

6 Data Management for Performance Assessment

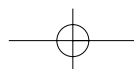
Background

Performance assessment by its nature requires data of all sorts, collected at various times and analysed by different means and presented to different audiences. With every piece of collected data, there is a potential benefit and an associated cost. A good data management programme will capture necessary information for performance assessment, maximize the utility of data collected and minimize the cost of collection and processing. In this chapter, data management implies more than merely collecting and processing data. A data management programme will also provide a means to optimize the quality of information from those of field data. The process of data management consists of two inter-related activities: (i) the design and management of the data measurement process, and (ii) the actual database management. The latter activity can be divided in a group of 'in-office' activities and a group of communication activities. The process of data management is depicted in Fig. 6.1. This chapter describes each of these phases in data management.

Data System Management

The design for cost-effective management of the data system configuration is the most critical phase in the entire data processing task. It handles key questions like 'Which data need to be measured?'

The generalized path between measured data and the presentation of performance indicators is shown in Fig. 6.2. The number of indicators that are selected for communication with end users of management information depends on the audience. A grouping of indicators is given



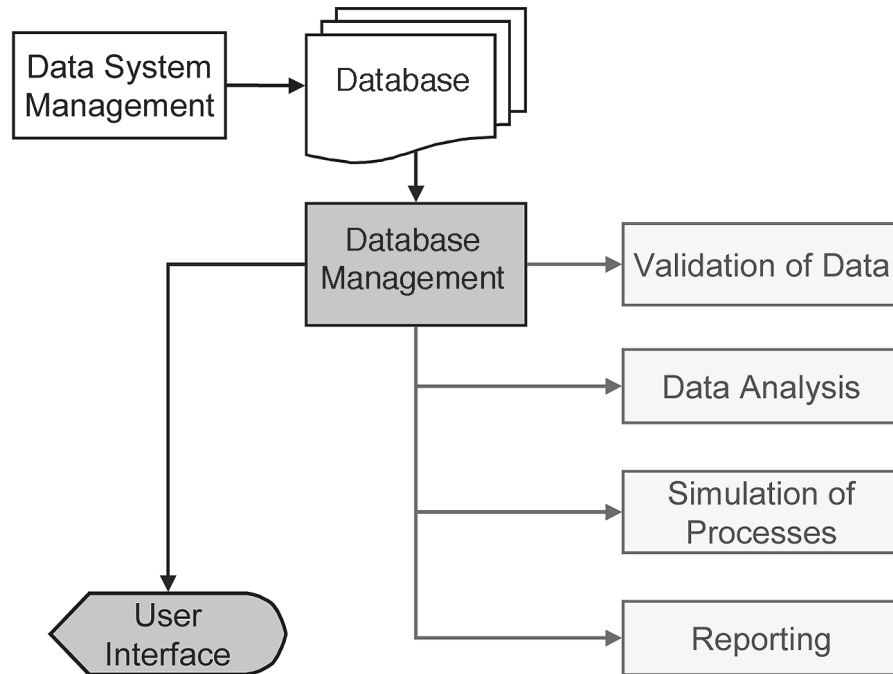


Fig. 6.1. Data processing.

in Chapter 3. The above question, ‘Which data need to be measured?’, also requires an answer on the density of measurement locations within the irrigated area and on the time interval between measurements.

As mentioned above, the design for cost-effective management of the data system configuration is the most critical phase in the entire data processing task. It handles key questions like:

- Which data need to be collected? This includes the density of measurement locations within the irrigated area (where?) and the time interval between measurements (how often?). The volume of data to be measured depends on the number of indicators included in the programme (see Chapter 2).
- How are data measured, e.g. should data be measured by own staff, can data be obtained or bought from other parties, can data measurement be automated in a cost-effective way?
- How are data stored? For rather straightforward assessment, an off-the-shelf spread sheet may be adequate. If the spatial distribution of indicator values needs to be reported, however, a geographic information system (GIS) is most adequate.
- How is information reported to the user of end results?

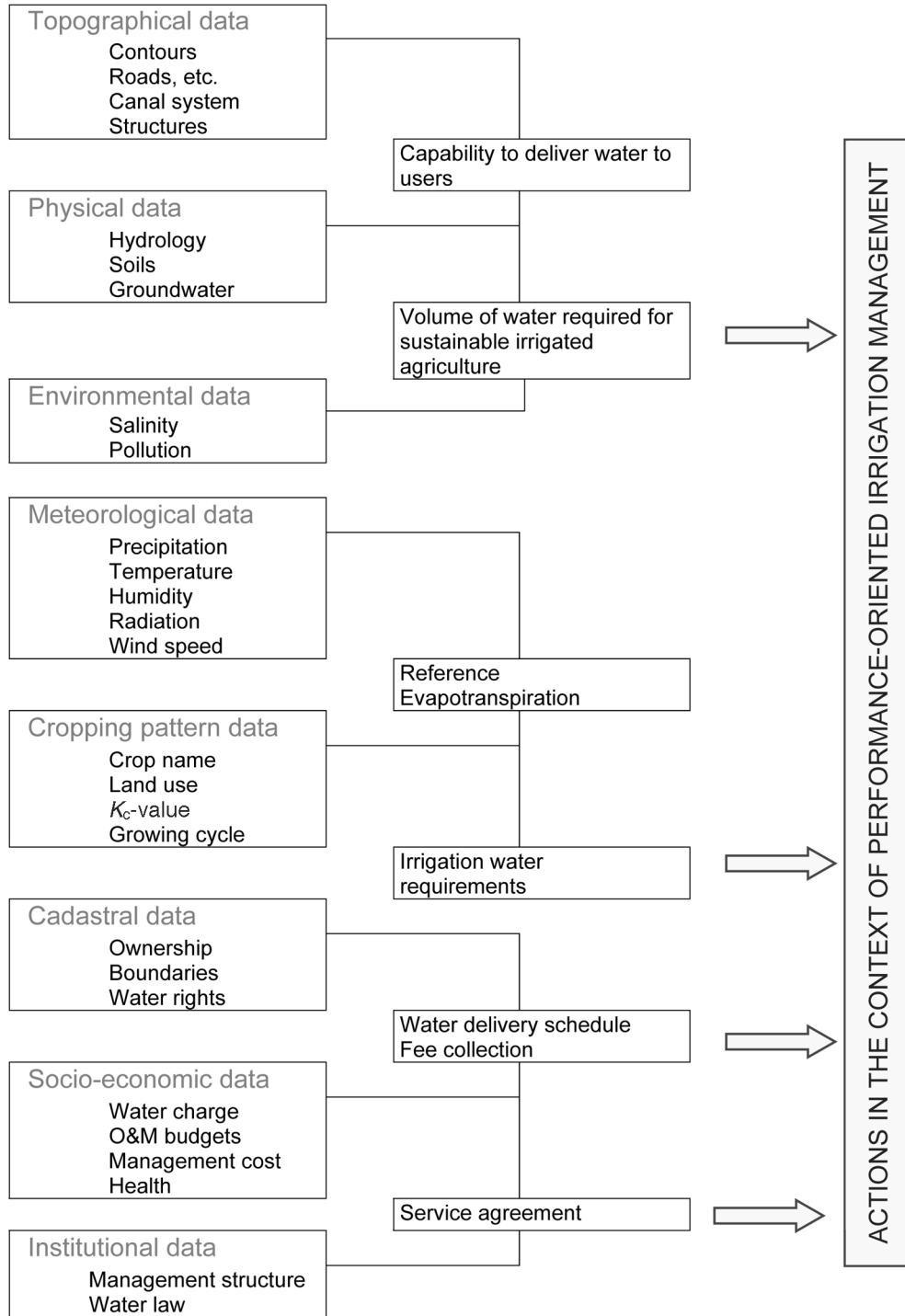
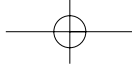
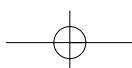
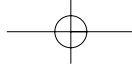


Fig. 6.2. Path from measured data to irrigation performance indicators (Bos, 2001).





Database Management

Database management can be divided into two groups of activities: (i) the in-office activities with all measured data, and (ii) the communication with end-users through 'read only' information and a user interface.

In-office activities

Before field data can be used, a thorough screening and analysis should be carried out. Thereafter, data can be used in simulation programs. These routine in-office activities lead to different styles of reports for a variety of readers (end-users). The discussion below follows the in-office activities on data management and gives general guidelines.

Validation of data

Whenever data are collected or measured, the value obtained is simply the best estimate of the true value. The true value is either slightly greater or less than the measured value. The usefulness of performance indicators is greatly enhanced if a statement of possible error accompanies the result. The error may be defined as the difference between the true value and the value that is calculated with the aid of the appropriate equations.

It is not relevant to give an absolute upper bound to the value of error. Due to chance, such bounds can be exceeded. Taking this into account, it is recommended to give a range that is expected to cover the true value of the measured quantity with a high degree of probability. This range is termed the uncertainty of measurement, and the confidence level associated with it indicates the probability that the range quoted will include the true value of the quantity being measured. A probability of 95% is commonly used as the confidence level for all errors (see 'Accuracy of Measurements and Indicators' below).

During data validation, three types of error must be considered (Fig. 6.3):

- Spurious errors as a result of human mistakes and instrument malfunctions.
- Random errors due to experimental and reading mistakes.
- Systematic errors (which may be either constant or variable).

Spurious errors are errors that invalidate a measurement. Such errors cannot be incorporated into a statistical analysis. Steps should be taken to avoid such errors and discard the results. Alternatively, corrections may be applied. Spurious errors can only be detected if time series of data are screened on irregularities and impossible values.

Random errors are errors that affect the reproducibility of measurement. It is assumed that data points deviate from the mean in accordance

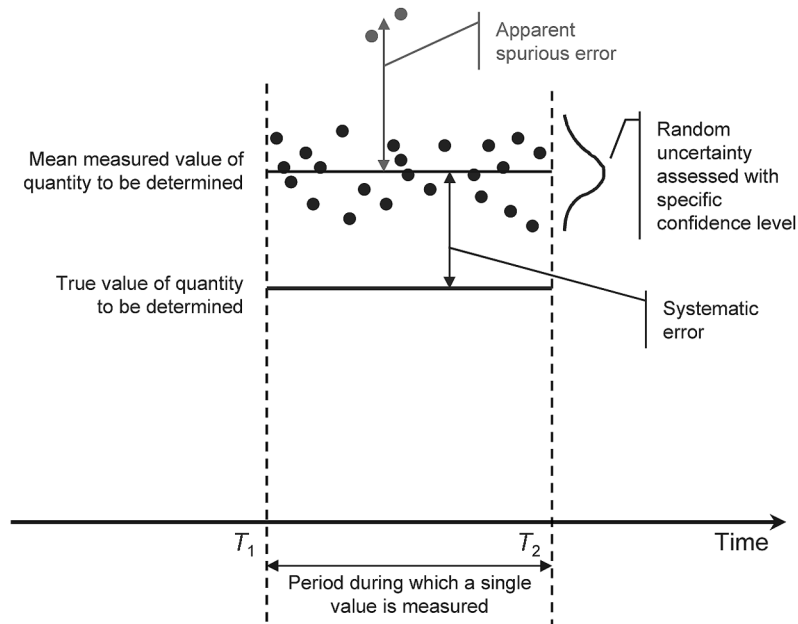
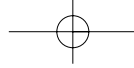


Fig. 6.3. Illustration of terms.

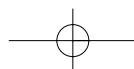
with the laws of chance as a result of random errors. The mean random error of a summarized measurable value over a period is expected to decrease when the number of measurements during this period increases. As a result, the integrated value over a long period of observations (more than about 15 observations) will have a mean random error that approaches zero. It is emphasized that this refers to time-dependent errors only.

Systematic errors are errors that cannot be reduced by increasing the number of measurements as long as equipment and conditions remain unchanged. Whenever there is evidence of a systematic error of a known sign, the mean error should be added to (or subtracted from) the measurement result.

Data should be validated immediately after collection in order to detect spurious and systematic errors. The cause of such errors should be corrected to avoid a gap in data during significant parts of the irrigation season. The distinction between accuracy and precision, as illustrated in Fig. 6.4, should be considered.

Data analysis

As discussed in Chapter 3, the major reason for measuring (or quantifying) the actual value of a key aspect is to see if target values of indicators are met. If the indicator value deviates too much (is outside the allowable range) of the indicator, then (corrective) adjustments need to be made. Subsequently, the impact of this corrective action on performance



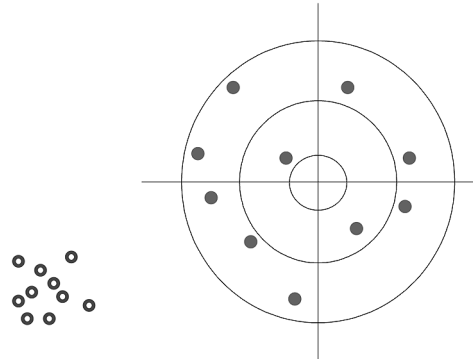
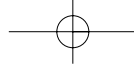


Fig. 6.4. The closed points have high accuracy and low precision; the open points have high precision and low accuracy.

needs to be monitored. Therefore, data need to be analysed and reported upon. The period between data measurement and analysis varies with the purpose of the assessment as follows:

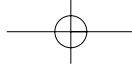
- Operational: to adjust operation of irrigation or drainage infrastructure, data analysis is required on a real-time or near-real-time basis.
- Strategic: analysis coincides with key cycles in the irrigation or drainage process like growing season, hydrological cycles, etc. It is recommended to analyse data at least once per year (annual report on performance).
- Diagnostic: a diagnosis usually is only needed following the identification of one or more problems. Analysis is related to the nature of these problems. All data need to be analysed before a report is written.

Simulation of processes

Often the information (data) needed to enable performance-oriented management differs from the physical data that actually can be measured. The physically measured data then have to be converted into the needed data through a simulation model. For the most common processes, such models are available for use on a personal computer. For example, a flow rate (in m^3/s) cannot be measured directly. However, if a weir of known dimensions is constructed, a rating equation can be derived in the shape (Clemmens *et al.*, 2001):

$$Q = K_1(h_1 - K_2)^u \quad (1)$$

in which the values of K_1 , K_2 and the power u are constants for the constructed weir. If the head with respect to the weir crest, h_1 , is measured, the flow rate can be calculated. If heads are recorded in digital format (Fig. 6.5), a spreadsheet can be used to transfer the heads during a



selected period (e.g. day, week, month, season, etc.) into a volume of water passing the weir during this period. Parameters that can be simulated using available software are listed in Table 6.1.

Reporting

In reporting information on the performance of irrigation and drainage it is essential to review this information with respect to the average knowledge level of the reader on irrigation and drainage related processes. Thus, the same information should be reported with different terminology and different levels of detail for reader groups (water users, decision makers, system managers and researchers). Although all data can be given either in tables or in graphs, most readers prefer graphs. Researchers also may ask for data in digital format for further study.

As discussed in Chapter 3, the reporting on indicator values always is done with respect to the target value of the indicator. Depending on the purpose of the assessment (see Table 3.2), the information is presented as:

- A function of time, showing the indicator trend with respect to its target (critical) value (and the related allowable range around this target). Such a presentation in time is particularly recommended for indicators that influence crop growth (e.g. depth to groundwater, Fig. 6.6). Since 1982, the irrigation water into the area is measured and

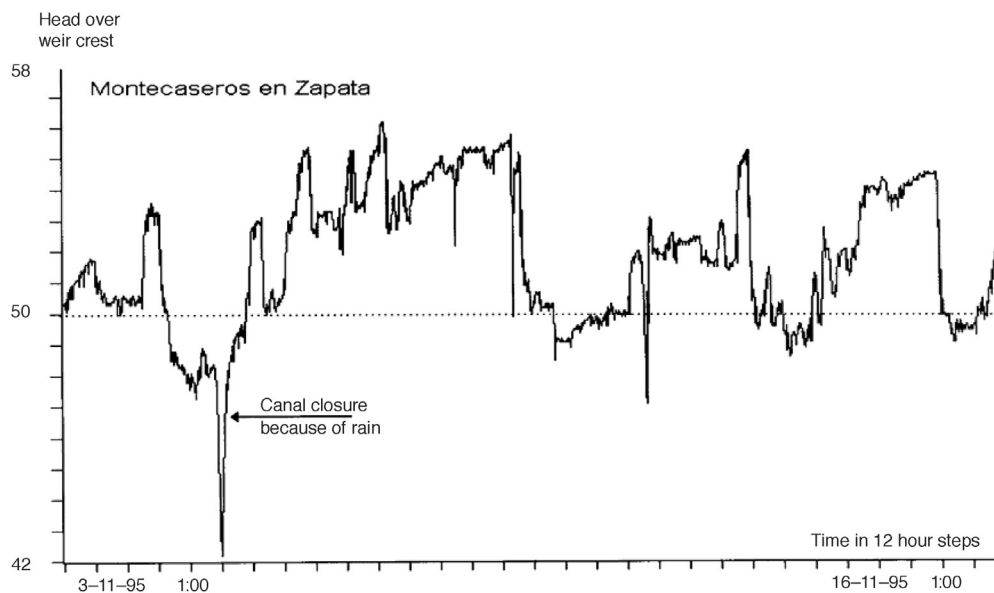
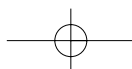
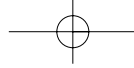
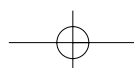


Fig. 6.5. Digital registration of head over the weir crest in an irrigation canal, Mendoza, Argentina.



**Table 6.1.** Overview of simulation processes for performance assessment.

Simulated parameter	Models available for simulation
Flow rate, discharge	The flow over a broad-crested weir or long-throated flume can be simulated by WinFlume (Clemmens <i>et al.</i> , 2001). The head–discharge rating can be established with an error of 2%.
Potential evapotranspiration	The potential evapotranspiration of a cropped area can be simulated by using two methods. One method uses meteorological data and crop data to simulate ET_p . Common simulation models use the Penman–Monteith concept. Well-tested models are CROPWAT (Smith <i>et al.</i> , 1992) and CRIWAR 2.0 (Bos <i>et al.</i> , 1996). Because of assumptions in the theory and because of uncertainty in the used crop coefficients, the error in ET_p is about 20%. The second method estimates ET_p according to the Priestley and Taylor equation (Priestly and Taylor, 1972) using 24-h net radiation values derived from satellite data. The use of net radiation data of a particular crop under actual field conditions determined by satellites avoids the need to use generic crop coefficient data (Mekonnen and Bastiaanssen, 2000). The error in ET_p also is 20%.
Actual evapotranspiration	The actual ET from an agricultural area can be simulated from the energy balance for each pixel of a satellite image with thermal bands. Several software packages are commercially available. A well-tested program is SEBAL (Bastiaanssen <i>et al.</i> , 1998). The error in ET_a is 20%.
Effective precipitation	Effective precipitation can be defined in various manners. The most scientifically justified method was developed by the US Department of Agriculture (1970). The method is given in CRIWAR (Bos <i>et al.</i> , 1996). The error in the calculated effective precipitation may be as high as 20%.
Groundwater flow	Up to 100 groundwater models are available to simulate the inflow and outflow for an (irrigated) area plus the related water-level fluctuations. Some models are widely used. MODFLOW (McDonald and Harbaugh, 1988) is a popular program to simulate three-dimensional flow including the flow of chemicals in the groundwater. SIMGRO (Veldhuizen <i>et al.</i> , 1998) was developed to simulate groundwater and surface water flow plus the water movement in the unsaturated zone. As such, it is suitable for integrated water management. MICROFEM (Hemker and Nijsten, 1997) is a semi three-dimensional program.
Soil moisture	Volumetric soil water content can be estimated empirically from satellite data, i.e. from the ratio of the latent heat flux over the net available energy fraction. The available energy then is the difference of net radiation and soil heat flux. This soil moisture value describes the average soil wetness in the root zone. If roots are absent, it describes the moisture conditions in the upper 0.05 m of the soil (Bastiaanssen <i>et al.</i> , 1998).
Biomass production	A biomass growth routine after concepts of Asrar <i>et al.</i> (1985) can be used to estimate the above-ground growth of vegetation. The temporal integration of above-ground biomass growth is a good indicator of crop yield, provided that the ratio between physical harvestable yield and total biomass is known or can be established (e.g. Donald and Hamblin, 1976; Gallagher and Biscoe, 1978).



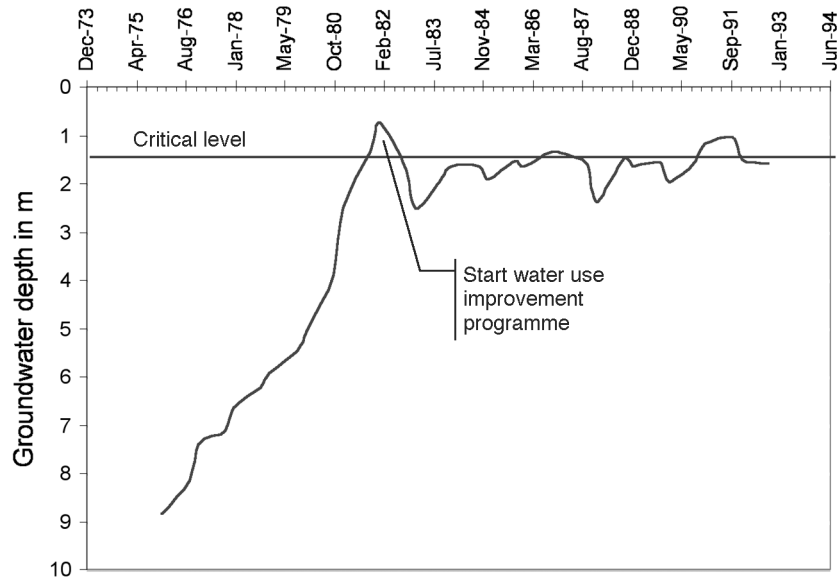
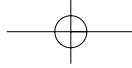


Fig. 6.6. Groundwater table data with respect to the critical level for salinity, Sirsa district, Haryana, India.

managed in such a way that the depleted fraction has an average value of about 0.6. As a result, the groundwater table remains sufficiently low to avoid salinity in the root zone.

- With an indicator value for all irrigation units (drainage areas) within the considered area. This shows the spatial distribution of the indicator. Whether the indicator value is within the allowable range or not is commonly shown with colour codes. Figure 6.7 presents information in a graphical manner. If a GIS system is used, a real scale presentation is recommended (see Figs 3.17 and 3.20).

To assess performance of irrigation and drainage (assess the use of various resources), and to decide on corrective actions in order to improve the use of these resources, the plotting of indicator values against another indicator or parameter that influences the value of the indicator is recommended. Figure 6.8 shows the impact of the depleted fraction, $ET_a/(V_c + P)$, on the fluctuation of the groundwater table. The trend line cuts the x-axis usually between 0.6 and 0.7. Thus, the water manager can influence groundwater table fluctuation by diverting another volume (V_c) of flow from the water source.

As discussed in Chapters 2 and 3, the target (intended) value of an indicator should be based on research on: 'boundary conditions' influencing the value of this indicator; critical values of the indicator that influence crop yield; and attainable (benchmark) values of the indicator that should be aimed at under similar boundary conditions. Reports on

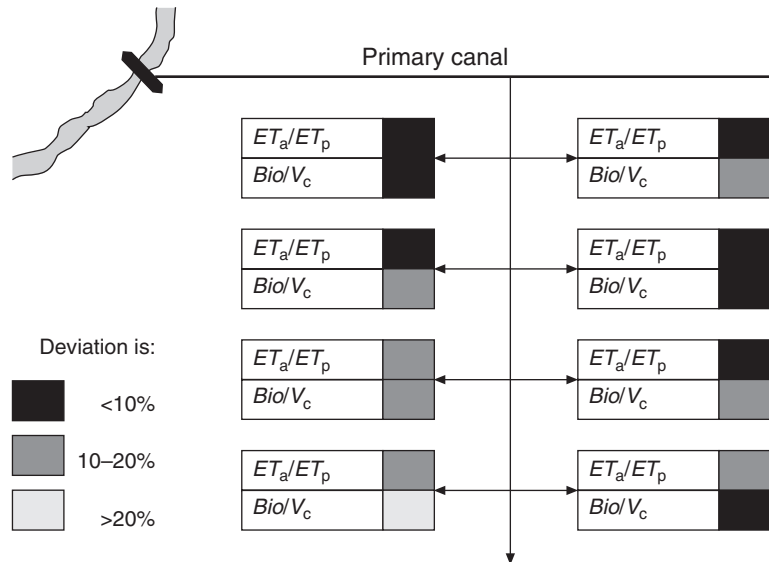


Fig. 6.7. Spatial presentation of performance indicators. ET_a/ET_p is the 'Relative evapotranspiration' and Bio/V_c is the 'Biomass production per m^3 water supply' (see Chapter 3).

such research should include information on the measured mean and standard deviation of the indicator. Also, information on the allowable (operational) range should be given (Table 6.2).

User interface

For the design of a 'user interface', the first step is to define the needs of the user group. In irrigation and drainage we broadly distinguish two user groups: (i) the managers of the irrigation and drainage agency, and (ii) the customers and relations (water users, politicians, etc.) of the agency. The following concepts are recommended:

- The needs of the agency manager are directly related to the input and validation of data and with simulation processes (calculations, etc.) that produce graphs and tables. A custom-made set of screens within a commercially available spreadsheet program is recommended. Figure 6.9 (pp. 130–131) shows an example screen of such an interface.
- To facilitate communication between the agency managing irrigation or drainage and its customers (water users, public in the region, etc.) additional information is needed of better public relations quality. Besides good written information, maps are needed showing the spatial variation of indicators and parameters. To produce these maps, the

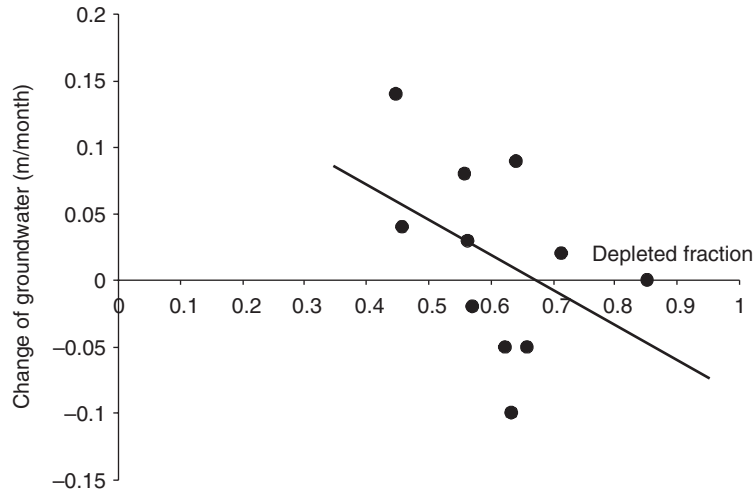
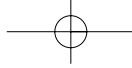


Fig. 6.8. Fluctuation of the groundwater table (in m/month) as a function of monthly averages of the depleted fraction (Nilo Coelho project, Brazil).

use of a geographic information system (GIS) is recommended. For most agencies a low-cost GIS would be adequate. An example of a GIS screen is shown in Fig. 6.10 (p. 132).

Accuracy of Measurements and Indicators

Terminology

This section gives procedures for expressing the accuracy of measured data with a randomly distributed error and the way in which these errors propagate in the calculated indicator (Bos, 1974; Clemmens, 1999). For a more detailed discussion related to irrigation, and a further reference, see Mood (1954). Examples are given on estimating accuracy where numbers are added, subtracted, multiplied or divided.

If a parameter is quantified, the obtained value is a sort of 'best measured value' of this parameter (X_1). Quantifying this parameter again through an independent measurement yields a second value (X_2) that may differ from the first measurement. If the results of many (n is more than 15) independent measurements are plotted in a histogram an envelope can be drawn around the number of measurements having a shape as shown in Fig. 6.11 (p. 133).

The average value of the measured parameter is calculated as:

$$X_{\text{average}} = \frac{\sum_{i=1}^n X_i}{n} \quad (2)$$

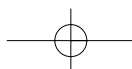
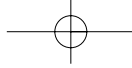


Table 6.2. Benchmark values for performance indicators for pressurized systems in irrigated fruit crops in Nilo Coelho (Brazil).

Indicator	Measured mean	Standard deviation	Operational range	Percentage of data in operational range	Acceptable range	Percentage within acceptable range
Overall consumed ratio	0.78	0.26	0.7–1.0	43	0.6–1.1	64
Depleted fraction	0.61	0.17	0.7–1.0	22	0.6–1.1	50
Crop water deficit (mm/month)	30.3	13.6	0–30	58	0–40	80
Relative evapotranspiration	0.76	0.10	0.8–1.0	35	0.7–1.0	73
Relative soil wetness	1.16	0.32	0.8–1.2	51	0.6–1.2	63
Biomass production (in kg) per m ³ water supply	2.01	1.06	>1.8	58	> 1.5	58
Average				44		64



The deflection points of the envelope curve deviate $\pm s$ from the average value. The value of this 'standard deviation' can be calculated from

$$s^2 = \frac{\sum_{i=1}^n (X_i - X_{\text{average}})^2}{n - 1} \quad (3)$$

With a normal distribution of the measured parameter, the values X_i are under the envelope curve of Fig. 6.11, while 95% of all values are within a confidence band with a width of $\pm 2s$. A common way of expressing the 'error' of a measured parameter is by using the 'interval with a 95% confidence level'. This confidence interval (*CI*) is defined as:

$$CI = \pm \frac{2s}{X_{\text{average}}} \quad (4)$$

The above factor of two assumes that n is large. For $n = 6$ the factor should be 2.6; $n = 10$ requires 2.3 and $n = 15$ requires 2.1.

For example, suppose that crop cuttings (more than 15) were made to determine the yield of cotton, resulting in an average yield of 4.2 t/ha. Using a spreadsheet to calculate the standard deviation, the assessor of performance finds that $CI = 0.10$, so that the true yield falls within $\pm 10\%$ of 4.2 t/ha or between 3.78 and 4.62 t/ha with 95% confidence. In other words, if cotton yield measurements under the same conditions could be repeated 100 times, 95 of the measurements would fall within $\pm 10\%$ of the estimated average yield of 4.2 t/ha. Reporting 4.2 t/ha $\pm 10\%$ provides much more information than just reporting the average yield. Common errors for parameters being related to irrigation and drainage are shown in Table 6.3 (pp. 133–136).

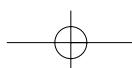
Propagation of errors

When presenting indicators, we typically take two or more parameter values, add them, multiply them and express as ratios. How do we express uncertainties in these cases?

Adding and subtracting

When adding or subtracting two values, $y = y_1 + y_2$ (or $y = y_1 - y_2$), with the confidence intervals for y_1 and y_2 being CI_1 and CI_2 respectively, an approximate estimate of the confidence interval around y expressed in terms of CI is

$$CI = \frac{\sqrt{y_{\text{av},1}^2 CI_1^2 + y_{\text{av},2}^2 CI_2^2}}{y} \quad (5)$$



A	B	C	D	E	F	
8	<p>Project Name = Water Year =</p> <p>Total Project area (command and non-command) Total field area in the command area</p> <p>Estimated conveyance efficiency Estimated seepage for paddy rice Estimated surface losses from paddy rice to drains Estimated field irrigation efficiency for other crops</p> <p>Flow rate capacity of main canal(s) at diversion point(s) Actual Peak Flow rate into the main canal(s) at the diversion point(s)</p> <p>Average ECe of the Irrigation Water</p> <p>This worksheet has 9 tables that require inputs FOR ONE YEAR, in addition to the cells above.</p> <p>Table 1 – Field Coefficients and Crop Threshold ECe Table 2 – Monthly ETo, mm Table 3 – Surface Water Entering Command Area Boundaries Table 4 – Internal Surface Irrigation Water Sources Table 5 – Hectares of Each Crop in the Command Area, by Month Table 6 – Groundwater Data Table 7 – Precipitation, effective precipitation, and deep percolation of precipitation Table 8 – Special agronomic requirements Table 9 – Crop Yields and Values</p>	Example Project				
9		1998				
10			100,000			
11			80,000			Hectares; gross, including roads, all fields, water bodies Physical area in hectares. NOT including double cropping
12						
13			80			Percent, %
14			10			Percent, % of irrigation water delivered to fields (averaged over the irrigation season)
15			10			Percent (%) of irrigation water delivered to fields
16			60			Percent, %
17						
18			70			Cubic Meters per Second (CMS)
19			65			Cubic Meters per Second (CMS)
20						
21			1.0			dS/m (same as mmho/cm)
22						
23						
24						
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34						
35						

		Table 1 – Field Coefficients and Crop Threshold ECe				
		Water year month →	Threshold ECe	Threshold ECe		
	Crop #			Mar	Apr	May
36						
37						
38						
39						
40			dS/m			
41	1	Paddy Rice #1	3	0.75	1.00	1.00
42	2	Paddy Rice #2	2			
43	3	Paddy Rice #3				
44	4	Crop #4	2			0.60
45	5					
46	6					
47	7					
48	8					
49	9					
50	10					
51	11					
52	12					
53	13					

Fig. 6.9. Example screen of a custom-made spreadsheet as user interface (Burt et al., 2001).

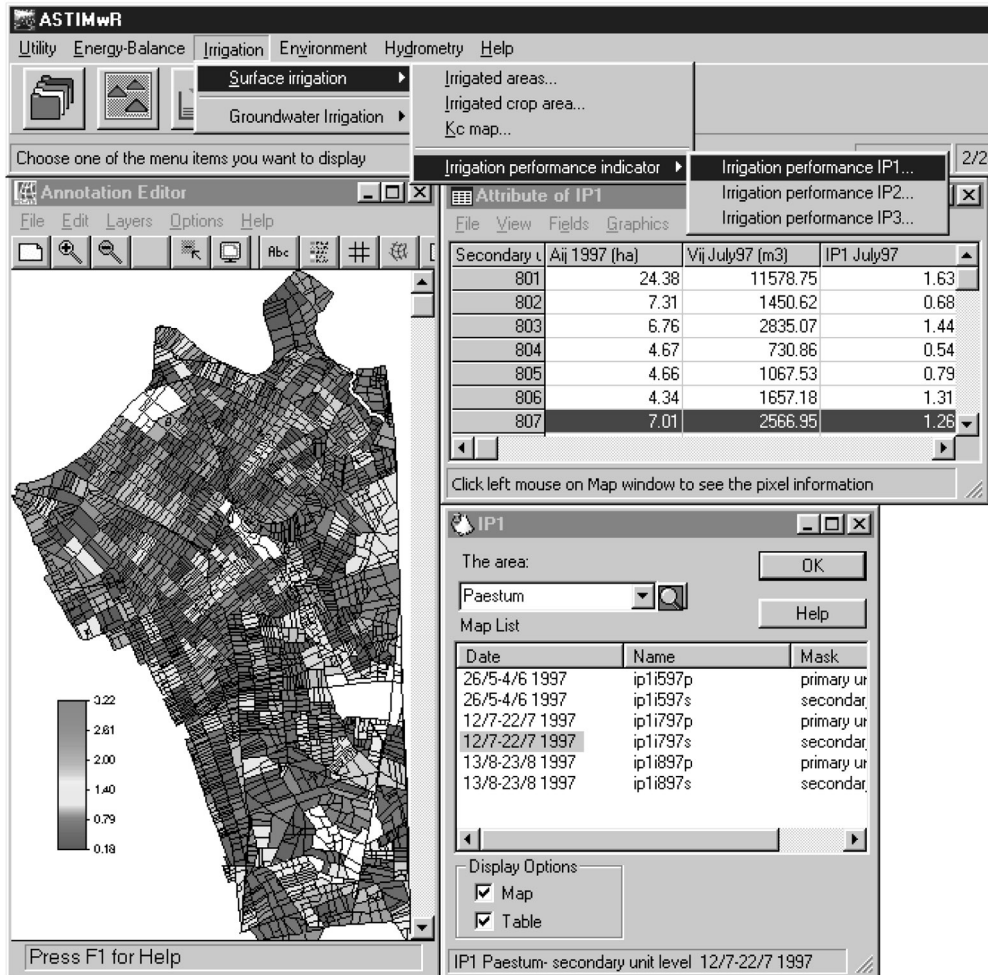


Fig. 6.10. Example of a user interface based on a GIS (ITC, 2000).

If the difference between the average values of two subtracted (independently measured) parameters is less than their standard deviation, there is a chance that one single measurement of the 'smaller' parameter exceeds the single measurement of the 'larger' parameter (Fig. 6.12). For a meaningful estimate of this difference many (more than 15) independent measurements of each parameter must be made.

Multiplication and division

For multiplication, $y = y_1 \times y_2$, an approximate estimate of the confidence interval around y expressed in terms of CI is

$$CI = \sqrt{CI_1^2 + CI_2^2 + CI_1^2 CI_2^2} \quad (6)$$

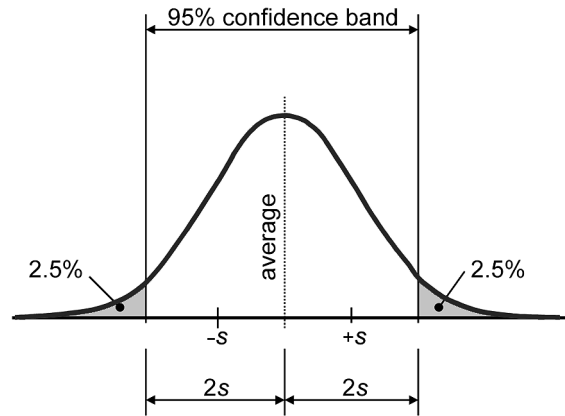
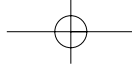
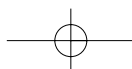
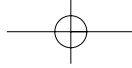


Fig. 6.11. Illustration of terminology.

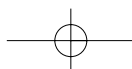
Table 6.3. Definition of parameters, their methods of measurement or qualification and the estimated measurement error (95% confidence level).

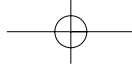
Parameter	Definition	Method by which term is measured or source of data
Added mass of marketable crop	Difference between crop yield (in kg/ha) between an irrigated crop and rain-fed crop grown while the remaining conditions are the same.	Subtract crop cuttings from adjacent irrigated and rain-fed fields. Because several non-water factors are affecting yield the error exceeds 25%.
Biomass production	Total growth of vegetation (biomass added) above ground level during a selected period (day, month or season).	Subtract crop cuttings from adjacent plots at the beginning and end of the considered period. Because of spatial variation in growth the error is 15%. If biomass growth is derived from remotely sensed data the error is 20%.
Command area	Irrigable area downstream of one (considered) flow control structure.	Measured by planimetry from the most recent map of the irrigable area (5% error) or from small pixel size satellite images (5% error).
Consumption of water	Water that is actually evapotranspired from the field and by the crop (ET_a). Consumed water enters into the atmosphere.	Point measurements can be made by lysimeters that are then extrapolated to a larger area. Remote sensing (RS) can be used to measure ET_a for a large area (for each pixel). In both cases the error is 20%.



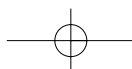
**Table 6.3.** *Continued.*

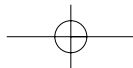
Parameter	Definition	Method by which term is measured or source of data
Benchmark	The desired value of process output (or performance indicator).	The benchmark level is set by comparison with best practices of comparable processes. The set value is not subject to a statistical error.
Crop yield	Marketable yield of the cultivated crop in terms of kg/ha.	Measured by crop cuttings in the field upon harvest (error 10%).
Delivery of water	Volume of water transported (through a canal or pipe line) from a source to a customer or group of customers (water users).	If the volume of water is calculated from 15 or more individual flow measurements the error will be reduced to the systematic error in these measurements (e.g. gates 5%, weirs 2%).
Depth of delivered water	Volume of water delivered to a command area divided by the size of this area. This depth commonly has the same dimensions as precipitation and evapotranspiration, e.g. mm/day.	Is calculated as the volume of water delivered to a command area divided by the irrigated area within this command (1 mm/day = constant flow of 0.116 l/s per ha).
Design water level	Water level in a canal according to the design.	In length units and is related to a (standard) reference level. The value is not subject to a statistical error.
Discharge	Flow rate out of an area in m ³ /s.	Measured by a current meter (7% error) or a flow measurement flume (long-throated flume 4% error, other structures 10% error).
Duration of water delivery	The actual duration (in time) of water delivery to an area via the structure serving this area.	Is calculated from the difference between two time readings (error 2%).
Effective precipitation	Part of precipitation that can be used to replace irrigation water.	Calculated by the US Department of Agriculture method as given in CRIWAR. The error exceeds the error for precipitation and may be about 20%.
Evapotranspiration, ET	Consumption of water by a crop and the field on which the crop is grown. This water passes into the atmosphere. ET is one process within the hydrological cycle.	Potential ET is calculated from a variety of equations. Most widely tested is Penman–Monteith (error 20%). Actual ET can be measured by lysimeter (5% error) or calculated from remote sensing data (20% error).



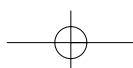
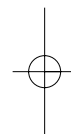
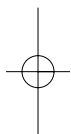
**Table 6.3.** *Continued.*

Parameter	Definition	Method by which term is measured or source of data
Fee	Money a water user has to pay to the water-delivering institution. The fee can be charged per volume delivered, per area irrigated or a combination of both.	The fee must be based on the service agreement. The value is not subject to a statistical error.
Flow rate	Volume of water passing a cross-section in a unit of time (usually second).	In m ³ /s or in l/s for low flows. Measured by a current meter (7% error) or a flow measurement flume (long-throated flume 4% error, other structures 10% error).
Groundwater depth	Distance from the soil surface in the field to the groundwater level.	The groundwater depth is measured by lowering a sounder or transducer into an observation well. The random error is about 0.02 m. A systematic error of 0.05 m can occur in the ground surface elevation.
Initial irrigable area	Irrigable area at the beginning of the considered period. This period may start, for example, after completion or rehabilitation of the system.	Is determined from the design (rehabilitation) drawings of the project. The error is related to the accuracy of the map (error 1% or more).
Irrigable area	Area (in ha) with physical infrastructure that enables the delivery of irrigation water.	Is determined from the design (rehabilitation) drawings of the project. The error is related to the accuracy of the map (error 1% or more).
Irrigated area	Part of the irrigable area to which irrigation water is actually delivered during the growing season of the irrigated crop.	Is determined from collected field surveys on actual crops grown in the area (error 20%) or from satellite images with 15 or 30 m pixel size (error 5%).
Irrigation interval	The actual time in between the start of two successive water deliveries.	Is calculated from the difference between two time readings (error 1%).
Potential evapotranspiration	$ET_{\text{potential}}$ is the evapotranspiration by a crop that is not stressed by water shortage during its growing season.	Calculated by the equation of Penman–Monteith (CRIWAR or CROPWAT). Error is about 20%.
Regulation interval	The time interval between the start of two successive control actions for a control structure or regulator.	Is calculated from the difference between two time readings (error 2%).

Continued

**Table 6.3.** *Continued.*

Parameter	Definition	Method by which term is measured or source of data
Salt yield	Quantity of salts (in kg/ha) mobilized by water draining from an area. The salt yield is discharged from the area with the surface drainage water and with the groundwater.	Is calculated from the product of the flow rate and salt concentration. The surface flow is measured with a structure (error depends on structure, 2% or more) and the groundwater flow is calculated from a model (error 10% or more). Salt concentration should be measured with a modern sensor (2% error).
Service level	Amount of things provided to an organization, a project or a group of people that it needs in order to function properly and effectively.	Should be based on the (national) water law, policies or other agreements. The value is not subject to a statistical error.
Set-point	The desired value of process output (or performance indicator).	See also benchmark.
Soil moisture	The percentage (by volume) of water in the soil. If the soil is saturated it quantifies the pore space (about 40%).	Point measurements can be taken by laboratory drying of a sample (5% error) or by <i>in situ</i> electric resistance measurement (3% error). If extrapolated to a larger area, the error increases rapidly to 25%. If measured with remote sensing, the error is 20% for the considered area (including the spatial distribution).
Target value	Same as benchmark.	See also set-point.
Users participation	Participation of a water user in the (functioning of) the irrigation or drainage system.	Because 'participation' cannot be defined clearly, the error is around 40%. Thus not sufficiently accurate for performance assessment.
Volume of water	Flow rate passing a control section during a given period (day, month, season), e.g. in m ³ /day, m ³ /month or m ³ /year.	If the volume of water is calculated from 15 or more individual flow measurements, the error will be reduced to the systematic error in these measurements (e.g. gates 5%, weirs 2%).



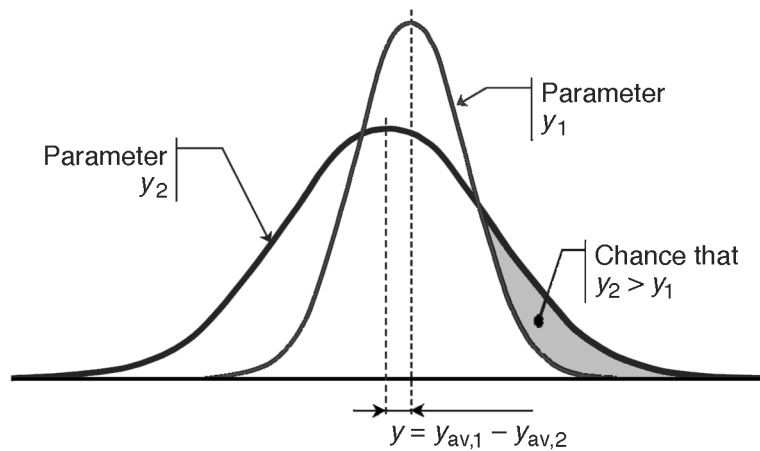
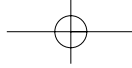


Fig. 6.12. Chance that one $y_2 > y_1$ while $y_{av,1} > y_{av,2}$.

For division, $y = y_1/y_2$, an approximate estimate of the confidence interval around y expressed in terms of CI is

$$CI = \sqrt{CI_1^2 + CI_2^2} \quad (7)$$

Example

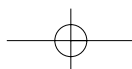
We want to compute the crop yield per cubic metre of water evapotranspirated by rice (the productivity). The yield of rice is based on interviews with farmers. From a statistically drawn sample, an average yield of 4000 kg/ha, $CI = 5\%$ is obtained.

An estimate of the areas under rice is 75 ha. This estimate is based on the system map and on inspection of the fields. There is uncertainty because some new houses have been built since the map was made, and it is difficult to know where some farmers have left some land fallow. So an estimate of a confidence interval of 7% is made for 'area under rice'.

Estimates of evapotranspiration for each crop in the area are based on climatic parameters following standard procedures. A value of 500 mm of ET_a for rice is obtained. There are many sources of uncertainty, including the measurement of climatic parameters, the degree of water stress during the growing season and errors associated with the means of estimating. An estimated confidence interval is set at $\pm 20\%$.

First, calculate the number of tonnes produced: $4000 \text{ kg/ha} \times 75 \text{ ha} = 300,000 \text{ kg}$ of rice. Substitution of the CI -values into Equation 6 gives

$$CI = \pm \sqrt{0.05^2 + 0.07^2 + 0.05^2 \times 0.07^2} = \pm 0.086$$



Then, calculate the volume of water (in m³) of evapotranspiration: 0.5 m × 75 ha = 375,500 m³. The *CI*-value of this volume is

$$CI = \pm \sqrt{0.02^2 + 0.07^2 + 0.02^2 \times 0.07^2} = \pm 0.073$$

Finally, divide the total rice yield by the cubic metres of water of evapotranspiration: productivity is 300,000/375,500 = 0.8 kg/m³. The *CI*-value is estimated through Equation 7 and gives a value of

$$CI = \pm \sqrt{0.086^2 + 0.073^2} = \pm 0.113$$

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