>58</td>
<td>62</td>
</tr>
<tr>
<td>Tail</td>
<td>21.5</td>
<td>2.529</td>
<td>7.5</td>
<td>0.15</td>
<td>80</td>
<td>64</td>
<td>58</td>
</tr>
<tr>
<td>27670L Adampur distributary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head</td>
<td>39.5</td>
<td>5.640</td>
<td>6.9</td>
<td>0.25</td>
<td>84</td>
<td>55</td>
<td>42</td>
</tr>
<tr>
<td>Middle</td>
<td>32.7</td>
<td>5.940</td>
<td>5.7</td>
<td>0.25</td>
<td>60</td>
<td>51</td>
<td>55</td>
</tr>
<tr>
<td>Tail</td>
<td>26.4</td>
<td>3.120</td>
<td>6.5</td>
<td>0.30</td>
<td>62</td>
<td>59</td>
<td>35</td>
</tr>
<tr>
<td>179415L Fatheabad distributary</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td>55</td>
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<td>204200L Fatheabad distributary</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Head</td>
<td>30.4</td>
<td>4.540</td>
<td>6.8</td>
<td>0.30</td>
<td>81</td>
<td>56</td>
<td>54</td>
</tr>
<tr>
<td>Middle</td>
<td>20.3</td>
<td>2.550</td>
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<td>0.30</td>
<td>76</td>
<td>71</td>
<td>19</td>
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<tr>
<td>Tail</td>
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<td>2.090</td>
<td>8.0</td>
<td>0.30</td>
<td>79</td>
<td>68</td>
<td>27</td>
</tr>
<tr>
<td>780L Kutiyana distributary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head</td>
<td>39.5</td>
<td>5.640</td>
<td>5.4</td>
<td>0.30</td>
<td>92</td>
<td>65</td>
<td>30</td>
</tr>
<tr>
<td>Middle</td>
<td>32.7</td>
<td>5.940</td>
<td>6.2</td>
<td>0.25</td>
<td>86</td>
<td>68</td>
<td>35</td>
</tr>
<tr>
<td>Tail</td>
<td>26.4</td>
<td>3.120</td>
<td>4.9</td>
<td>0.25</td>
<td>96</td>
<td>75</td>
<td>61</td>
</tr>
<tr>
<td>2000R Sheronwali distributary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head</td>
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<td>4.760</td>
<td>7.5</td>
<td>0.20</td>
<td>72</td>
<td>78</td>
<td>65</td>
</tr>
<tr>
<td>Middle</td>
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<td>3.630</td>
<td>6.6</td>
<td>0.20</td>
<td>67</td>
<td>87</td>
<td>49</td>
</tr>
<tr>
<td>Tail</td>
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<td>3.200</td>
<td>5.8</td>
<td>0.20</td>
<td>58</td>
<td>74</td>
<td>58</td>
</tr>
</tbody>
</table>

AE = application efficiency; SE = storage efficiency; DU = distribution uniformity; Ic = cumulative infiltration, depth and equity

Conveyance losses at different points were measured to compute the water being supplied to different farms and the equity, as represented by the Christiansen uniformity coefficient (Ca), and modified inter-quartile ratio (IQR) were computed (Table 3).

The values of Ca range from 0.63 to 0.95 for different watercourses with an average value of 0.8. So, if Ca were chosen as the criterion parameter for equity, the values of equity are apparently quite high. Of course, there is a decrease in equity as the size of the watercourse increases. The distribution looks more non-uniform when one computes IQR, which represents the ratio of the
average depth in the most favoured quarter to the average depth in the least favoured quarter. The IQR value at the lowest discharge of 19.5 l/s is 1.33 and it increases to 2.58 at the highest discharge of 68 l/s, with an average value of 1.85. In other words, the farms located in the head reaches of the watercourses receive nearly twice the water supply going to the tail-end farms.

Table 3. Values of equity measures in different watercourses

<table>
<thead>
<tr>
<th>Distributary</th>
<th>Water-course No</th>
<th>Design discharge (l/s)</th>
<th>Cu</th>
<th>IQR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gorakhpur</td>
<td>5000L</td>
<td>45.0</td>
<td>0.81</td>
<td>1.69</td>
</tr>
<tr>
<td></td>
<td>3275L</td>
<td>45.0</td>
<td>0.78</td>
<td>2.01</td>
</tr>
<tr>
<td></td>
<td>8758L</td>
<td>46.4</td>
<td>0.88</td>
<td>1.65</td>
</tr>
<tr>
<td>Khajuri</td>
<td>9400L</td>
<td>28.0</td>
<td>0.95</td>
<td>1.48</td>
</tr>
<tr>
<td></td>
<td>11260L</td>
<td>19.5</td>
<td>0.91</td>
<td>1.33</td>
</tr>
<tr>
<td>Fatehabad</td>
<td>179415L</td>
<td>68.0</td>
<td>0.82</td>
<td>2.58</td>
</tr>
<tr>
<td></td>
<td>204200L</td>
<td>45.6</td>
<td>0.73</td>
<td>2.29</td>
</tr>
<tr>
<td>Adampur</td>
<td>44000L</td>
<td>29.7</td>
<td>0.94</td>
<td>1.36</td>
</tr>
<tr>
<td>Kutiyana</td>
<td>780L</td>
<td>45.5</td>
<td>0.89</td>
<td>1.60</td>
</tr>
<tr>
<td>Sheronwali</td>
<td>2000R</td>
<td>34.6</td>
<td>0.63</td>
<td>2.53</td>
</tr>
</tbody>
</table>

Relative water supply

The relative water supply is the ratio between the water supplied and the demand in an irrigation unit over a period of time. The concept is related to the available water supply, demand and management intensity in an irrigation system. The capacity of the system to control water is determined both by physical resources and the institutions. The degree to which capacity is actually realized is called intensity of management. By varying the intensity, it is possible to match supply and demand. As shown by Oad and Podmore (1989), a low relative water supply requires a more intense management.

The relative water supply varied across the watercourses, the seasons and the reaches. Watercourse 9400L (Khajuri) and 179415L (Adampur) (Table 4) had relatively higher adequacy, with values of about 80 percent, than watercourse 5000L (Gorakhpur) with 49 percent and 2000R (Sheronwali) with 58 percent. Watercourse 179415L was actually drawing more water than its designed discharge due to the inaccurate installation of an adjusted proportion module outlet. The sill level of the adjusted proportionate module was lower than provided for in the design. Relative water supply values during the summer, when crop water requirements are
partly met by rainfall, were higher by 8-12 percent than in winter. There was marked variation in the relative water supply along the watercourse, with values at the head exceeding those at the tail by 25 percent. For example, the average value at the head of watercourses in winter was 0.65 as against 0.50 in the tail reach. Such large differences obviously call for immediate remedial measures.

<table>
<thead>
<tr>
<th>Distributory Water-Course</th>
<th>Location along the watercourse</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Head</td>
<td>Middle</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>Winter</td>
</tr>
<tr>
<td>Gorakhpur</td>
<td>5000L</td>
<td>0.58</td>
</tr>
<tr>
<td>Khajuri</td>
<td>9400L</td>
<td>0.88</td>
</tr>
<tr>
<td>Fatehabad</td>
<td>139415L</td>
<td>0.72</td>
</tr>
<tr>
<td>Adampur</td>
<td>780L</td>
<td>0.83</td>
</tr>
<tr>
<td>Sheronwali</td>
<td>2000R</td>
<td>0.61</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>0.72</strong></td>
<td><strong>0.65</strong></td>
</tr>
</tbody>
</table>

$L = \text{left-hand side}; R = \text{right-hand side}$

**Productivity of the water delivery system**

Irrigation systems are meant to provide water to increase land productivity by maximizing water use. The excess or deficit of the water supply has an impact on crop yields, though the effect varies with each stage. There are several approaches to simulate the effect of a water supply regime (Bhirud et al, 1990; Vijayaratna, 1988); the most elegant, which has potential for large-scale application, is due to Lenton (1984). Lenton’s water delivery performance takes into account both the adequacy and the timeliness of the water supply and essentially represents productivity on a 0-1 scale. The potential productivity of Abernathy (1987) is similar to Lenton’s (1984) water delivery performance index and it produces a number in the range of 0 to 1 obtainable under a given water supply regime.

The computed values of productivity are given in Table 5. There are similarities as well as differences with the results obtained in the relative water supply analysis: the productivity of water delivery is higher in the head reaches of all the watercourses, the average value during summer being 0.61 in the head as against 0.48 in the tail reaches; but the relative productivity potential is higher in winter than during the summer. This may be due to the occurrence of rain during supply periods in the summer. In such cases, the supply becomes a surplus. The higher
sensitivity to moisture of crops grown during the summer could also be the reason for the low water productivity.

Another important difference is that, in general, the values of productivity are lower than those of seasonal relative water supply. This implies a mismatch in time terms between supply and requirement. In other words, the water supply is wanting in timeliness. Timeliness and reliability both carry the implications of some external demand or need to be fulfilled. Small and Svendsenden agree that in the absence of any readily identifiable distinction between reliability and timeliness, the single concept of timeliness would be more useful. In the above analysis, the need for improving the timeliness of water supply at different growth stages is clearly indicated.

### Table 5. Water delivery performance in terms of relative productivity potential

<table>
<thead>
<tr>
<th>Distributary Water-course</th>
<th>Location along the watercourse</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Head</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>Winter</td>
</tr>
<tr>
<td>Gorakhpur</td>
<td>5000L</td>
<td>0.49</td>
</tr>
<tr>
<td>Khajuri</td>
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<tr>
<td>Fatehabad</td>
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<tr>
<td>Adampur</td>
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<td>0.79</td>
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<tr>
<td>Sheronwali</td>
<td>2000L</td>
<td>0.51</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>0.61</td>
</tr>
</tbody>
</table>

### Interventions for improving the performance

The problems of non-uniform and inadequate water application at the farm, inequitable distribution along the watercourse, and rigidity of irrigation schedules that lower water productivity can, to some extent, be overcome by making certain modifications in the system. The detailed description on how the interventions are to be designed is given elsewhere (Tyagi et al, 1995) and cannot be reproduced here for want of space. However, suggestions and modifications can be briefly mentioned.

- **Improvement in water distribution equity and efficiency.** Equity in water distribution along the watercourse and irrigation efficiency on the farm can, to a large extent, be resolved through the proper design of the unit command area size. A model has been
developed for designing an optimal unit command area incorporating the concepts of equity, efficiency and productivity. It is validated with data from watercourses on the Sudkan distributary. The design of watercourses by adopting the suggested procedure led to improvement in three performance criterion parameters (equity, efficiency and productivity), thereby clearly establishing the need and scope for modifying the existing design standards.

Further scope for improving the water delivery performance lies in variable time warabandi from head to tail of the watercourse or through the installation of tube wells toward the tail reach of the course. The design procedures for these interventions need, however, to be established.

- **Relaxing the rigidity of the delivery schedule.** It is possible to make intra-seasonal modification in the existing rigid water delivery schedules without involving structural changes. A mathematical model has been formulated to evaluate the different rotational and on-demand water supply schedules with a view to suggest intra-seasonal changes. Application of the model to the Gorakhpur distributary of the Fatehabad branch has suggested the possibility of obtaining 94 percent of on-demand yield with intra-seasonal change in the irrigation interval after 100 days of sowing of wheat with only 66 percent of the on-demand water requirement. The suggested model provides a rationale and the procedure to modify water delivery schedules.

- **Improving timeliness.** The problem of time mismatch between supply and demand may be solved by providing auxiliary storage at the head of the watercourse and allowing for intra-seasonal variations in water delivery schedules. A procedure has been outlined to estimate the availability of canal water for auxiliary storage and to establish its economic feasibility. For the demand and supply conditions obtaining in the Adampur distributary of the Fatehabad branch canal, provision of auxiliary storage could improve wheat yields by 20 percent with a benefit-cost ratio of 1.3.
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Some experiences on modernization in irrigation system rehabilitation in Sri Lanka

Dr G.G.A. Godaliyadda¹, K.R.P.M. Mullegamgoda², A.M.U.B. Alahakoon³

Introduction

The history of irrigation in Sri Lanka goes back more than two thousand years and over time many irrigation systems were abandoned due to various reasons. During the British colonial rule many of the irrigation systems were renovated to promote irrigated agriculture. After Independence the main emphasis of the government of Sri Lanka was on agricultural development through the renovation of ancient irrigation works and resettlement of the landless population in the dry zone. The main objectives of the development were:

- to increase food production;
- to provide land for the landless;
- to earn or save on foreign exchange; and
- to generate employment and raise the income of the farming community.

However, the renovated irrigation systems deteriorated within a couple of decades due mainly to poor maintenance and flows being carried over the designed capacities of the canals to cater to the excessive use of water by farmers. This has led to serious operational problems in many irrigation systems, the worse being the inability to irrigate the planned area. During the last two decades, many irrigation systems have been rehabilitated mainly to bring back land under cultivation as originally planned and to assure more reliable water supplies to farm lands. However, many rehabilitation projects have not contributed much to increase water delivery and water use efficiency through management innovations. Of course, physical rehabilitation has contributed to some extent to increase efficiency. At the same time, it is not correct to say that there have been no modernization efforts on physical structures or management to improve irrigation system operations in Sri Lanka.

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Rehabilitation projects

The main rehabilitation projects implemented in Sri Lanka during the last few decades can be listed as follows:

1. The Tank Irrigation Modernization project 1976-1982
2. The Gal Oya Rehabilitation project 1981-1986
3. The Major Irrigation Rehabilitation project 1985-1992
4. The Irrigation System Management project 1986-1996

The Tank Irrigation Modernization project

This was the first modernization project implemented in five main irrigation systems in North Central Sri Lanka and North Sri Lanka under World Bank funding. Even though this was the first project of this nature, it had several innovative efforts of physical modernization to improve the operational aspects in irrigation water delivery. The project was criticized by many as drastic changes were brought in the technological designs without any consultation of the beneficiaries. If the objectives of the project had been known to the beneficiaries before implementation, it might have been more successful. In this project much weight was given to modernization design proposals for rotational water distribution within field (tertiary) canals feeding a turnout area of about 40 acres. The distributary (secondary) canals were split into several segments to facilitate the water distribution to head and tail farms. Separate control gates for each canal segment were provided at the head end. The segments were continued until the tail-end field canals to get them isolated from the branching-off canals. In the main canal cross realtors with gates and in distributary canals duckbill weirs with regulators were introduced to regulate the flow. A flow measuring device at the sluice (Parshall flume) and many measuring weirs were installed at every off-take to improve the operational capabilities of the systems.

The improved water management programme

Subsequently, using the above improved physical facilities, water management programmes were implemented in many systems. In the Mahakanadarawa irrigation system where water management was implemented successfully, it was possible to irrigate the entire service area with rotational water distribution within turnout areas with the co-operation of the farmers.
some reason, though, the programme was not continued, and the success of such innovative modernization efforts was short-lived.

The pilot project on on-demand delivery

In one of the systems, i.e. Mahakanadarawa, under the direction of the World Bank a pilot project on on-demand delivery was introduced in a distributary canal service area. Starting from the outlet of the main canal up to the farm outlet, underground concrete pipelines were laid and each farm was provided with a valve to get water as and when required. Even though the project intended farmers to use water on demand, they continued to take water as in a conventional system.

Simultaneously, a similar project was implemented in the 150ha service area of a distributary in Area H of the Mahaweli scheme. This automated supply system consists of a reservoir, a downstream level-control gate, level top canal, and low pressure concrete pipes supplying individual turnout valves. The principal objective was to compare demand irrigation to conventional agency-controlled rotational irrigation. The project operated for six seasons (three years) and interesting useful results were achieved. As in the previous case, a few years after the study period the project reverted to conventional rotation irrigation, as did the rest of Area H. There were no follow-up attempts to replicate such interventions even though the farmers responded positively to such methods (Plusquellec, 1996).

Technical assessment area and dry land preparation

Under the tank irrigation modernization project, there was a very close link between the Irrigation and Agriculture Departments from the inception. The Agriculture Department was involved in planning the cropping pattern and calendar and applying other agronomic inputs. A technical assessment area was set up to demonstrate various techniques in crop cultivation. Even the preparation of land with initial moisture in the soil without using irrigation water was demonstrated. This too had been considered in the design of the tank irrigation modernization project.

The Gal Oya Rehabilitation project

The Gal Oya irrigation system, the largest system operated and managed by the Irrigation Department of Sri Lanka, was rehabilitated under USAID funding in the early 1980s. There was
no innovative design procedure before the implementation of the project. The rehabilitation requirements at secondary and tertiary organizations were defined by staffers known as institutional organizers. The entire system was rehabilitated by providing the necessary structures for better control and delivery of water. Different flow measuring devices were introduced in Gal Oya where farmers did not feel that the devices were obstructing the flow.

Computer-aided irrigation system operation

One of the innovative efforts on system operation implemented in this project was the computer-aided water scheduling model with a two-way communication network for daily monitoring of the water deliveries throughout the system (Godaliyadda, 1987). The model computes the weekly irrigation requirements based on crop water requirements according to growth stages, soil percolation rate, rainfall with application and conveyance losses. The daily diversion requirement at major diversion points and branching-off points were monitored and gauge readings were transmitted to the central office through telephones. Similarly the instructions from the central office were transmitted to the field through the same arrangement.

The Major Irrigation Rehabilitation project

There was no significant difference in physical rehabilitation in relation to previous projects in systems selected under this project. Even though this project too was funded by the World Bank, many of the innovative design concepts in the tank irrigation modernization project were not fully adopted.

Under the direction of the World Bank, a pilot project was implemented in a distributory canal in the Rajangana system with two structural modifications: an automatic constant downstream level gate associated with modular distributors at the head of the distributory canal, and baffle distributors at the head of field canals. The pilot area of 150 ha was compared with the conventional gates system. It was found that there was no significant difference in terms of water use and crop yields. However, there are some doubts about the reliability of the data. The operational cost of the new design was 40-percent lower that the conventional design. The feeling of both the Irrigation Department and the farmers is that this kind of design provides greater facility in operation and possibility in checking the quantity of water delivered to the fields (Plusquellec, 1996).
The National Irrigation Rehabilitation project

This is the largest project of all those listed above which undertook many major systems for rehabilitation under World Bank funding. One of the features of this project was beneficiary participation on physical rehabilitation. According to the project agreement, a voluntary beneficiary contribution of 10 percent from the overall civil cost of the system rehabilitation was enforced.

Operation and maintenance manual

Even though there were no modernization efforts of physical rehabilitation, several improvements have been introduced for the operation and maintenance of irrigation systems, such as the preparation of an operation and maintenance manual for each irrigation system rehabilitated and the implementation of the after-care programme to fully achieve the objectives of the projects on operation and maintenance.

Proposed typological approach to the modernization of irrigation system operation

The basic assumption of this approach is that irrigation systems have a heterogeneous behaviour with respect to operation. The goal is to bridge the gap between generic recommendations and site-specific recommendations. Generic rules are often mandated at national or regional levels and do not incorporate site-specific constraints at present. Local managers integrate these constraints by rule of thumb (Godaliyadda, 1998).

The foreseen applications of the typology are twofold: at global, national and regional levels, as a grid for characterizing irrigation systems as a whole and for assessing the requirements for operation; at local level, as a grid of criteria to divide the irrigation system into more homogeneous units (subsystems) with respect to operation. At system level, subsystems appear to have different behaviours and thus managers should distribute efforts in a non-homogeneous way. For instance, a double-bank canal fed by a reservoir and having an intermediate reservoir is much easier to operate than a single-bank canal fed by river diversion and having inflows into the system. To reach the same level of performance, the second case should receive more attention and efforts.

Four main types of irrigation systems have been identified in Sri Lanka. Under the current practice of operation, very little improvement can be expected. Introducing new operation
strategies to take into account the opportunities offered by physical features is more promising. On a more global perspective, it is expected that the typology will prove to be useful in resource allocations for the modernization of irrigation systems for improved operation (Godaliyadda, 1998).

Proposed pilot projects

Modernization operational techniques are programmed to be tested in the near future using the typological approach in the Minipe diversion system with a 74km-long single-bank main canal and in the Kirindi Oya reservoir system with a 20km-long double-bank main canal.

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Modernization of farmer-managed irrigation systems in Nepal: process and learning

R. P. Bhandari 1 and D. R. Pokharel 2

This paper is intended to highlight the changes in the modernization of irrigation during the last decade in Nepal, focus on observed performance, and show that there is room for improvement.

Background
The Himalayan kingdom of Nepal, landlocked between India and China, occupies an area of 147 141 km². The country is divided into 75 administrative districts and five development regions (Table 1). There are three parallel ecological zones running east to west: the Terai, the Hills and the Mountains. Nepal’s resource base for agriculture is severely limited by topographical constraints. Only about 20 percent of the total land area is under cultivation. The predominant position occupied by agriculture in the Nepalese economy is due to the fact that about 90 percent of the population depend on agriculture, which contributes about 43 percent of GDP and 70 percent of total export earnings at nominal prices (Agricultural Perspective Plan, 1994). Although agriculture dominates the national economy, its contribution is rather declining. Nepal, once a rice-exporting country, has now to import rice occasionally to meet domestic needs. The identified reasons for the poor performance of agriculture are: inadequate provision of irrigation, production inputs, credit, market and extension of appropriate technology to support production growth (Agricultural Perspective Plan, 1994). Among these factors, irrigation has been identified as the key to accelerate, intensify and sustain agricultural growth (Sharma, 1994).

Table 1: Development regions & administrative districts

<table>
<thead>
<tr>
<th>Development region</th>
<th>Number of admin. districts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern</td>
<td>16</td>
</tr>
<tr>
<td>Central</td>
<td>19</td>
</tr>
<tr>
<td>Western</td>
<td>16</td>
</tr>
<tr>
<td>Mid-Western</td>
<td>15</td>
</tr>
<tr>
<td>Far-Western</td>
<td>9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>75</strong></td>
</tr>
</tbody>
</table>

1 Irrigation Engineer, Research & Technology Development Branch, Department of Irrigation, Katmandu, Nepal
2 Acting Chief, District Irrigation Office, Syanja, Nepal
Since time immemorial, farmer-managed irrigation systems have played a major role in the irrigated agriculture of Nepal. Before 1951, there were only three state-run or agency-managed irrigation systems in the country (Ansari, 1995). The planned irrigation development in the country, with the establishment of a state agency (the present Department of Irrigation), began only after 1951. At first, a lot of interventions were made in the farmer-managed irrigation systems under the banner of modernization and some new irrigation schemes were taken up. The mode of intervention was to take over the selected irrigation systems from farmers’ management and treat them as new schemes, thus keeping farmers completely aloof. All of the capital cost was borne by the agency and segregation occurred between the farmers and the agency. Original farmer-managed irrigation systems became the agency-managed irrigation systems. Even after the planned involvement of the state in irrigation development, the irrigation development status is still led by farmer-managed irrigation systems (Table 2). Another reality is that the present irrigated area is merely 30 percent of the total irrigable area.

<table>
<thead>
<tr>
<th>Irrigation system type</th>
<th>Area (ha)</th>
<th>Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmer-managed</td>
<td>406 986</td>
<td>38.5</td>
</tr>
<tr>
<td>Agency-assisted farmer-managed</td>
<td>332 130</td>
<td>31.5</td>
</tr>
<tr>
<td>Agency-managed</td>
<td>292 546</td>
<td>27.7</td>
</tr>
<tr>
<td>Private</td>
<td>23 955</td>
<td>2.3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1 055 617</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

Based on record compiled by Institutional Development Support Component, DoI, July 1997

The farmer-managed irrigation systems were built, operated and maintained by the farmers themselves with little or no help from state or outside agencies. They contribute substantially to the agricultural production of the country, have been managed well and, in general, give better yields. Usually, their infrastructure is simple and lacks provision for water control and management. In other words, they run on the tradition of self-help. The agency-managed irrigation systems, on the other hand, in spite of their recurrently increasing operation and maintenance costs, have not improved their performance. When they were taken over by the state, the old irrigation systems were thought to have much potential for increased performance, as they were rudimentary, lacked permanent structures, were susceptible to damage during floods and to silt problems and had high water losses. In consequence, farmers had to contribute much labour and resources to run these systems. This led the government to rethink its irrigation strategy. By the mid-1980s the government became aware of the importance and strengths of the farmer-managed irrigation systems for the country’s
agriculture. There was also recognition of the scope for improving the systems through their rehabilitation and the extension of irrigated area, which would be possible by minimizing water losses and improving management efficiency. Besides, the operation and management requirements (labour and cash) could also be reduced to a manageable level. With this realization the strategy on irrigation development shifted to the participatory approach. With the aim of streamlining government’s efforts and investment in a sectoral approach, two specific projects, namely the World Bank/IDA loan-funded Irrigation Line of Credit (ILC) and the Asian Development Bank loan-funded Irrigation Sector Project, have been implemented. UNDP provided the technical assistance for both projects.

The Irrigation Line of Credit
ILC was initiated in FY1988-89 with a loan from IDA/WB. The project was launched to implement a sector programme in irrigation development in the Western Development Region on a pilot basis. Later, the scope of the project was extended to all three western development regions. The project was designed to support the following types of small and medium-sized subprojects:

- rehabilitation of existing farmer-managed irrigation systems (REHAB);
- turnover rehabilitation of selected agency-managed irrigation systems (TO);
- construction of new surface schemes (NEW); and
- construction and improvement of groundwater schemes to be managed by farmer groups (GW).

ILC has now been succeeded by the Nepal Irrigation Sector project. The accomplishments under ILC are presented in Table 3.

Table 3: Accomplishments under ILC

<table>
<thead>
<tr>
<th>Subproject type</th>
<th>No of subprojects</th>
<th>Command area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>REHAB</td>
<td>260</td>
<td>25 995</td>
</tr>
<tr>
<td>TO</td>
<td>25</td>
<td>3 119</td>
</tr>
<tr>
<td>NEW</td>
<td>14</td>
<td>4 730</td>
</tr>
<tr>
<td>GW</td>
<td>219*</td>
<td>4 210</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>38 054</strong></td>
</tr>
</tbody>
</table>

* Number of tube wells
The Irrigation Sector Project

ISP was initiated in 1989 with a loan from ADB. The original target was to provide irrigation facilities over 25,000 ha of land through the rehabilitation of existing farm-managed irrigation systems and the construction of small and medium-sized irrigation schemes in 22 districts of the central and eastern development regions. ISP has been succeeded by the Second Irrigation Sector project. The accomplishments under ISP are presented in Table 4.

<table>
<thead>
<tr>
<th>Subproject type</th>
<th>No of subprojects</th>
<th>Command area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>REHAB</td>
<td>277</td>
<td>46,371</td>
</tr>
<tr>
<td>NEW</td>
<td>99</td>
<td>11,211</td>
</tr>
<tr>
<td>Total</td>
<td>376</td>
<td>57,582</td>
</tr>
</tbody>
</table>

Objectives of ILC and ISP

The overall objectives of ILC and ISP were to substantially boost agricultural production through the development and improvement of new and existing farmer-managed irrigation systems with the active participation of beneficiary farmers. The specific objectives could be listed as follows:

1. establish a sector programme approach instead of the previous project-by-project approach;
2. make the programme demand-driven instead of supply-driven as in the past;
3. help develop, test and establish effective subproject selection criteria and implementation procedures which would provide the basis for operating the sector programme; and
4. reduce the burden of the irrigation cost on the national budget, particularly for operation and management, through increased farmers’ participation to cover operation and management costs in full as well as a share of capital costs.

Framework of intervention under ILC and ISP

Given these objectives, the projects followed specific steps in the process of intervention:

1. Selection stage: formal demand, identification, survey, appraisal.
2. Implementation stage: formation of water user associations, agreement, construction.
3. Operation and management stage: commissioning, operation and maintenance, support to agriculture.

Some of the key points for selection are as follows:

- the subproject should be demanded by the farmers in writing;
it should be economically viable, producing an internal rate of return of at least 10 percent;

- it should be appraised, including in aspects such as historical background, socio-economic conditions, agricultural situation, local organization, engineering and geo-hydrology;

- it should be reviewed and recommended by the regional appraisal committee; and

- it should be approved by the approval co-ordination committee.

The regional appraisal committee is formed at the regional level and has four members:

<table>
<thead>
<tr>
<th>Position</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chairperson</td>
<td>Regional Irrigation Director</td>
</tr>
<tr>
<td>Member</td>
<td>Regional Agriculture Director</td>
</tr>
<tr>
<td>Member</td>
<td>Regional Manager, Agriculture Development Bank</td>
</tr>
<tr>
<td>Member</td>
<td>Regional Director, National Planning Commission</td>
</tr>
</tbody>
</table>

The approval co-ordination committee is formed at the central level and has five members:

<table>
<thead>
<tr>
<th>Position</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chairperson</td>
<td>Representative, Ministry of Water Resources</td>
</tr>
<tr>
<td>Member</td>
<td>Deputy Director General, Department of Irrigation</td>
</tr>
<tr>
<td>Member</td>
<td>Representative, Ministry of Agriculture</td>
</tr>
<tr>
<td>Member</td>
<td>Representative, Agriculture Development Bank</td>
</tr>
<tr>
<td>Member</td>
<td>Representative, National Planning Commission</td>
</tr>
</tbody>
</table>

The formation of the two committees intends to involve the line agencies and the planning agency in scrutinizing the process of irrigation development that will lead to the selection of the best potential subprojects.

Some of the key points for implementation are as follows:

- After the approval of the subproject the farmers are supposed to form a water user association, which has a written constitution and is registered to receive legal status.

- The water user association signs a formal agreement on cost sharing (its participation varying between 7 and 25 percent of total cost through contributions in cash and kind), on the construction work execution process, on operation and maintenance responsibility, etc, with the Department of Irrigation.

- The construction proceeds as per the previously signed agreement. The water user association part has to be completed by the association, whereas the remaining part will be executed through either the association or a local contractor or both, depending on the nature and volume of the work;

- The construction supervision is the joint responsibility of the Department of Irrigation and the water user association.
Some of the key points for the operation and management stage are as follows: after completion of the construction work, commissioning work starts with joint inspection and recommendation for further consideration if some improvement works remain to be done; then it is the duty of the water user association to operate and maintain the system and approach other line agencies for agricultural support.

**Key findings from ILC and ISP**

Some of the key findings from the evaluation of ILC and ISP processes and performance are discussed below.

**Selection criteria.**

Economic viability and users’ requests were the main parameters considered for the selection of a subproject. The main drawback of the selection criteria was artificially inflated requests and inflation of the command area.

**Organization.**

Users’ involvement showed in good construction quality control and a deepening sense of ownership. But in some cases, farmers’ organizations faltered over problems of low-quality construction or of the contracting of business to elite farmer leaders or the people they favour. There have also been cases of farmers’ organizations shifting their focus from system management to contracting, and conflicts arising over money matters.

**Participation.**

The cost-sharing arrangements, as per the agreed memoranda, in many cases were compensated for by the contractor, or some elite leaders who could capitalize from the construction business directly or indirectly.

**Design of facilities.**

The project movers did a very good job in listening to farmers and taking their ideas into consideration. Headworks were properly placed, canal alignments usually followed existing lines, and turnouts were placed where the users needed them. In other words, the design of the facilities matched the needs. But the technology used could not be considered as simple as the capability of the users. Several systems used gated regulators that proved difficult to maintain.
Many regulators became immovable due to lack of lubrication. Stone masonry lining was the most used lining and has proved difficult for farmers to maintain, as this requires skilled labour and cash resources. Most systems were over-designed and incorporated technology which is not easy to operate and manage. Too much lining was used. Not enough time was spent on determining the best places for lining based on seepage losses.

Follow-up.
After construction was done, there has been a lack of follow-up activities, leading to dissension within the water user associations. In some cases, registration was felt important to receive programme assistance and later nothing more was heard about it.

Operation and maintenance.
As described in the subheading of design, the technology used for modernizing the farmer-managed irrigation systems is not simple, given the farmers’ original lack of modern technological know-how and sophistication. The quality of de-silting and embankment improvement works carried out by the users was not good, but there was hardly any indication of proper maintenance of the newly added structures.

Cost effectiveness.
The projects did little to save costs. The reasons might be that little time was spent educating the farmers, that there were no rewards encouraging agency staffers to save money and, perhaps more important, that the farmers’ contribution may have been borne by contractors or a few elite farmer leaders.

Water delivery performance.
In most cases, the water delivery is good. The reasons might be the good quality of the works and the existence of the newly constructed facilities.

Co-ordination with other line agencies.
Very little progress has been made, despite the formal presence of related line agencies through the provision of the regional appraisal and approval co-ordination committees.
Lessons learned
The irrigation sector programme took advantage of the strengths of the existing farmer-managed irrigation systems, such as strong organization and sense of ownership and ability to mobilize resources for operation and maintenance. But it could not capitalize fully on these strengths by providing user-friendly facilities with the least possible physical intervention.

The procedural framework for modernizing numerous farmer-managed irrigation schemes scattered throughout the country has been tested in the main, but there is room for improvement in execution. Control over the recurring and serious problems of artificially inflated user requests and inflation of the command area is indispensable to reach the programme goal.

The intended objective to change the traditional supply-driven programme to demand-driven has been partially achieved. The demand forms in many cases are coerced by the agency staff or contractors or elite farmer leaders, leading to a demand-created programme. In other words, on paper the demand is as per the set criteria and in the specified formats and sizes but the farmers themselves are still unaware of their own demands and of whatever else is happening within their irrigation system.

The tendency to build much more than is needed puts a question mark over the cost effectiveness of the programme. Besides, budgetary allocation on a district basis may not be the best way to select a cost-effective subproject and give it priority in implementation.

The long-term sustainability of the programme is in question, as the farmers do not demonstrate the skills necessary to maintain new structures or the ability to mobilize cash resources to purchase the materials required for maintenance.

Conclusion
The initial performance of the new strategy in modernizing farmer-managed irrigation systems shows encouraging signs as far as the procedural framework is concerned for such a great number of systems. Still, the formula “users’ participation in agency programmes” should be reversed to “agency’s participation in users’ programmes” as the farmer-managed irrigation systems are the main users and the need for modernization is theirs rather than the state’s.
For this, sufficient time should be given to the real users to learn about the programmes, to become familiar with the objectives and the conditions of support of their systems and to let them come up with genuine demands of their own.

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Worldwide training programme initiative 235
Modernizing irrigation operations: spatially differentiated resource allocations

D. Renault & I.W. Makin
Irrigation Specialist, and Head of Design and Operations Programme, respectively, IWMI

Abstract
Modernization of irrigation implies interventions in different components of system management. This paper focuses on operations and proposes a methodology for an improved assessment of irrigation canal behaviour and the environment in which operations take place. An underlying assumption is that irrigation systems are generally heterogeneous and therefore the allocation of operational resources should be matched to the spatial distribution of management requirements.

A descriptive model of irrigation systems is presented by defining three domains. First, the cause, frequency of occurrence and magnitude of perturbations to the flow regime are considered as the perturbation domain. Second, the behaviour of the physical system when subject to perturbation is considered as the sensitivity domain. Third, the impact of system operations on agricultural yields is examined in the vulnerability domain, which enables the development of the specifications of a required water service.

Combining the vulnerability and sensitivity domains makes the definition of the precision with which systems must be operated possible. The inclusion of the perturbation domain allows for the specification of the required mode of operation to be implemented to achieve the required water service, including specification of the required frequency of intervention. The whole provides scope for the definition of the demand for operation at a spatially de-aggregated level.

Introduction
Irrigation modernization is increasingly recognized as a fundamental transformation in the management of water resources within agricultural areas. Such transformations may include improved structures, physical or institutional or both; rules and water rights; water delivery services; accountability mechanisms and incentives. In this paper we address how modernization provides an opportunity to redefine and update operational procedures within irrigation schemes. By incorporating broader perspectives and paying attention in particular to the spatial distribution of significant variables, this paper defines new approaches to the allocation of operation resources. The critical step, i.e. the means by which to obtain and manage the resources, is not addressed here.

The objective of this paper is an improved methodology for evaluation of the resource demands for effective canal operations to enable more cost-effective operational management. The basis of the proposed approach is whether or not operational requirements are homogeneously
distributed throughout the entire scheme. If not, we would argue, operations require different responses in different sections of the scheme.

Demand for operational resources consists primarily in answering the following questions:

- What mode of operation?
- What degree of precision?
- With what frequency of checking and intervention?
- What monitoring system is required?

The need to re-evaluate and update approaches to operations is given impetus by the tremendous changes that have occurred in the irrigation sector over the last few decades. These result from increasing competition for both water and financial resources and also growing concern over the environment and health impact of irrigation. Water management is no longer narrowly focused but must embrace a broad perspective including water quality, conjunctive management, multiple uses of irrigation waters, a watershed perspective, new water rights and priorities for distribution. A traditional quantitative and rather uniform management system for irrigation schemes is no longer sufficient to address current issues. Furthermore, these trends will continue and system operators will have to develop more cost-effective operational plans to satisfy the increasingly influential users-payers.

As opportunities to develop new areas are increasingly restricted, many existing irrigation schemes are, or will in the near future be, undergoing major changes, either physical or institutional, or both. It is necessary to scrutinize the basic irrigation activities, operation and maintenance, in order to ensure that the new systems are economically sustainable.

**Canal operations in technical literature**

Canal operation and flow control techniques are well documented, particularly for system design analysis - Zimbelman D.D. (1987), Paudyal and Loof (1988), Plusquellec H. (1988), Plusquellec H. et al (1994), RIC (1997). However, there are few published studies on how managers should operate existing systems, evaluate the operational requirements or allocate resources and effort to optimize system performance. In many schemes, a mixture of rule of thumb and local experience is the basis for operational decision-making. There is no standardized base for retention of operational experience and, due to senior staff rotation, there
is a risk of permanent loss of knowledge if such information is not formally recorded in an understandable form.

Any renewed approach to canal operations must bridge the gap between on-site management and official plans for operation and maintenance, and other such operational guides. These guide manuals are increasingly required by authorities and funding agencies at the completion of structural works (new projects or rehabilitation). However, unless it is recognized that the operational framework cannot be fully planned at design stage and that finetuning over some years of practice is a fundamental requirement (Uittenbogaard and Kuiper, 1993), it is proposed that an adaptive or learning process is preferable to strictly prescriptive approaches (Handbook, 1990; Skogerboe and Merkley, 1996).

**Operations in the irrigation process**

Operations are the manipulation of physical structures in the irrigation system to implement management decisions about water allocation, schedules of delivery and distribution. Operations are also the routine actions taken to minimize the impact of perturbations by maintaining steady or quasi-steady state water profiles in the system and to prevent overtopping at peak discharges.

Operations are routinely required to implement distribution decisions and, as a consequence, the terms are sometimes confused, even though they are fundamentally different. To clarify the thinking, technical irrigation management implies three levels of decisions – allocation, scheduling and distribution – and one level of implementation – operations.

**Operations and types of irrigation systems**

It is self-evident that irrigation systems are not identical in regard to their operational requirements. Some are highly automated and, although this requires larger investments in construction, they often need fewer human and financial resources for day-to-day operation. Other systems are manually controlled and require full and intensive operations during irrigation. We can classify the irrigation systems as:

- **Fully operated systems**, where all structures (intake-outlets-cross-regulators) require regular and routine operation during irrigation, (setting on-off, setting and monitoring);
- **Non-operated systems**, generally operating on the proportional distribution principle, common in India and Pakistan. Fixed dividing structures ensure an equitable distribution of water. No operations are required to adjust the on-going flow within the structured system (Shanan, 1992).

- **Minimal operation systems**, such as those equipped with modules and combined with automatic or fixed regulators. Interventions are generally limited to on-off operations and flow regulation is achieved by control modules or baffles.

This classification of control systems is essentially valid only for intermediate level canals such as distributaries. Main canal systems and field canals are generally fully regulated. We can therefore conclude that whatever control technique in the intermediate distribution system, major irrigation systems include (at least) portions with gates that must be operated.

**The basic assumption of heterogeneity and the spatial analysis**

Technical manuals for irrigation operations, in general, implicitly assume homogeneity: first, homogeneity in the requirements for operation and therefore homogeneity in the distribution of operational efforts. In many cases this assumption simply does not hold true. Rather, the basic assumption in operating an irrigation system should be that the scheme is heterogeneous, unless it can be clearly shown to be homogeneous.

There is limited literature on the heterogeneity in irrigation. One very noteworthy approach, proposed by Ng Poh-Hok (1987), for the design of an irrigation system uses the concepts of irrigation form and irrigation context. Poh-Hok proposed that these must match in order to be successful. He considered the assumption of heterogeneity, a generic term regrouping variability, uncertainty, diversity and complexity, before presenting a conceptual model of irrigation as a consistent aggregation of elementary homogeneous units. These elementary units were defined as a socio-geographic unit, homogeneous in form and context.

Steiner and Walter (1993) considered the spatial variability of all factors influencing irrigation management, such as the physical characteristics of the context, the quality of infrastructure, etc. These authors later on focused exclusively on the level of spatial variability of climate and simulated the consequences of different allocation schedules.
Consideration of heterogeneity also underpinned the methodology developed for water management on a large scale for the Bhakra system in Haryana, India, by Schakel and Bastiaansen (1997). Irrigation management throughout an area of 1.2 million ha was de-aggregated considering 67 homogeneous geo-hydrological units.

The assumption of heterogeneity in the physical characteristics, the context and therefore of demands for operation is fully recognized here. It is proposed that this assumption is valid not only for large-scale systems but also for smaller ones, of say, one thousand hectares. Therefore the analysis of demand for operational resources should start with a spatial analysis leading to partitioning systems into elementary units with homogeneous characteristics, for convenience’s sake called subsystems.

An important consideration is the link between heterogeneity and equity. It is clear that the justification of the widespread application of the assumption of homogeneity is partly related to the goal of achieving equity within a system. This goal should not be ignored in any new approach to operations. Without care, the introduction of the heterogeneity concept may conflict with equity: for example, considering the value of crop per area could lead to reinforcing existing inequity by providing better service to already well-served users.

**Methodology**

Open-surface canals are subject to modification of flow characteristics (discharge-water depth) resulting from scheduled and unscheduled events. In the usual operational mode the management objective is to maintain steady state conditions when such events occur. The methodology developed here aims to characterize the frequency and magnitude of perturbation events likely to occur in a subsystem. The frequency of change in the distribution pattern defines the perturbation domain. By characterizing the physical properties of the irrigation structures and evaluating the behaviour of canal systems when operated or affected by perturbations, the sensitivity domain is defined. Finally, the analysis of the impact of operation on agricultural yields, on the environment and on the watershed makes it possible to define the vulnerability domain.

Analysis of the vulnerability domain makes the definition of the required water service possible. Considering the required water service performance and combining this with
sensitivity analysis of the infrastructure enables the specification of the precision of water depth control required. The mode of canal operation required is defined by the combination of the vulnerability and perturbation domains. Finally the perturbation domain determines the required minimum frequency of system observation and regulation.

The approach can be viewed as a series of overlays of spatially distributed variables, illustrated in Figure 1 (appended). Although defined by technical considerations, the process must be sociologically acceptable and also fit the defined objectives of the irrigation scheme.

**Opportunities and constraints for water service**

**The vulnerability domain**

Vulnerability is a generic term employed here to describe opportunities and constraints or impact of operation at different scales of space and time. Vulnerability of an irrigated area can be seen as the propensity to be positively or negatively affected by irrigation operations. For instance, a highly vulnerable area would be a unit in which impact and side effects of low-quality operations are high (sensitive crops, areas without drainage facilities). Inversely, low vulnerability areas are those in which impacts and consequences of low-quality operation are either temporally or permanently dampened (paddy fields can stand interruption of water supply for short periods). Vulnerability goes beyond the confines of water for crops and includes consideration of larger-scale water management. Finally vulnerability leads to the estimation of requirements for water service, as both are proportionate.

Some of the wider aspects of water management that define the vulnerability domain are:

- **Water quality.** Modern agricultural methods and scarcity of fresh water result in irrigation having to deal with water loaded with chemicals (pesticides, nutrients) and other pollutants. Acknowledgement of the importance of water quality is one of the main challenges for current irrigated agriculture, with implications for both surface and groundwater. Many shallow aquifers are important for domestic supply. These often receive some recharge from dry season percolation from irrigated areas representing simultaneously a gift – an additional source – and a threat – pollution. In situations of this kind, managers will have to consider both uses and arrive at an effective compromise.

- **Recycling of irrigation water.** Drainage flows from irrigated areas can be important assets in water management. Losses in one place become inputs for other areas. The presence of
such recycling can substantially ease the upstream management problem by allowing less precision in distribution, knowing that any surplus will not be lost. Return-flow systems – drainage and surplus irrigation are channelled back to the irrigation network itself – represent an opportunity for managers to store positive perturbations, for example to harvest rainfall.

- **Water harvesting and conjunctive management.** Water harvesting during rainfall is an important opportunity for water management, and specific operation procedures may be designed to maximize harvesting while preventing overtopping. Conjunctive use of water (surface, groundwater and rainfall) can provide additional flexibility to farmers. Groundwater is frequently used to compensate for rigidity or low performance in the surface water delivery system. Areas lacking access to additional supplies from groundwater deserve greater attention than areas where pumping facilities can compensate for inadequate or unreliable deliveries.

- **Soil and water salinity and water logging.** The rise in soil and water salinity, the increase in waterlogged areas, are environmental hazards of great importance in arid regions. They represent a severe threat to irrigation schemes. It is clear that operation of irrigation systems must take into consideration the spatial distribution of these hazards in order to provide a selective and adapted service of water. In practice, solutions are relatively site-specific and generic guidelines are difficult to derive. But, as a principle, partitioning of the irrigated area should distinguish areas where freshwater has to be provided and areas in which excessive percolation should be avoided to prevent saline groundwater from rising.

- **Multiple uses of water.** In many irrigation schemes, water is used not only for crops but also for many other purposes including domestic water supply, environmental uses, fisheries, perennial vegetation and hydropower. Rules for multipurpose systems operations are complex because of potential conflicts in setting targets for the different uses and also, on occasion, by the lack of suitable accounting procedures. Multiple use of water will be increasingly integrated in management concerns, whether these uses are considered at design time or not. A first step in the management of multiple uses is to define consistent water and productivity accounting procedures, as proposed by Molden (1997).

- **Water rights, equity and priorities in distribution.** Water distribution priorities may be based on rights and established uses. However, in systems experiencing water shortages these priorities should define a policy to share limited water among shareholders. Priorities may be defined on the value of crops (high/low), soil water-holding capacity, etc. As the
mission of irrigated agriculture changes from subsistence to more highly productive agriculture, it may be necessary sometimes to revise previous policies. It may become necessary to avoid penalizing highly sensitive or high-value crops in case of shortage. In many cases, distribution policies should be rethought and, where appropriate, changed to enable new operational strategies.

- **Health impact.** Despite the positive effects of irrigation on the economy and income of farmers, there is no doubt that, in some circumstances, it also has a negative impact on the health of communities through vector-borne diseases. The maintenance of water in canals for long periods can affect the reproductive cycle of disease vectors. The link between system operations and community health can be strong. The recommendations of health experts are converging on a desire for more variability in canal flow regimes to, for example, reduce mosquito breeding (Hunter et al, 1993). However, there is a clear conflict between the requirements of the health sector for fluctuations in water depths, and the irrigation management objective of stable water profiles. New techniques of operation may be required where mosquito breeding is related to irrigation practices.

- **The position within the system.** The impact of operations on the command area is evidently greater for structures located toward the head of the canal system. Therefore location is included in the analysis of vulnerability.

**Water service and irrigation performance indicators**

The spatial characteristics of the vulnerability domain can be converted into specific water service targets and measured with water supply performance indicators (Bos M.G., 1988). Adequacy, efficiency, dependability, timeliness and equity are the common indicators of performance (Molden and Gates, 1990). Flexibility of access to water and reliability of deliveries are important criteria of performance that should be considered.

Performance indicators for operation can be derived from the vulnerability domain considering both water deliveries for irrigated crops and water management in a broad perspective. In the analysis presented here, only the primary indicators are considered, namely adequacy, efficiency and timeliness. Performance targets are expressed as tolerances with respect to the target discharge rate as shown in equation 1.
Equation 1 shows that discharge at a given location should be maintained within the two limits, i.e. target discharge -z % or +y%.

\[
\text{Tol}(Q) = \begin{cases} 
+\text{y}\% \\
-\text{z}\%
\end{cases}
\] (1)

\(z\) is the tolerance factor related to adequacy, reflecting the capacity of the command area to accommodate water shortage and incorporating concern over deliveries. This factor (z) will vary as the period considered changes: a relatively high tolerance may be stipulated for a short period (days, weeks), although the tolerance becomes smaller as the period considered is extended (month, season).

\(y\) is the tolerance factor for efficiency and reflects the capacity of a subsystem to accept surplus water (positive perturbation). As for the (z) factor, the permissible tolerance of (y) is a function of time and of the physical characteristics of the subsystem, such as the opportunities for return-flows, re-use, etc.

A similar relationship can be developed considering the time of delivery, equation 2.

\[
\text{Tol}(\text{Time}) = \begin{cases} 
+\text{u} \\
-\text{v}
\end{cases}
\] (2)

in which

\(u\) reflects the maximum acceptable delay in water delivery and

\(v\) expresses the maximum allowable advance in delivery without water loss.

The perturbation domain

Free surface irrigation systems are hydraulically complex. In general, system operations are reduced to controlling water levels at cross-regulators in an attempt to maintain stable water levels at off-take structures. However, steady water level profiles seldom occur in irrigation systems due to variations at the upstream boundaries of the system (perturbations of intake flow rate) and also the effects of operational interventions themselves. Hence operation is a never-ending challenge as adjustments are made to bring the system to the intended steady conditions in spite of the perturbations.
A perturbation at a given location is defined as a change to the on-going discharge. Such change arises from two sources, first, planned changes in the delivery, and second, unexpected or transient changes. Unexpected or transient perturbations are more difficult to manage precisely because they are unexpected and effective control depends on early detection (degree of information).

**Management of unexpected perturbations**

When a perturbation occurs in a canal, the effects travel both up and downstream from the location at which the perturbation is created. However, the main impact is noticed downstream. For analysis, the perturbation domain is divided into two parts: generation, and propagation, also expressed as the active and reactive processes.

The active process can be analysed in three constituent parts: the causes of perturbations such as return flows, illicit operation of structures, and drift in the setting of regulators; the frequency of occurrence; and the magnitude of the perturbations experienced:

- Causes of perturbations are to a large extent determined by the network properties of the system (source of supply; hydraulic layout; interconnections with other networks such as drainage, unregulated return flows, etc). These properties are described more fully by Renault and Goddyaladda (1999). However, a second source of perturbations is the operation of the irrigation regulation system itself. Off-take and regulator operations generate transient conditions in the network which may translate upstream from the branch channels if the submerged flow occurs at the division from the main. In such cases the sensitivity of off-takes is the major determinant of the propagation of the transient (Renault and Hemakumara, 1997). Perturbations may also be generated at the off-take due to deliberate or accidental modification of the flow section, either because of changes in gate setting or of trapped debris. Perturbations are also generated by unscheduled operation of structures for unauthorized withdrawals, flow rejection or over-tapping. Table 1 (appended) summarizes the major components and properties causing perturbations.

- Position in the network, to some extent, controls the frequency of occurrence of transients and partially explains the well-known head vs. tail issue in irrigation. In this analysis, the occurrence and magnitude of perturbations occurring at any given point depend on the number and behaviour of upstream structures (cross-structures and off-takes). Generally,
the more numerous and the greater the sensitivity of upstream cross-regulators, then the greater the magnitude and frequency of perturbations. Inversely, for systems with sensitive off-take structures, perturbations generated in the head reaches will be attenuated by upstream off-takes and the lower off-takes will see smaller transients.

- Water service considerations: perturbations are expected whenever a change in the distribution takes place. Therefore, the distribution policy (on demand, supply-based, free access) is a key determinant of the frequency of perturbations. The greater the flexibility of the delivery service provided, the higher the frequency of changes in discharges in the canal system. Proper consideration of the impact of service flexibility is essential to identify the specific operation modes and structure characteristics required for acceptable performance.

The sensitivity domain
Sensitivity describes the ratio of output to input of a particular process. In the context of irrigation, sensitivity analysis describes the behaviour of structures during the propagation of transient conditions (the reactive process). The behaviour of delivery structures, such as off-takes and outlets, in response to water level perturbations in the parent channel is the delivery sensitivity, described by the ratio of the relative off-take discharge \( dq/q \) to the change in upstream water level \( \Delta H_{US} \), equation 3.

\[
S = \frac{dq}{\Delta H_{US}} \quad (3)
\]

All irrigation structures (off-takes, regulators, canal reaches) have a distinct sensitivity. A comprehensive analysis of the sensitivity of irrigation off-takes leads to the identification of several indicators defining delivery and conveyance impact, including up and downstream translation of transients, and water level changes due to hydraulic conditions and adjustment of structures (Renault and Hemakumara, 1997). The relative sensitivity of regulator and off-take combinations has been studied in depth (Albinson, 1986). The rationale for sensitivity analysis is that more sensitive structure groups must be monitored and operated with greater care than less sensitive groups.

An important consideration for canal operations is the sensitivity of structures and their impact on the propagation or attenuation of transient flows that enter the canal system. In the absence
of operational interventions the evolution of perturbations through the subsystem defines a
decay curve integrating the conveyance sensitivity of the reaches and associated regulators and
off-takes. Systems with sensitive structures tend to attenuate the transient flows by diverting
surplus through off-takes, less sensitive structures propagate the perturbation downstream
(Renault, 1999a).

Converting water service objectives to operational targets
A study of the domains discussed above enables the specification of requirements for
operational interventions in a specific subsystem. By converting tolerance for discharge
variations to a tolerance on water depth, the frequency and precision of control interventions
can be specified. The link between operation and irrigation performance is established through
generic dependency below:

\[
\text{Vulnerability} \left\{ \begin{array}{l}
\text{Irrigation} \\
\text{Water management}
\end{array} \right\} \Rightarrow \text{Water Service} \Rightarrow \text{WSPI} \Rightarrow \left\{ \begin{array}{l}
\text{Tol(Q)} \\
\text{Tol(T)}
\end{array} \right\} \times \left\{ \begin{array}{l}
\text{Sensitivity}
\end{array} \right\} \Rightarrow \left\{ \begin{array}{l}
\text{Precision(H)} \\
\text{Precision(Setting)}
\end{array} \right\}
\]

\[
\text{Vulnerability} \left\{ \begin{array}{l}
\text{Opportunities for perturbation management}
\end{array} \right\} \times \left\{ \begin{array}{l}
\text{Perturbation Probability} \\
\text{Magnitude}
\end{array} \right\} \Rightarrow \left\{ \begin{array}{l}
\text{Operational modes} \\
\text{Frequency}
\end{array} \right\}
\]

The first relation indicates that the required precision of structure operations is the product of
the tolerance on delivery and the sensitivity of the structure. The second relation defines the
mode and the frequency with which the system should be operated in view of the type,
frequency and magnitude of perturbations the system is subject to.

Control of water levels along the canal is the result of the combined effects of the hydraulic
properties of the canal section, regulator characteristics and periodic operational manipulation
of cross-regulator structures. The precision with which target water levels are controlled at
cross-regulators (ΔH) is an indicator of operational performance directly influenced by
management. Conversely, the extension of influence of cross-regulators, the backwater curve, is
controlled by the physical characteristics of the reach and discharge rate.
In an analysis of the demand for operations, the determination of the precision of control can be assessed quantitatively. Given a target of water service, defined by tolerance factors (equation 1), and considering the delivery sensitivity (equation 3) the required precision of operations can be determined as:

$$\Delta H_{US} = \frac{\alpha}{S}$$

(4)

in which

$\alpha$ or $z$ are substituted for $\alpha$ when considering adequacy or efficiency. In this case, ($y$) and ($z$) are specified as a tolerance in linear dimension rather than a percentage deviation.

$S$ is the sensitivity of the structure

$\Delta H_{US}$ is the required precision of control of water level.

The required operational precision is proportional to the specified tolerance and inversely proportional to the delivery sensitivity. Therefore, an off-take of low sensitivity (0.5 m$^{-1}$) would require a precision equal to twice the tolerance in discharge expressed in relative terms. Thus if the tolerance on adequacy or efficiency is set as $\pm 10\%$, then the subsystem may be operated with a precision of $\pm 20$cm. Equation 4 is valid for a single structure; however, similar relationships can be determined at system level linking system sensitivity indicators, the required precision of control, and operational performance (Renault, 1999b).

In general, evaluation of the requirements for operational inputs requires a qualitative approach with the goal of clearly identifying the significant properties strongly influencing potential operational strategies in each subsystem. These properties may include, for example, opportunities for recycling losses or the vulnerability within the system. Ultimately, these properties can be combined to classify the demand for operation as low, medium or high demand.

**Case study of the Kirindi Oya irrigation settlement project in Sri Lanka**

The proposed methodology is illustrated using the Kirindi Oya Irrigation and Settlement project, one of the largest agricultural development programmes in Sri Lanka. The system was completed in 1987.
Scheme summary

Kirindi Oya has two different command areas, which can be subdivided into four subsystems:

- The Old Ellegala command area that existed prior to the development of the new system. The Ellegala zone is in a flat alluvial area covering about 4 000 ha. Water is delivered to the area from an interconnected system of five old tanks, a diversion structure (anicut) across the Kirindi Oya and also from the new project. The area has priority in water allocations. It can be subdivided into two subsystems, the Left Bank Old, 2 850 ha, and the Right Bank Old, 1 150 ha.

- The new command area was completed in 1987. This command is in slightly undulating topography located upstream and on both sides of the alluvial plain of the Ellegala system. The new command is served by two subsystems:
  - the Right Bank New canal, delivering to five newly developed subcommands (Tracts 1, 2, 5, 6 and 7), totalling 3 300 ha and a reservoir (Bandagiriya) and the associated command area at the tail of the main canal. The Bandagiriya command receives scheduled deliveries from the Kirindi Oya area and surplus flows from the tail of the main canal.
  - the Left Bank New canal, whose command area is fully developed in tracts 1 and 2, and partly developed in tract 3 with a command area totalling 1 835 ha.

- **Climate.** The climate is classified as tropical humid with two seasons: a wet season between October and February-March (*maha*) and a dry season from April to September (*yala*). The average seasonal rainfall is 750 mm in *maha* and 240 mm in *yala*. Annual evapotranspiration is approximately 2000 mm.

- **Water resources and water management.** Water for agriculture is derived from direct rainfall on paddy fields and releases from the system reservoirs. The main reservoir (Lunugamwehera, 200 Mcm) was developed to extend irrigation to the new command areas and to secure irrigation for a double crop in the old Ellagala command. An important characteristic is the cascade of tanks in the system that enables capture of run-off, overflows and drainage from upstream areas. These captured flows are collected and stored in downstream reservoirs and used for irrigation at a later stage of the season. The Kirindi Oya project is the last water user before the river discharges in the ocean and therefore water savings in this scheme are true savings as defined by Seckler (1996).
• **Crops.** High-yielding varieties of rice are grown over the entire project area during the *maha* season. However, during the *yala* season, only the Ellagala area is routinely cultivated for rice; the new command is only cultivated when water availability is high. Some other field crops are grown on uplands in the new area during *yala*.

**Improving system performance**

Due to a perceived mismatch between available resources and potential uses of water, the entire extent of the new command has not been fully developed. Even though development is not complete, cropping intensity in the irrigated areas has not reached the expected levels but has remained at about 178 percent (increased from 140 percent) in the Ellagala area and only 108 percent in the new commands. Current operational strategies are largely based on overflow practices, which result in large water losses from the command areas where recycling is not feasible.

Schemes in coastal areas, such as Kirindi Oya, should seek to maximize effective water use, as water not used is lost to the sea. It can be shown that irrigation intensity at the project can be raised to 200 percent in both new and old areas provided a global efficiency of 43 percent is obtained (Renault, 1997). To achieve this level of efficiency, operational resources must be allocated effectively. Such allocations of resources depend on accurate assessments of the required levels of operational control. The analysis of operational requirements at the project addresses two aspects: the water service required at the command area, and the management of the operation of reservoirs. In addition, specific operational procedures should be evaluated to improve the management of rainfall, aiming to harvest and store as much rainfall in reservoirs and paddy fields as possible.

An analysis of the demand for operation at the Kirindi Oya project is presented here, based on the framework proposed above, examining in turn the vulnerability, perturbation and sensitivity domains of the system.

**Vulnerability domain.** Water is quite abundant and annual average resources (local rainfall plus reservoir inflows) are sufficient to sustain two crops a year provided the system is operated effectively (Renault, 1997). The *maha* rainfall is reasonably dependable, however the *yala* rainfall is less so. There are no major salinity or waterlogging problems in the area.
The existence of the cascade system with several tanks makes it possible for the scheme to be very efficient in harvesting rainfall. During the *maha* season, the cascade tanks should be operated at the lowest level possible to maximize storage capacity. This requires the direct supply from the main reservoir, and drainage return flows from new command areas should be restricted.

Single bank or contour canals are common in Sri Lanka. One characteristic is the potential to capture run-off from lateral watersheds. The Right Bank Old canal is a contour canal and this opportunity could be combined with the storage capacity of three intermediate reservoirs during rainy periods. Some parts of the Left Bank New canal are also of the single-bank type.

**Water management.** The potential to recycle drainage or spilled water from command areas is one criterion that divides the entire scheme into two categories. All tracts on the Left Bank New canal and tracts 1 and 2 of the Right Bank New canal drain to tanks supplying the old area. Conversely tracts 5, 6 and 7 of the Right Bank New canal drain to a lagoon and ultimately to the sea, resulting in large water losses. Drainage flows from that canal subsystem largely return straight to the main river channel and on to the ocean, with little opportunity to recycle the losses.

The Left Bank Old command area is characterized by a widespread interconnection between drainage and irrigation networks due to the flat topography. It is almost impossible to define precise command areas for small outlets (Mallet, 1996) or to specify the hydraulic characteristics of channels or structures. Surplus flows at one point become inputs elsewhere and therefore, in the terminology developed by Renault and Godaliyadda (1999), this unit is classified as a return-flow system. The Left Bank Old subsystem must therefore be managed as a single unit, considering several entry points to the network such as tank outlets and canal inlets, a number of drainage outlets to the river and the ocean. To increase the efficiency of water use, all drainage outlets should be monitored to avoid excessive losses. An effective feedback control system is essential to enable proper control of the inlets of the subsystem.

There is no conjunctive use in the area, pumping from the river, drainage and irrigation canals are restricted to small-scale gardening enterprises.
Multiple use of water is important in the project area. However, there are no major conflicts between irrigation and the other uses of water, such as domestic supply, bathing, homesteads, gardens and perennial vegetation, environmental uses (wetlands, wildlife habitat), tourism (lagoons and national parks) and fisheries. Irrigation is the major user of water, representing more than 90 percent of water use in the basin. Availability of water for irrigation ensures availability for other uses. There are no specific health-related issues.

**Agriculture.** Paddy cultivation is relatively less vulnerable to variations in water supply than other field crops, due to the buffer effect of the flooded paddy field. As the area is mainly cultivated for paddy rice in both seasons, the area can be considered as homogeneous and of low vulnerability. This is an important characteristic for tracts where recycling is not feasible, as it may allow implementation of strategies to reduce overflows. Special consideration may be required for the new areas where some farmers are cultivating other field crops that will be more vulnerable to water shortages. Soils in the Ellagala area are heavier than in the new command areas. Although this has some implications for water allocation and drainage flows (percolation rates are estimated at 3mm/d and 6mm/d respectively, IIMI, 1994), it has little impact on operational strategy, or on system efficiency, as the dominant criterion is the ability to recycle water.

**Water rights and equity.** In theory, all farmers at the project have equal water rights. In practice, farmers of the old areas have established a powerful position and are able to impose allocations of water in their favour. Records of cropping intensity show that the Ellagala area has averaged 178 percent whilst the new areas have achieved an average of only 108 percent (Renault, 1997). The Ellagala area also obtains irrigation supplies in advance of the new areas, contrary to an effective water savings policy. Under these conditions, any attempt to improve water management must secure 200 percent irrigation intensity to farmers in the Ellagala subsystem before attempting to implement any changes of supply to the new area.

**Environment.** The area surrounding the project has several facets of environmental and wildlife importance: the entire area is a recognized wetland sanctuary of importance to migrating birds; the Bundala National Park is to the south-west of the scheme. The lagoons in the park are partly supplied by water draining from the right bank new canal area. Fortunately there are no conflicts between improved irrigation management and existing environmental concerns:
improved water management in irrigated areas will extend the period of water in tanks and will reduce fresh water inflows to the lagoons, which are felt as a hazard at present.

**Water service and performance indicators.** In subsystems with no opportunities for the recycling of excess flows, the tolerance on deliveries (equation 1) must be minimized and a feedback link between drainage flows and inlet settings should be established. In areas where recycling is possible, the delivery tolerance can be less strict. However, a feedback loop control is required to maximize potential storage in downstream tanks.

**Perturbation domain.** Analysis of the perturbation domain focused on the occurrence and magnitude of external and internally generated perturbations. The upstream boundary conditions of each subsystem are homogeneous; all systems are supplied from the main reservoir or tanks and are regulated by manually operated gates. The anicut supplying the Ellagala area is now supplied, indirectly, from the main reservoir.

**Lateral flows.** The Right Bank New canal is a double-bank canal and therefore not greatly influenced by rainfall. The Left Bank Old canal is also a double-bank channel. Parts of the Left Bank New and the entire Right Bank Old canals are single-bank and therefore susceptible to be affected by large perturbations during periods of rainfall.

**Position in the system.** Field observations have confirmed that the Left Bank New and Right Bank New canals are subject to an increasing range of water level fluctuations between head and tail locations. The range variation of water level at selected off-takes during maha 1993 in the Left Bank New canal increased from 65 mm at head to 90 mm in the middle reaches to 110 mm at the tail. Observations on the Right Bank New canal show a similar trend; records for six seasons indicate average increases from 75 mm at head to 120 mm at the tail.

**Users.** Discipline varies between the systems. In the old system, there are few problems of discipline, probably as a result of the relatively reliable water supply. In the new system, farmers must contend with shortages of water to the extent that some local people have not been able to establish themselves as farmers and have had to seek other employment. Even those who have been able to establish themselves as farmers have less influence in decision-making regarding allocations of water. As a result, unauthorized operations of gates and
harmful interventions at cross-structures do occur. System managers have coped with these problems by issuing more water than theoretically required to the main canal. The lack of discipline may be a serious constraint to increased precision in operations aimed at improved efficiency. The strategy should be to achieve highly reliable supplies in all areas.

The Left Bank New canal illustrates the impact of unreliability of supplies. Although built to the same design and at the same time as the Right Bank New canal, its structures are in poor condition compared to the latter’s. Many gates are broken or missing at cross-regulators after only twelve years of operation. One cause may be the relatively high delivery sensitivity along this canal, causing farmers to make unilateral interventions when supplies are inadequate.

**Operational procedures.** To improve economy of water use in command areas with no opportunity to recycle drainage flows, managers will have to adopt more effective procedures than the existing overflow method of management. Two alternative procedures might be considered, first a strategy of progressive reduction of deliveries, second, the introduction of rotational delivery. Progressive adjustment to reduce downstream drainage discharges would impose permanent and progressive modifications of inflows (deliveries). This option would require precise operation and methods to fine-tune deliveries so as to minimize inflows while avoiding the drying-up of downstream field units. Ultimately this method would result in a minimum steady state discharge. Rotational operations, either an on/off schedule or with alternating high and low discharges, will result in frequent fluctuations in canal discharges, requiring greater supervision of the whole system.

**The sensitivity domain**

- **Offtake sensitivity.** The sensitivity of off-takes clearly distinguishes different subsystems at the Kirindi Oya project. Along the Right Bank New canal, the off-takes are relatively insensitive (average $S = 0.46$) and homogeneous ($CV = 0.1$). However, along the Left Bank New and Right Bank Old canals, the off-takes are sensitive (average = 2 and 2.2 respectively) and fairly inhomogeneous ($CV = 0.4$ and 0.96 respectively). This means that the same level of precision in water depth will generate discharge deviations four times greater in the latter two canals than in the Right Bank New canal.

- **Regulators and reaches.** Three situations can be distinguished with regard to the regulation of water levels in the main channels:
• **not regulated**: for example, the Right Bank Old canal is effectively not regulated, as the density of regulators is very low and most existing structures are no longer functional;

• **poorly regulated**: the Left Bank New canal has adequate provision of regulators but the existing condition is poor, with gates missing or inoperable; and

• **well regulated**: the Right Bank New canal is well equipped for regulation and regulators are in good shape.

**Spatial variation of operational demands.** The operational requirements to achieve specified levels of water delivery service and acceptable levels of water use economy at the project are analysed for daily operation of water releases and regulation of the canal systems. Requirements for improved scheme operations related to the scheduling and tank management-rainfall harvesting tasks are not addressed here.

Considering four classes of operational requirements, varying from low demand to very high demand (D1, D2, D3 and D4), five subsystems were identified. An evaluation of the characteristics of the demand for operations in each is summarized in Table 2. Although the ranking used here may be subject to discussion, the identification of significant operational features of each subsystem allows for a spatially differentiated allocation of management resources, Figure 2.

The next step would be to determine what allocation of resources would be required to match the demand. It seems clear that the number of operators required will vary from area to area to match the operational demand in order to improve the overall efficiency of the system.

**Conclusions**

The case study of Kirindi Oya illustrates the existence of heterogeneity of requirements for operational resources, even within a medium-sized, mono-cropped irrigation system. The analysis is based on an overlay process considering three operational domains: vulnerability, sensitivity and perturbation.

System managers can address heterogeneity of operational demands through two different strategies. They may accept the reality of spatially variable operational requirements and allocate resources accordingly. Alternatively, the effects of spatial variability can be minimized
by interventions in the physical system. In either case it is expected that the improved
evaluation of the spatial variability of demands for operation will be useful in the design of:

- more cost-effective strategies and procedures for operation, leading to a better use of
  available means; and
- priorities for the rehabilitation or modernization of physical infrastructure.

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<table>
<thead>
<tr>
<th>Component</th>
<th>Related properties for operation</th>
<th>Partition of criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source supply</td>
<td>• Fluctuations of source</td>
<td>Reservoir</td>
</tr>
<tr>
<td></td>
<td>• Degree of control</td>
<td>River diversion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Canal branch diversion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Canal series diversion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Return flow</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non return flow</td>
</tr>
<tr>
<td>Layout</td>
<td>• Variability of on-line discharge</td>
<td>Single bank canal</td>
</tr>
<tr>
<td>Lateral flows</td>
<td></td>
<td>with runoff</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Double bank canal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Without runoff</td>
</tr>
<tr>
<td></td>
<td>Runoff ditches</td>
<td>No ditches</td>
</tr>
<tr>
<td>Off-takes</td>
<td>• Upward sensitivity for conveyance</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>• Sensitivity to setting</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Regulators</td>
<td>• Sensitivity to setting</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>User</td>
<td>• Illicit operation</td>
<td>Discipline</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No discipline</td>
</tr>
</tbody>
</table>
Figure 1. Overlay process for mapping distribution of efforts for canal operation
Figure 2. Spatial evaluation of the demand for operation at the Kirindi Oya Irrigation and Settlement project.
### Table 2. Evaluation of the demand for operation per subsystem in KOISP

<table>
<thead>
<tr>
<th>SUBSYSTEM</th>
<th>Tracts 1 &amp; 2 of Right Bank New</th>
<th>Left Bank Old</th>
<th>Left Bank New</th>
<th>Right Bank Old</th>
<th>Tracts 5 &amp; 6/7 of right bank new canal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class of demand D1</td>
<td>LOW</td>
<td>D2 MEDIUM</td>
<td>D3 HIGH</td>
<td>D4 VERY HIGH</td>
<td>D4 VERY HIGH</td>
</tr>
<tr>
<td>VULNERABILITY (1) Water management</td>
<td>Recycled, lumped &amp; de-aggregated system</td>
<td>Return-flow RF lumped system</td>
<td>Recycled, lumped &amp; de-aggregated system</td>
<td>Non recycled, de-aggregated system, improved operational procedure</td>
<td>Non recycled, de-aggregated system, improved operational procedure</td>
</tr>
<tr>
<td>WATER SERVICE Water supply performance (2)</td>
<td>Adequacy allowed to fluctuate TOL Q = ± 20 %</td>
<td>Adequacy allowed to fluctuate TOL Q = Δ20 %</td>
<td>Option 1 precise adequacy TOL Q = Δ5 %</td>
<td>Option 1 precise adequacy TOL Q = Δ5 %</td>
<td>Option 2 TOL Q = Δ10 %</td>
</tr>
<tr>
<td>SENSITIVITY of STRUCTURES LOW Sensitivity for delivery = 0.46 propagates perturbations</td>
<td>HIGH but compensate by RF</td>
<td>VERY HIGH 2</td>
<td>VERY HIGH 2.2</td>
<td>LOW 0.46</td>
<td></td>
</tr>
<tr>
<td>PRECISION of water depth control (estimated)</td>
<td>&lt; 40 cm TOO LARGE</td>
<td>10 cm as an indication</td>
<td>Δ10 cm</td>
<td>Δ2.2 cm</td>
<td>IRREALISTIC</td>
</tr>
<tr>
<td>PERTURBATIONS LOW probability &amp; magnitude</td>
<td>LOW probability &amp; magnitude</td>
<td></td>
<td>MEDIUM probability linked to • the high sensitivity of the off-takes • some single bank canal sections</td>
<td>HIGH probability &amp; magnitude • because of absence of water depth control • during rainfall episodes • because of improved operational procedures</td>
<td>HIGH probability &amp; magnitude • because of improved operational procedures</td>
</tr>
<tr>
<td>Indications for operational modes, procedures and frequency</td>
<td>• Allow fluctuations • Periodic adjustment of inflow from tank balance</td>
<td>• Lumped approach • feedback control from drainage</td>
<td>• Frequent checking to minimize impact of sensitivity • Periodic adjustment from tank balance</td>
<td>Note: A specific control project will have to be designed for Right Bank Old canal including some rehabilitation or modernization works</td>
<td>• Precise control of level • high frequent adjustments • loop control from downstream drainages • Rainfall harvesting whenever STO exits</td>
</tr>
<tr>
<td>Type of control suggested</td>
<td>Lumped low-frequency FBC from tank balance</td>
<td>De-aggregated FBC from drainage outlets</td>
<td>Lumped low frequency FBC from tank balance</td>
<td>De-aggregated high-frequency FBC from drainage outlets</td>
<td>De-aggregated high frequency FBC from drainage outlets</td>
</tr>
</tbody>
</table>

1. The agricultural and environmental aspects do not partition the scheme (mono crop minor concerns)
2. The tolerance for time is irrelevant here as deliveries are continuous

FBC: feedback control –
Abstract
The Teesta Barrage project is a large multipurpose water resources project in the state of West Bengal, India. The project covers aspects of irrigation, flood control and power generation. Currently an improved management system is being developed for efficient operation of the scheme. The information technology-based improved management system covers the aspects of annual and seasonal planning, integrated operation of the barrages, scheduling of the operation of one of the main canals and the corresponding distribution network and improved manual control of the barrage and canal operation. The IT-based system will use the real-time data of inflow into the barrages, canal flow and rainfall from selected remote locations. The management system, which includes both a radio-based and an electronic data communication network covering the office of the controlling authority, the field office, barrage locations and identified field locations, is scheduled to be commissioned before the monsoon of 1999.

Introduction
The Teesta Barrage project comprises multiple interconnected barrages and corresponding main canals branching off them and covering a very large area. The target area on completion of all the stages of the planned development will be of a little more than 0.9 million ha, covering the entire northern part of the state of West Bengal. A main conveyance system of about 200 km in length with a distribution network of a few thousand kilometres is planned to cover the entire command area.

Characteristics and representation of the system
The barrages
The Teesta barrage across the river of the same name is one of the many barrages of the interconnected barrage system of the Teesta Multipurpose scheme.

The Mahananda barrage across the Mahananda river receives diverted flow from the river through the Teesta-Mahananda Link canal. The Mahananda Main canal branching off the right bank of the barrage conveys the flow diverted through the link canal to irrigate a limited command area (of about 50 000 ha) and generate hydroelectric power through an in-line power
plant. The Mahananda Main canal in turn links the barrage with the Dauk barrage. Construction of the main canal system to cover areas beyond the Tangon river is in progress.

**The conveyance system and distribution network**

The conveyance system comprises the following main canals:

1. the Teesta-Jaldhaka Main canal off-taking from the left bank of the Teesta barrage;
2. the Teesta-Mahananda Link canal off-taking from the right bank of the Teesta barrage;
3. the Mahananda Main canal off-taking from the right bank of the Mahananda barrage;
4. the Dauk Nagar Main canal; and
5. the Nagar Tangon Main canal.

A diagram of the main canals is presented on the next page. The distribution network planned for each of the main canals comprises distributary, minor, sub-minor, outlets and other watercourses in the outlet commands.

**The Teesta-Mahananda Link canal**

The Teesta-Mahananda link canal is meant to divert the flow from the Teesta river to the Mahananda. This flow is further conveyed through the Mahananda Main canal on the right bank of the Mahananda barrage. The link canal also irrigates an area of about 40 000 ha through ten distributaries and augments supplies to an established run-of-the-river irrigation scheme. The length of the Teesta Mahananda Main canal is about 25 km.

**Characteristics of the general command area**

The annual rainfall in the Teesta command varies from about 3 000 mm in the head reach to 700 mm in the tail end of the southern part of the command, with an average of 1 650 mm. The general slope of the command area is gradual and oriented south. The soil throughout the command area is predominantly either sandy or clayey loam. The effective depth of soil varies from 0.6 m to 2.4 m. The predominant crop during kharif (monsoon) is paddy, and wheat is the major crop grown in the rabi (winter) season.
Figure 1. Diagram of the main canals in the Teesta Barrage project

Operation of the present system
The scheme has been operated in the last few years to provide irrigation to the developed portion of the Teesta-Mahananda Link Canal command area. The diversion of flow to the
Mahananda barrage for further conveyance through the Mahananda Main canal for hydropower generation started at the end of the 1998 monsoon.

The scheme was designed to use the available flow at the Teesta barrage for catering to the requirements of irrigation in the project command and for hydropower generation. The use of the Mahananda river flow is limited to fulfilling the agreed share of the state of Bihar. The barrages are also used to regulate flood flows in a limited manner. The conveyance and distribution systems were designed on the basis of peak irrigation requirements in the immediate post-monsoon period and rotational canal operation was envisaged. The state policy assigns first priority to irrigation supplies, and fulfilment of the requirements of hydropower generation is limited to the adequacy of inflow at the Teesta barrage (only during the monsoon season).

Flow availability at the Teesta barrage site
Teesta is a perennial river. The catchment area up to the barrage site across the Teesta is of about 8,500 km². Preliminary estimates of the availability of flow indicate a lean season of six months duration (November to April). The variation of flow availability at the Teesta barrage site between the lean season and the monsoon months is significant. However, there is not much variation in flow from December to March.

Barrage operation
At present, the barrages are operated according to the method formulated by the Irrigation & Waterways Directorate of the government of West Bengal. The method focuses on the ability to divert maximum flows through the main canals for fulfilling irrigation and hydropower requirements, keeping in view the structural safety of the barrage and feasible flood regulation, based on data, information or warnings received from the upstream gauging station at short notice (about one hour).

Irrigation requirements
About 150-percent cropping intensity has been considered throughout the entire command area in the design of the scheme. Traditionally farmers grow paddy in the vast tract of land covered by the scheme command area. Indicative figures suggest that paddy is cultivated in about two thirds of the command area during the kharif season and pulses are cultivated in about 10
percent of the command area during the *rabi* season. The present cropping intensity in the *rabi* season is much lower than that in the *kharif* season. Perennial and hot-weather crops have an insignificant coverage. The estimation of demand for irrigation is made on the basis of duty prescribed according to accepted departmental norms.

**Hydropower generation**

Three in-line hydropower generation stations, in series, have been planned on the Mahananda Main canal. One hydropower station has so far been commissioned. The remaining two power stations are at different stages of construction. Each station has three turbines with a capacity to generate 22.5 MW and a corresponding flow requirement of 330 cumecs (three turbines with a discharge capacity of 110 cumecs each). Initial analysis indicates that the flow requirement for hydropower generation can be fulfilled only during the monsoon months, i.e. June to September, and that there is a reasonable probability of meeting the requirement in October.

**Variation of demand, spatial and temporal**

The large command area implies spatial variation in soil characteristics, topography and rainfall pattern. It is likely that there would be variation in soil characteristics both at local level (outlet level) and at the subcommand level (individual main canal commands) contributing to spatial variation in demand. The variation of demand during the monsoon can be significant, owing to varying rainfall across the command, especially as the tail end of the command receives significantly less rain than the head reach.

In the case of the *rabi* season, demand is unlikely to fluctuate because of the rainfall situation in the command area. Most of the rainfall in this region occurs during the monsoon months. The demand variation in *rabi* would be attributable to actual cropping patterns and the period of sowing.

The demand of water for hydropower generation would be a constant component of the total demand for water. The state policy assigns first priority to the fulfilment of irrigation requirements. Supplies for hydropower generation are made on the basis of the actual availability of flow and demand for hydropower generation is most likely to be fulfilled during the period of high availability, i.e. the monsoon months of June to September.
Allocation and distribution of flow
With the focus on construction of the main canals and the distribution network, the operation is limited to feasible flood regulation at the Teesta and Mahananda barrages and operation of the Teesta-Mahananda Link canal to provide irrigation supplies to the area commanded by the link canal and to the diversion of the flow to the Mahananda for further conveyance through the Mahananda Main canal for hydropower generation.

As part of the ongoing efforts to develop an information technology-based system, a decision framework is being evolved to effectively operate the scheme to cater to likely situations, especially that of low availability at the Teesta barrage, keeping in mind the aspects of equity and sustainability. The decision framework would also help devise suitable ways for responding to changes in the climatic conditions, depending on whether or not rain falls in certain parts of the command.

The communication system
The present communication facilities available are limited to Department of Telecommunications telephones at the field offices and in the offices of the project and subproject administrators. The communication facilities available at the barrage sites are inadequate for continuous monitoring and control of operation by the project authority. Feedback about operation problems, emergency maintenance or repair needs, or required changes in canal operation because of rainfall in a particular subcommand, cannot be received in time from the field, making it impossible to intervene or guide the field operators in further action.

System operation: improvements proposed
System-wide planning, long term and short term
For the main canals, it is possible to plan specific allocations for individual seasons on the basis of expected availability and most effective deliveries for irrigation. Two distinctly different approaches are being worked on for the winter and monsoon seasons. Planning of operation of the scheme in the *kharif* season would be based on the requirement of meeting varying irrigation demand for paddy, the dominant *kharif* crop, and fulfilment of hydropower generation requirements and other statutory obligations and commitments. Short-term
adjustments would be possible by taking into account the occurrence of rainfall in the command area. *Rabi* or hot weather season planning would take into account the limited availability of the Teesta river throughout the season and would help decide on the number of turns and the suitable dates for starting the individual turns of canal operation and their duration. Planning for both the *rabi* and the *kharif* seasons would be the most effective use of available river flows, keeping in mind equity and other system-specific constraints.

**Integrated operation of barrages**

The operation of the barrages in the *kharif* season would focus on feasible flood regulation, keeping in mind structural safety and the diversion of the required flow through the main canals. A system of integrated operation of the Teesta and Mahananda barrages during the lean season is being designed with the objective of managing the available flows to maximize power generation with a high degree of assurance after assigning first priority to the fulfilment of irrigation requirements.

**Scheduling of canal operations**

The approach toward improved scheduling of canal operations focuses on their effectiveness in fulfilling the irrigation requirements across the command area and supplies for hydropower generation. The proposed system will also ensure operation rescheduling in the shortest possible time to respond to climatic changes in the command area or to variations of inflow at the barrages. A decision framework for the allocation and distribution of flow in case of deficit availability will be evolved. This will be used to manage flows effectively.

**Monitoring and control operation – barrages and canal system**

The improved system used for monitoring the operation of the scheme would rely on the radio-based voice and data communication networks. The voice communication network would cover the barrage locations, remote sites along the Teesta-Mahananda Link canal, field offices and the central control station located in the administrative office of the project. The data communication network would cover the barrage locations, identified sites along the Teesta-Mahananda Link canal and a few rain-gauge stations in that canal command. While the telemetry system would provide barrage pond level, canal flow level and rainfall data, the voice communication network would be used to obtain information on gate positions and other queries.
The barrages will continue to be operated by manual control on the basis of details worked out by the Directorate of Irrigation and Waterways. The control strategy for the operation of the Teesta-Mahananda Link canal is being worked out. All necessary instructions for the control of canal and barrage operations and changes required from time to time will be communicated over the voice communication network as required.

**Summary and conclusion**

The information technology-based improved management system for the Teesta-Mahananda link canal being developed for the Teesta Multipurpose Water Resources project in West Bengal by CMC Ltd is a comprehensive management system. The IT-based system covers integrated operation of the barrages, long-term and short-term plans of operation, scheduling of the operation of the main system and of the distribution network, and improved monitoring and control for proper implementation of planned operations. The improved monitoring and control system will also help in effecting required changes in response to changes in river flow availability or the rainfall situation in the command area. The IT-based system under development will rely on state-of-the-art technology. It would be easy to customize for implementation in any other project with similar components, and could be integrated in regional or river basin-level management systems. The present project includes components of user training and limited implementation support.
Modernization of irrigation system operations: institutional development and physical improvement

Indra Lal Kalu
Team Leader, TA Team (CADI/APTEC), IMT Project

Introduction
Improving irrigation system performance is now perceived as a more pressing need than developing new irrigated areas, after large budgetary allocations have gone for decades into expanding irrigated acreage. In most developing countries, investment in irrigation has not produced the expected results. The actual irrigated area turns out to be much smaller and crop yield and cropping intensity fails to increase appreciably. Whether to further invest while hoping for the best has become questioned. Instead, planners have started to give priority to the improvement of existing irrigation systems. In Nepal, several irrigation systems managed by farmers for centuries perform better in terms of crop yield, equity and farmers’ satisfaction than most agency-managed systems. Also, the irrigation service fee (water tax) collected by the latter is very low, resulting in reduced budgetary allocations for operation and maintenance. This, in turn, has caused deferred maintenance and reduced irrigated areas.

How to break out of this vicious circle is a common concern for both planners and concerned officials. Some advocate improving management; others emphasize physical improvement. Various approaches have been implemented in Nepal. Some experiences on the modernization of irrigation system operation are presented in this paper.

The modernization approach
Modernization has been felt as a need at all times. Yet, modernization is different things to different people. An FAO conference defined it thus:

“Irrigation modernization is a process of technical and managerial upgrading (as opposed to mere rehabilitation) of irrigation schemes combined with institutional reforms, if required, with the objective to improve resource utilization (labour, water, economic, environment) and water delivery service to farms.”
In the same line, Perry (1995) grouped three basic elements for successful irrigation performance: defined water rights; an infrastructure capable of providing service as embodied in the water rights; and assigned responsibilities for all aspects of system operation.

But in the early 1970s and 1980s, these concepts were not acted upon and several irrigation development projects were implemented, including command area development, with the belief that physical improvements would automatically lead to better performance. Various improvement works like rehabilitation and development of the physical system, construction of tertiary or field channels, drains, service canals and link roads to markets were undertaken. But as soon as the projects were completed, operation and maintenance were neglected and the system soon reverted to the conditions prevailing before the projects were started. In some projects, field channels were demolished, gates were stolen or broken, drainage ditches were again converted to fields, the systems were ruined and became dysfunctional. For instance, in the first stage of the Sunsari-Morang project, in all outlets gates were fixed and a complex five-day rotational water distribution policy was recommended, but the farmers used to the free use of water did not co-operate and broke or damaged the gates (Singh).

Similarly, in the Marchwar lift irrigation project, proportional distributors were introduced to comply with the farmers’ practice in adjacent chatis mauja, the old acclaimed farmer-run irrigation system in Nepal. At some outlets, capacity was less than 5 l/s, which farmers did not find useful to soak their paddy fields for land preparation, so they started to breach the canal (Euro Consult/East Consult). In the design of the structure, beneficiary farmers were hardly consulted, and the design reflected the engineers’ wishful thinking rather than the farmers’ needs; besides, operation rules were not properly taught to the farmers or even to the staff. Although most of the physical improvements did improve performance, few were accepted and the others were demolished or broken.

To improve irrigation management, the Department of Irrigation has implemented irrigation management transfer projects with financial support from the Asian Development Bank and USAID and under cost-sharing arrangements with the water user associations. Molden and Makin (1997) consider management transfer in itself as modernization in that it is a means to attain enhanced system objectives.
The project seeks to establish sustainable and effective rehabilitation and improvement of the physical system. Once a branch or main canal is rehabilitated, it is turned over to the local water user association. The detailed implementation procedure in Phase I is presented in Figure 1 (appended).

In the second and third phases, rehabilitation activities play a major role and involve significant costs. The rehabilitation is provided as an incentive for water user groups to undertake management responsibilities. The basic purpose of rehabilitation is to bring the system back to functional status so that the farmers can operate, maintain and manage it themselves. In order to be demand-driven and cost-effective, the water user association has to bear 26 percent of the total rehabilitation cost. A subproject management committee is formed, with some six water user association representatives under the chairmanship of the project manager, to partake in planning, design, tender, construction supervision and the water user association’s contribution mobilization activities. The subproject management committee members assist the project staff in the march toward physical improvement. The project office prepares a detailed design and estimate of the proposed work, the committee members and the staff prioritize the works and classify them under the following subcategories:
1. Emergency and flood damage repair
2. Essential structure maintenance
3. Catch-up maintenance
4. System improvement
5. System (hydraulic) calibration
6. Service roads and field-to-market roads.

The estimated cost is fixed within the budget and then the members of the subproject management committee are given the choice to choose works for water user association contributions. In principle, contributions proportionate to irrigated landholdings are recommended. Then a memorandum of agreement and action plan are signed by the project manager and the water user association, based on which the activities are carried out. The action plan covers institutional development activities such as the various training programmes related to capability-building, e.g. water management, resource generation and record-keeping.
During the construction, the subproject management committee members are authorized to supervise the work, control quality and make recommendations in committee meetings. The impact of management transfer in one system is presented below.

**Management transfer at the Panchakanya Irrigation System**

The Panchakanya Irrigation System is a small (600 ha) gravity irrigation system fed by a spring. Due to deferred maintenance, the canal lining had broken at many places and heavy seepage used to occur and, because of dysfunctional gates, water control was not effective. The silting of the spring reduced the discharge in the source. Although the system was designed to irrigate 600 ha, it irrigated 267 ha only.

After the implementation of the irrigation management transfer policy in 1995, a water user association was democratically formed in two tiers, as shown in Table 1. A subproject management committee was also formed to represent the association for project implementation works such as signing the memorandum of agreement and the action plan, and decision-making on rehabilitation works.

<table>
<thead>
<tr>
<th>Level</th>
<th>No</th>
<th>Members at each level</th>
<th>Total members</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main committee</td>
<td>1</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Branch committee</td>
<td>9</td>
<td>5</td>
<td>45</td>
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</tbody>
</table>

To remedy the above-mentioned problems, clear the silt at the spring and improve the lining in the main canal, gates to control water delivery were installed by the office and earthwork was carried out by the water user association. Likewise, gauge plates were fixed upstream and downstream of cross regulators to monitor the flow in the canal. These gauges were calibrated and water measurement tables were prepared. The association nominated two of its members for water delivery, other representatives were trained to measure water by observing water depth in the gauges, and a manual describing canal operation plans was provided for the distribution of water under three water availability scenarios. A manual on canal maintenance was also provided and guidance on operation and management expenditure at Panchakanya was prepared and given to the water use association for the collection of an irrigation service fee. Various members of the association were trained on share system administration, canal operation and management, quality control and construction supervision, water measurement,
record keeping and gender awareness. After the completion of rehabilitation works, the
Panchakanya irrigation project was formally handed over to the water user association on 28
Nov 1998. Since then, the association has amended its constitution to increase resources,
increased the irrigation service fee from NRs75/ha for paddy to NRs150/ha, and started to
collect a Rs50/ha labour fee for maintenance instead of calling for labour contributions.

The general assembly also approved the request of the previously excluded tail-end farmers to
become share members by contributing Rs500/ha as an appreciation fee to irrigate the area in
lieu of the association’s contribution done in the main canal improvement. These farmers then
renovated almost two kilometres of canal by themselves. Now the association collects a general
membership fee, a share membership fee and fees from official visitors. The present resource
collection status of the water user association is given in Table 2.

<table>
<thead>
<tr>
<th>S. No</th>
<th>Item</th>
<th>Amount (NRs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>General membership fee @ NRs10/head</td>
<td>6 280</td>
</tr>
<tr>
<td>2</td>
<td>Share membership fee @ NRs30/ha</td>
<td>3 830</td>
</tr>
<tr>
<td>3</td>
<td>Labour fee @ NRs150/ha</td>
<td>61 075</td>
</tr>
<tr>
<td>4</td>
<td>Irrigation source fee</td>
<td></td>
</tr>
<tr>
<td></td>
<td>a) NRs150/ha for paddy</td>
<td>39 543</td>
</tr>
<tr>
<td></td>
<td>b) NRs75/ha for other crops</td>
<td>2 504</td>
</tr>
<tr>
<td>5</td>
<td>Income from sale of junk</td>
<td>22 680</td>
</tr>
<tr>
<td>6</td>
<td>Balance carried over</td>
<td>46 280</td>
</tr>
<tr>
<td>7</td>
<td>Visitor fee</td>
<td>4 055</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>186 248</td>
</tr>
</tbody>
</table>

Since the transfer of management, the water user association has been operating the system. By
May 1998, its members had cleared the source and cleaned the main canal at the cost of NRs12
655. Improvement after implementation (Neupane and Uprety, 1997) is as follows:

<table>
<thead>
<tr>
<th>Item</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water availability</td>
<td>750 lps</td>
<td>1200 lps</td>
</tr>
<tr>
<td>Irrigation cycle</td>
<td>12 days</td>
<td>3 days</td>
</tr>
<tr>
<td>Water duty</td>
<td>5 - 30 lps/ha</td>
<td>3.16 lps/ha</td>
</tr>
<tr>
<td>Project convenience efficiency</td>
<td>26%</td>
<td>51%</td>
</tr>
<tr>
<td>Actual irrigated area</td>
<td>267 ha</td>
<td>442 ha</td>
</tr>
</tbody>
</table>

(planned to extend to 600 ha)

After learning water measurement techniques, the association started to distribute water in
proportion to the purchased share, thereby compelling farmers to report their actual irrigated
area to report actual irrigated area. It also started keeping records of actual irrigated crop areas for each branch or outlet to allocate water. As the water supply is reduced in March-April for early rice, the association issues permits to grow early rice in limited areas.

The association seems to have accepted the improvement. It is now requesting the project office to demarcate the water source in order to fix water rights and do additional canal lining in the remaining portion of the tail. It has also requested to be provided with a detailed map showing branch canals to facilitate fee collection.

Looking at the progress made by the water user association in Panchakanya, it can be said that farmers readily accept simple rehabilitation works which they feel are needed. The association’s involvement and commitment from the beginning compel them to undertake management transfer and better manage the system. Adequate capability build-up training should be provided, particularly on water measurement, to let farmers realize the importance of water for the control of canal operation. And an adequate time period should be provided for project implementation.

**Summary and conclusion**

The modernization of irrigation systems is essential to improve system performance. Before introducing new technology, its adequacy and practicality should be tested and users’ preferences known. Institutional development (e.g. knowledge and skill) of the users should be advanced along with physical improvement to make the improvement sustainable and lasting.

**References**

Singh A.M. Water management at the Manichauri Secondary Canal Command, Sunsari Morang Irrigation Project, Biratnagar

Euro Consult/East Consult. 1996. A review on functionality of outlets, Marchwar Lift Irrigation Project


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Figure 1. Irrigation management transfer implementation procedures for Nepal’s Irrigation Management Transfer project

1. Initial Organization Phase

   - WUA
     - Introductory Workshop
     - Baseline Study
     - WUA Establishment
     - WUA Registration
     - SMC Formation

   - DOI
     - Selection of Management Transfer Subproject
     - Deputation of DOI Staff
     - Introductory Workshop
     - Inventory of Subproject Features

2. Preparation Phase

   - Rehabilitation
     - Joint System Walk-Through
     - DOI/WUA Discussion on Rehabilitation Priorities and Cost-Sharing
     - Prepare Draft AP/MOA
     - Finalize AP/MOA

   - Institutional Development
     - Establishment of WUA Office, Committees, Rules and Regulations
     - Share system Development & Certificate/Membership Distribution
     - WUA Record Keeping
     - Establishment of Canal Management Work-force
     - Begin ISF Information Campaign

   - Water Management
     - Basic Field Data Collection and Pilot Block Development
     - Participatory Parcellary Map Development
     - Begin Water Measurement and O&M Plan Development
3. Implementation Phase

**Rehabilitation**
- Implementation of AP;
- Construction of Civil Works
  - ESM
  - Catch-up
  - Maintenance
  - System Improvements

**Institutional Development**
- Capability Development of WUA

**Water Management**
- Implementation of O&M Plan and Water Management Plan
- Resource Mobilization and Management
- Canal Management Work-force Strengthening
- ISF Collection
- Preparation and Implementation of O&M Expenditure (Plan (SF))

FORMAL MANAGEMENT TRANSFER

4. Post Turnover Phase

**Rehabilitation**
- Annual System Walk-Through

**Institutional Development**
- Revised ISF Collections
- WUA Elections
- Advanced Share System Administration

**Water Management**
- Review and Revise O&M Plan
- WUA Technical Manager Takes Responsibility
- Development of WUA Water Rights
- Agriculture Services and NGO/INGO Linkage Development

TRANSITIONAL SUPPORT PHASE