



Appendix 2 Bibliography of Irrigation and Drainage Performance Indicators

The following table has been compiled from the available literature on performance assessment. It is sometimes difficult to compile such data as different authors use different terms for the same indicator. Wherever possible, the different names have been identified. Reference is made to the *Review of Selected Literature on Indicators of Irrigation Performance* by P.S. Rao (1993), who provides a valuable summary of literature on performance indicators. O&M, operation and maintenance; I&D, irrigation and drainage.

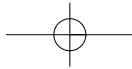


Performance indicator	Definition	Variables involved	Units	Criteria	Used by	Remarks
Water delivery and utilization						
Conveyance efficiency	$\frac{\text{Volume of water delivered (to tertiary unit)}}{\text{Volume of water diverted/pumped from source}}$	Discharge Duration	m ³ /s h	Efficiency	Bos and Nugteren (1974, 1990) Bos (1980, 1985, 1997)	Some refinement of definition between 1974 and 1997
Distribution efficiency	$\frac{\text{Volume of water received at field}}{\text{Volume of water delivered (to tertiary unit)}}$	Discharge Duration	m ³ /s h	Efficiency	Bos and Nugteren (1974, 1990) Bos (1980, 1985)	
Field application efficiency	$\frac{\text{Volume of water needed by crop } (ET_p - P_e)}{\text{Volume of water received at field}}$	Crop ET_p Effective rainfall, P_e Discharge Duration	mm mm m ³ /s h	Efficiency	Bos and Nugteren (1974, 1990) ICID (1978) Bos (1980, 1985, 1997)	Some refinement of definition between 1974 and 1997
Distribution uniformity	$\frac{\text{Average LQ depth irrigation water infiltrated}}{\text{Average depth infiltrated}}$	Infiltrated depth measured over an area	mm	Efficiency	Merriam and Keller (1978)	LQ – lower quartile
Irrigation system efficiency	$\frac{\text{Volume of water received at field}}{\text{Volume of water diverted/pumped from source}}$	Discharge duration	m ³ /s h	Efficiency	Bos and Nugteren (1974, 1990) ICID (1978)	
Overall project efficiency	$\frac{\text{Volume of water needed by crop } (ET_p - P_e)}{\text{Volume of water diverted/pumped from source}}$	Crop ET_p Effective rainfall, P_e Discharge Duration	mm mm m ³ /s h	Efficiency	Bos and Nugteren (1974, 1990) ICID (1978)	
Delivery performance ratio/management performance ratio	$\frac{\text{Actual supplied discharge}}{\text{Target discharge}}$	Actual discharge Target discharge	m ³ /s m ³ /s	Adequacy Equity Reliability	IMI (1987) Murray-Rust and Snellen (1993) Molden and Gates (1990) Van der Velde (1990)	Used by Van der Velde to identify canal maintenance problems in Lower Chenab system
Relative water supply (RWS)	$\frac{\text{Total water supply}}{\text{Crop water demand}}$ Levine (1982): $\frac{\text{Irrigation supply} + \text{rainfall}}{\text{Seepage} + \text{Percolation} + ET_p}$	Supply discharge Duration Crop ET_p Effective rainfall, P_e	m ³ /s h m ³ mm	Adequacy Equity	Levine (1982) Keller (1986) Weller and Payawal (1989) Bos et al. (1993, 1994) Perry (1996) Molden et al. (1998) Kloezen and Garcés-Restrepo (1998)	Widely used, and variously defined

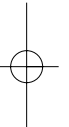
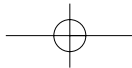
Water use efficiency (WUE)	$\frac{\text{Crop water demand}}{\text{Total water supply}}$	Supply discharge Duration Crop ET_p Effective rainfall, P_e	m^3/s h m^3 mm	Adequacy Equity Efficiency	Merriam <i>et al.</i> (1983) Merriam and Keller (1978)	Inverse of relative water supply
Relative irrigation supply	$\frac{\text{Irrigation supply}}{\text{Irrigation demand } (ET_p - P_e)}$	Discharge Duration Crop ET_p Effective rainfall, P_e	m^3/s h mm mm	Adequacy Equity	Molden <i>et al.</i> (1998) Sharma <i>et al.</i> (1991)	Inverse of irrigation efficiency terms used by Bos and Nugteren (1974)
Reliability Index	Percentage of observations which are within $\pm 10\%$ of the target discharge	Actual discharge Intended discharge	m^3/s m^3/s		Francis (1989) Makin <i>et al.</i> (1990)	
Water delivery capacity (%)	$\frac{\text{Canal capacity to deliver water at system head}}{\text{Peak consumptive demand}}$	Discharge Crop irrigation requirement	m^3/s m^3/s	Capacity Utility	Molden <i>et al.</i> (1998)	Gives an indication of the degree to which irrigation infrastructure is constraining cropping
Water distribution equity (also termed Delivery Performance Ratio, and Discharge Ratio)	$\frac{\text{Actual supply discharge}}{\text{Design discharge}}$	Actual discharge Design discharge	m^3/s m^3/s	Adequacy Equity	Francis and Elawad (1989) Wolters and Bos (1990) Van der Velde (1990) Bos (1997)	Some confusion in terminology with DPR as defined below
Water delivery performance (DPR)	$\frac{\text{Actually delivered volume of water}}{\text{Intended volume of delivered water}}$	Actual discharge and duration Intended discharge and duration	m^3/s h m^3/s h	Adequacy Equity	Lenton (1984) Molden and Gates (1990) Bos <i>et al.</i> (1993,1994) Bos (1997)	Some change in terminology between 1993 and 1997 definitions
Water delivery performance error	$e^2 = 1 / (n \sum (P_i - A_i))$	Actual water delivered (A) (at n specified locations l) Planned water delivery (P) (at n specified locations l)	m^3 m^3	Adequacy Equity	Sharma <i>et al.</i> (1991)	Useful measure for assessment of a number of outlets, such as all tertiary outlets on a secondary canal
Inter-quartile ratio	Ratio of water received on best-supplied quartile of land area, to that received on worst supplied quartile	Discharge Duration Irrigated area	m^3/s h ha	Equity	Abernethy (1984) Van der Velde (1990)	
Coefficient of variation	Statistical distribution of data	Discharge Irrigated area	m^3/s ha	Equity	Standard Abernethy (1984)	
Christiansen coefficient	Statistical distribution of data	Discharge Irrigated area	m^3/s ha	Equity	Merriam and Keller (1978) Abernethy (1984)	

Performance indicator	Definition	Variables involved	Units	Criteria	Used by	Remarks
Weekly delivery deficit	Number of weeks that water supplies are less than requirement	Water supply Water requirement	m ³ /s m ³ /s		Weller and Payawal (1989)	
Consecutive weekly delivery deficit	Number of consecutive weeks that water supplies are less than requirement	Water supply Water requirement	m ³ /s m ³ /s		Weller and Payawal (1989)	
Water availability index (WAI)	Observed water condition in paddy fields: 4.0 Water flowing paddy to paddy 3.0 Standing water in rice field 2.0 Soil is moist, in depressions 1.0 Soil is dry, surface cracks	Observed water/moisture conditions	-	Adequacy	Wijayaratne (1986)	Quoted in Murray-Rust and Snellen (1993)
Water availability index (WAI)	$\frac{\text{Total water supply available to scheme}}{\text{Total scheme water needs}}$	Total available water supply Total water needs	m ³ /year m ³ /year	Adequacy (input)	Ijir and Burton (1998)	Helps identify if water availability problems are due to external shortage of water or internal factors within the irrigation system
Efficiency of infrastructure	$\frac{\text{Number of functioning structures}}{\text{Total number of structures}}$	No. functioning structures Total no. of structures	No. of structures	Utility Control	Mao Zhi (1989) Ijir and Burton (1998) Bos <i>et al.</i> (1993, 1994)	Similar principle, different terminologies used by different researchers
Seepage loss ratio	$\frac{\text{Actual seepage rate}}{\text{Target seepage rate}}$	Seepage rate	m ³ /s	Efficiency	Bos <i>et al.</i> (1993, 1994)	
Water surface elevation	$\frac{\text{Actual water surface elevation at FSD}}{\text{Target water surface elevation at FSD}}$	Water surface elevation	m.a.s.l	Command/Control	Bos <i>et al.</i> (1993, 1994)	
Overall reliability	$\frac{\text{Volume delivered}}{\text{Target volume}} \times \frac{\text{Actual supply duration}}{\text{Target supply duration}}$	Discharge Duration	m ³ /s h	Reliability	Bos <i>et al.</i> (1993, 1994)	
Overall consumed ratio	$\frac{ET_p - P_e}{\text{Volume of water diverted at intake plus other inflow}}$	Crop ET _p Effective rainfall, P _e Discharge Duration	mm mm m ³ /s h	Efficiency	Bos (1997)	
Conveyance ratio	$\frac{\text{Volume delivered to distribution system} + \text{other deliveries}}{\text{Volume diverted at intake} + \text{other inflows}}$	Discharge Duration	m ³ /s h	Efficiency	Bos (1997)	
Distribution ratio	$\frac{\text{Volume delivered to fields} + \text{other deliveries}}{\text{Volume delivered at tertiary intake}}$	Discharge Duration	m ³ /s h	Efficiency	Bos (1997)	

Dependability of duration	$\frac{\text{Actual duration of water delivery}}{\text{Intended duration of water delivery}}$	Actual duration Intended duration	h h	Dependability Bos (1997)	Influenced by many parameters, of which one is water
Dependability of irrigation interval	$\frac{\text{Actual irrigation interval}}{\text{Intended irrigation interval}}$	Actual interval Intended interval	days days	Dependability Bos (1997)	
Relative change of water level	$\frac{\text{Change of level}}{\text{Intended level}}$	Level change Intended level	m m	Command Freeboard Bos (1997)	
Gross annual irrigation water quota	$\frac{\text{Total actual water delivered}}{\text{Actual irrigation area}}$	Discharge Duration Irrigated area	m ³ /s h ha	Adequacy Mao Zhi (1989)	
Agricultural production					
Yield	$\frac{\text{Crop production}}{\text{Cropped area}}$	Crop production Cropped area	kg ha	Production Standard	
Relative yield	$\frac{\text{Actual crop yield}}{\text{Potential crop yield}}$	Estimated yield Max. potential yield	kg/ha kg/ha	Production Davey and Rydzewski (1981) Abernethy (1986) Green (1989)	
Cropping intensity	$\frac{\text{Total area cultivated during the year}}{\text{Command area}}$	Total cropped area Command area	ha ha	Production Standard	Fundamental indicator of scheme performance
Area utilization	$\frac{\text{Harvested area}}{\text{Theoretically serviceable area}}$	Harvested area Service area (command area)	ha ha	Production Efficiency (of land use) Garces (1983)	
Specific yield/water use efficiency (kg/m ³)	$\frac{\text{Crop production}}{\text{Total volume of water supplied in season}}$	Crop yield Water supplied	kg m ³	Efficiency Productivity ICID (1978) Garcés (1983) Weller and Payawal (1989) Mao Zhi (1989)	Easier to use with mono-culture
Relative productivity of water	$\frac{\text{Potential crop production}}{\text{Total water supplied}}$	Potential crop yield Water supplied	kg/ha m ³ /ha	Efficiency Productivity Davey and Rydzewski (1981) Abernethy (1986) Green (1989) Mao Zhi (1989)	Similar principle, different terminologies used by different researchers
Relative crop planting dates	$\frac{\text{Variation (in days) from optimum crop planting dates}}$	Crop planting date	date	Weller and Payawal (1989) Tiffen (1990) Ijir and Burton (1998)	Similar principle, different terminologies used by different researchers



Performance indicator	Definition	Variables involved	Units	Criteria	Used by	Remarks
Annual yield	$\frac{\text{Annual crop production}}{\text{Command area}}$	Annual crop production Command area	kg ha	Production	General use Abermthy (1990)	Clearer with monoculture
Output per cropped area (\$/ha)	$\frac{\text{Value of production}}{\text{Irrigated cropped area}}$	Crop production Crop market price Irrigated crop area	kg/ha \$/kg ha	Production	Molden <i>et al.</i> (1998) Kloezen and Garcés-Restrepo (1998)	
Output per unit command (\$/ha)	$\frac{\text{Value of production}}{\text{Command area}}$	Crop production Crop market price Command area	kg/ha \$/kg ha	Production	Molden <i>et al.</i> (1998) Kloezen and Garcés-Restrepo (1998)	
Output per unit irrigation supply (\$/m ³) (water productivity)	$\frac{\text{Value of production}}{\text{Diverted irrigation supply}}$	Crop yield Crop market price Crop area	kg/ha \$/kg ha	Production	Molden <i>et al.</i> (1998) Kloezen and Garcés-Restrepo (1998)	
Output per unit water consumed (\$/m ³) (water productivity)	$\frac{\text{Value of production}}{\text{Volume of water consumed by ET}}$	Crop yield Crop market price Crop area Actual crop ET	kg/ha \$/kg ha mm	Production	Molden <i>et al.</i> (1998) Kloezen and Garcés-Restrepo (1998)	
Irrigated area performance	$\frac{\text{Actual area}}{\text{Target area}}$	Crop area	ha	Utility	Mao Zhi (1989) Bos <i>et al.</i> (1993, 1994)	
Cropping intensity performance	$\frac{\text{Actual cropping intensity}}{\text{Target cropping intensity}}$	Crop areas	ha	Utility	Mao Zhi (1989) Bos <i>et al.</i> (1993, 1994)	
Production performance	$\frac{\text{Total production}}{\text{Target production}}$	Crop types Crop yields Crop areas	– kg/ha ha	Production	Bos <i>et al.</i> (1993, 1994)	
Yield performance	$\frac{\text{Actual yield}}{\text{Target yield}}$	Crop yield	kg/ha	Production	Bos <i>et al.</i> (1993, 1994)	
Water productivity performance	$\frac{\text{Actual water productivity}}{\text{Target water productivity}}$	Crop type Crop area Crop yield Actual water supply Target water supply	– ha kg/ha m ³ m ³	Productivity	Bos <i>et al.</i> (1993, 1994)	



Agricultural economic and financial					
Profitability	$\frac{\text{Farm income minus expenditure}}{\text{Cost of production}}$	Crop yield Crop market price Costs of inputs	kg/ha \$/kg \$/kg	Profitability	Standard
Resource utilization	$\frac{\text{Value of production}}{\text{Cost of production}}$	Crop production value O&M costs	\$ \$	Efficiency	Abemethy (1990)
Fee collection index (also fee collection performance)	$\frac{\text{Irrigation fees collected}}{\text{Irrigation fees due}}$	No. people employed Fees collected Fees payable	No. \$ \$	Efficiency Sustainability	Garcés (1983) Abemethy (1990) Bos <i>et al.</i> (1993, 1994) Bos (1997) Ijir and Burton (1998)
Gross return on investment (%)	$\frac{\text{Standardized gross value of production}}{\text{Cost of irrigation infrastructure}}$	Crop yield Crop market price Crop area Cost of infrastructure	kg/ha \$/kg ha \$	Productivity Efficiency	Molden <i>et al.</i> (1998)
Financial self-sufficiency	$\frac{\text{Revenue from irrigation}}{\text{Total O&M expenditure}}$	Revenue O&M expenditure	\$ \$	Financial viability	Molden <i>et al.</i> (1998) Kloezen <i>et al.</i> (1997) Bos (1997) Ijir and Burton (1998)
Total financial viability	$\frac{\text{Actual O&M allocation}}{\text{Required O&M allocation}}$	Actual O&M expenditure Required O&M expenditure	\$ \$	Financial viability	Garcés (1983) Mao Zhi (1989) Bos <i>et al.</i> (1993, 1994) Ijir and Burton (1998)
Income from water charges per unit area (\$/ha)	$\frac{\text{Revenue from I&D charges}}{\text{Command area}}$	Revenue collected from I&D charges Command area	\$ ha	Financial viability Sustainability	Mao Zhi (1989) Kloezen <i>et al.</i> (1997)
Area-based profitability	$\frac{\text{Incremental benefit per unit area}}{\text{Total irrigation expenses}}$	Total incremental benefit Benefited area	\$ ha	Profitability	Mao Zhi (1989) Bos <i>et al.</i> (1993)
Water-based profitability	$\frac{\text{Incremental benefit per unit water}}{\text{Total irrigation expenses}}$	Total incremental benefit Total water consumed	\$ m ³	Profitability	Mao Zhi (1989) Bos <i>et al.</i> (1993, 1994)
O&M fraction	$\frac{\text{Cost of operation + maintenance}}{\text{Total agency budget}}$	Total irrigation expenditure O&M costs Total budget	\$ \$ \$	Operational viability	Bos (1997)

Influenced by many factors

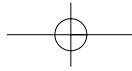
Similar principle, different terminologies used by different researchers

Varies for different systems, but a useful broad indicator nevertheless

Performance indicator	Definition	Variables involved	Units	Criteria	Used by	Remarks
Yield vs. water cost ratio	$\frac{\text{Added value of crop}}{\text{Cost of applied irrigation water}}$	Value irrigated crop Value rain-fed crop Cost of applied water	\$ \$ \$	Profitability	Bos (1997)	
Yield vs. water supply ratio	$\frac{\text{Added mass of marketable crop}}{\text{Mass of irrigation water delivered}}$	Mass of irrigated crop Mass of rain-fed crop Mass of irrigation water	kg kg kg	Productivity	Bos (1997)	
Irrigation benefit per unit area	Benefit from irrigated crops – benefit from crops without irrigation – costs of irrigation	Irrigated crop yield Non-irrigated crop yield Crop market price Costs of irrigation	kg/ha kg/ha \$/kg \$/ha	Productivity	Mao Zhi (1989)	
Socio-economic						
Quality of life	Can vary widely	Public health Standard of living Employment levels, etc.		Quality	Chambers (1988) Abernethy (1990)	Very difficult to measure and set standards
Farmers' satisfaction	The degree of satisfaction perceived by the farmers with the level of service provision	Farmer perception (obtained through questionnaire survey)	–	Satisfaction	Carces (1983)	Should be more widely used
Irrigation employment generation	$\frac{\text{Annual person days per ha labour in scheme}}{\text{Annual number official working days}}$	Total person days labour Total area Number of annual working days	No. ha No.	Employment	Chambers (1988) Bos <i>et al.</i> (1993, 1994)	
Irrigation wage generation	$\frac{\text{Annual average rural income}}{\text{Annual national (regional) average income}}$	Average rural income Average national income	\$/year \$/year	Income generation	Bos <i>et al.</i> (1993, 1994)	
Relative poverty	Percent population above poverty line (scheme) Percent population above poverty line (national)	Poverty line income Numbers earning and income levels (scheme and nationally)	\$/year No. \$/year	Livelihood	Bos <i>et al.</i> (1993, 1994)	
Technical knowledge of staff	$\frac{\text{Knowledge required to fulfil job}}{\text{Actual knowledge of staff}}$	–	–		Bos <i>et al.</i> (1993, 1994) Bos (1997) Ijir and Burton (1998)	Similar principle, different terminologies used by different researchers

Users' stake in irrigation system	$\frac{\text{Active water users' organizations}}{\text{Total number of water users' associations}}$	-	Bos <i>et al.</i> (1993, 1994) Bos (1997) Garcés (1983)
Response capacity	Measure of the ability of the O&M agency staff to address day-to-day O&M issues	-	Efficiency Efficacy
Manpower numbers ratio	$\frac{\text{Total O\&M staff numbers}}{\text{Total irrigable area}}$	No. ha	Ijir and Burton (1998)
Scheme development ratio	$\frac{\text{Total scheme area actually developed for irrigation}}{\text{Total potential development area}}$	ha ha ha	Ijir and Burton (1998)
Environment			
Sustainability of irrigated area	$\frac{\text{Current irrigable area}}{\text{Initial irrigated area}}$	ha	Utility Bos <i>et al.</i> (1993, 1994) Bos (1997) Ijir and Burton (1998) Standard
Irrigation and drainage water quality	Water quality measured against water quality standards	-	Quality
Relative groundwater depth	$\frac{\text{Actual groundwater depth}}{\text{Critical groundwater depth}}$	m m	Sustainability Bos (1997)
Relative EC ratio	$\frac{\text{Actual EC value}}{\text{Critical EC value}}$	ha ha	Sustainability Bos (1997)
Waterlogging index	$\frac{\text{Area affected by waterlogging}}{\text{Total command area}}$	ha ha	Productivity Sustainability Garcés (1983)

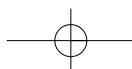


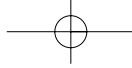


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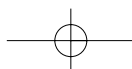
List of References Associated with Appendix 2

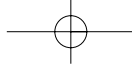
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