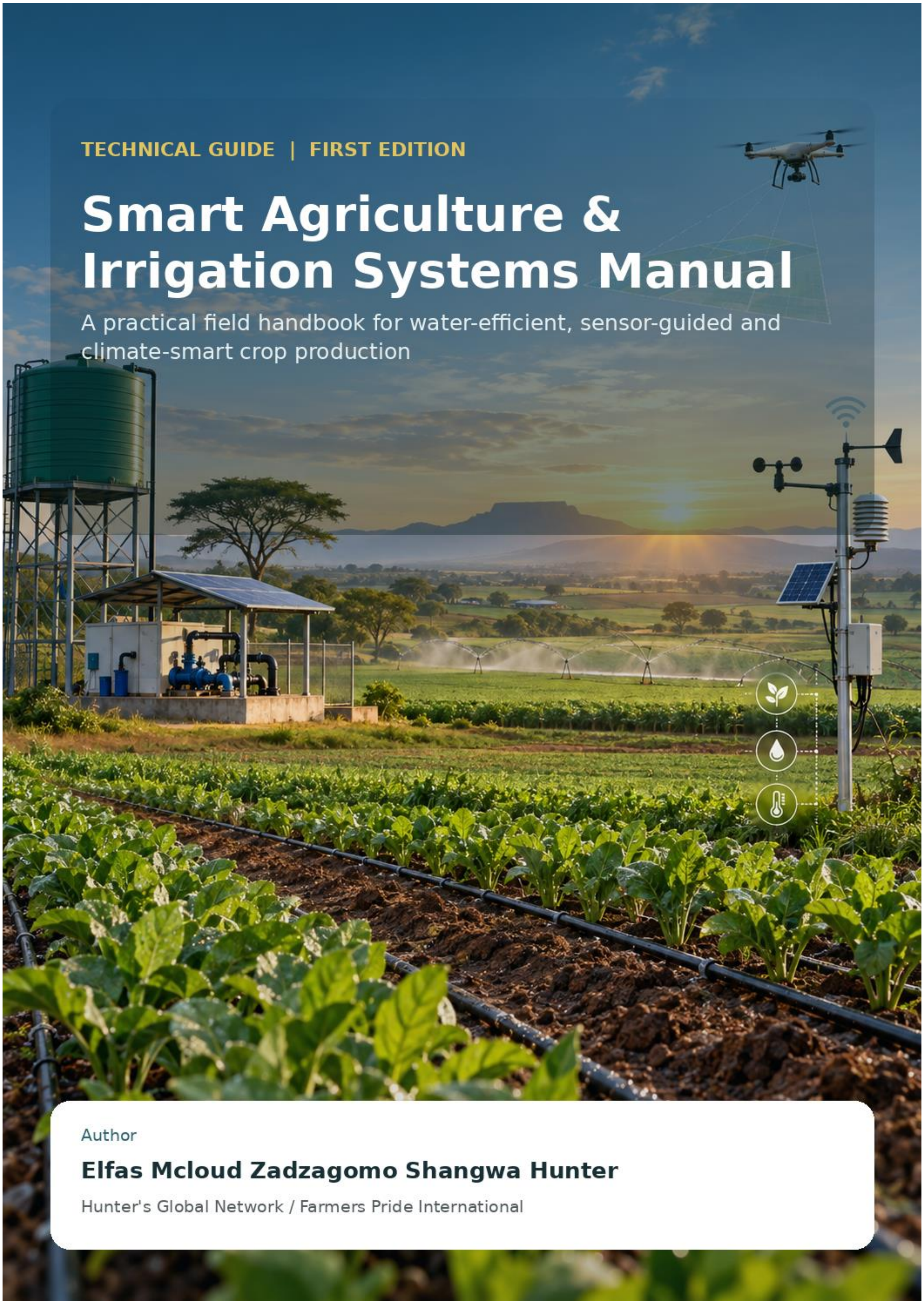

TECHNICAL GUIDE | FIRST EDITION

Smart Agriculture & Irrigation Systems Manual

A practical field handbook for water-efficient, sensor-guided and climate-smart crop production

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Purpose. To provide a practical, technically grounded handbook for planning, installing, operating and maintaining smart irrigation and climate-smart crop production systems. The guide is written for real farm use: decisions, calculations, inspections, commissioning and recordkeeping.

Technical note: values in examples are illustrative unless a specific source or standard is named. Final designs must be checked against local water quality, soil conditions, topography, crop requirements, equipment specifications and applicable engineering or electrical standards.

Foreword

Agriculture is moving from general rules of thumb toward measurable management. Water, nutrients, climate, soil and crop response can now be monitored with increasing precision. However, technology only creates value when it is connected to sound agronomy, correct hydraulic design and disciplined farm operations.

This manual therefore treats smart agriculture as a complete management system rather than as a collection of gadgets. A sensor is useful only if it is installed in the correct place, interpreted correctly and connected to a decision. An automated valve is useful only if the irrigation zone is properly designed. A fertigation unit is useful only if water quality, filtration and nutrient compatibility are controlled.

The goal is practical: build farms that use water deliberately, protect soil productivity, reduce avoidable losses and produce consistent crops under changing climate conditions.

Smart agriculture combines sound field engineering with digital monitoring and disciplined management.

Contents

PART I - SMART FARM FOUNDATIONS

Operating principle. The farm should be designed as a measurable system: each production block has a known area, crop, irrigation zone, water source, flow rate, pressure condition and management record. If one of these is unknown, control is weaker.

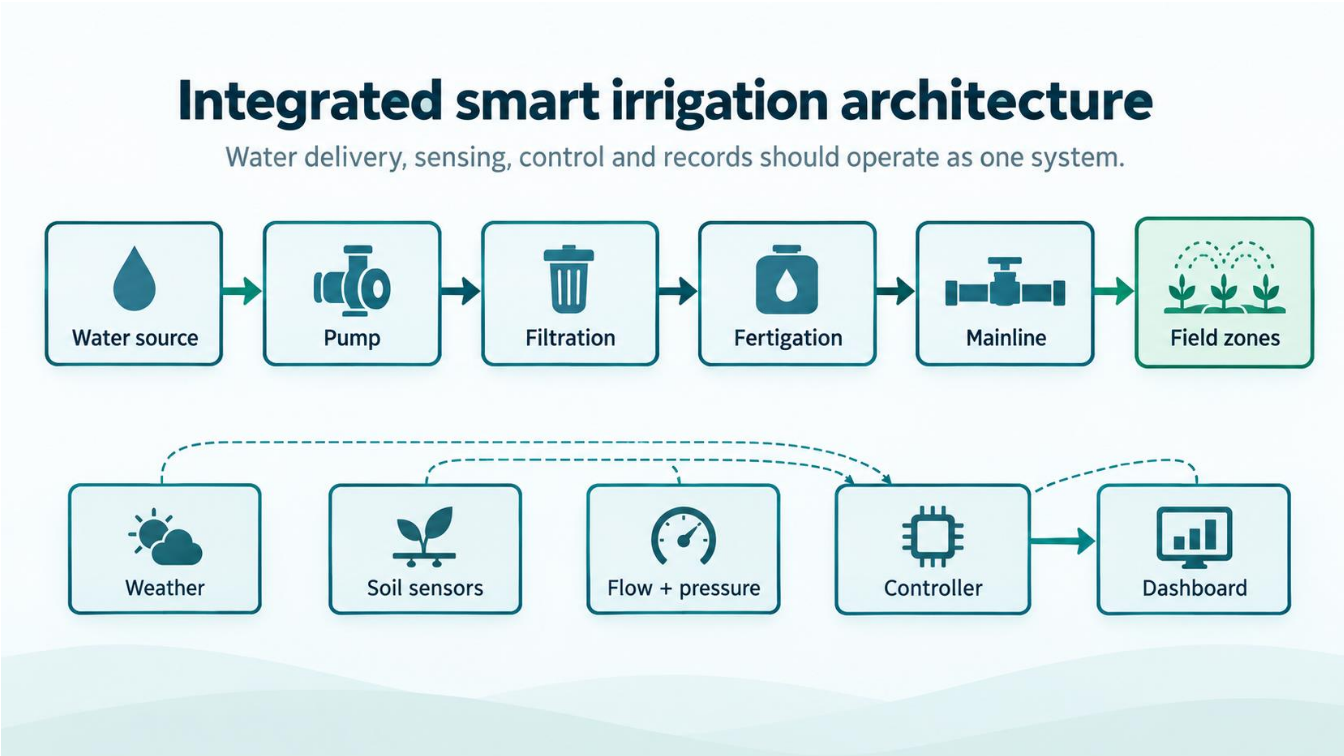

Figure 1. A smart irrigation system links water delivery, sensing, automation and farm records.

1. Smart Agriculture: What the System Must Achieve

Smart agriculture is the structured use of agronomy, engineering and information to improve farm decisions. The objective is not to automate every activity. It is to make critical decisions repeatable, measurable and easier to verify.

1.1 Five management questions

1. What is the crop trying to achieve at this growth stage?
2. What does the root zone currently contain in terms of water, air and nutrients?
3. What is the weather likely to remove from the crop-soil system?
4. What can the irrigation system apply uniformly within the available operating window?
5. How will the farm verify that the intended water and nutrient application actually occurred?

1.2 Core outcomes

- Consistent crop establishment and reduced early-stage stress.
- Controlled water use rather than uncontrolled runtime.
- Better fertiliser placement and reduced nutrient loss below the root zone.
- Early identification of leaks, blocked emitters, failed valves and abnormal pump behaviour.
- Improved resilience to heat, drought and variable rainfall.

- Records that allow managers to compare blocks, seasons and production methods.

A farm can use sophisticated sensors and still perform poorly if the hydraulic system is weak or staff do not respond to the data. Conversely, a simple but well-designed irrigation system with reliable records can achieve excellent control. Technology should therefore be added in layers according to need, management capacity and return on investment.

2. Farm Mapping, Zoning and Site Assessment

Every smart-farm project should begin with a field map. The map becomes the reference for irrigation design, crop records, sensor placement, labour instructions and maintenance. A block should not be defined only by convenience; it should reflect crop, soil, slope and hydraulic conditions.

A block-based layout makes irrigation, monitoring and records easier to control.

2.1 Minimum site survey

Survey item	What to record	Why it matters
Field area	Boundary, hectares, row direction	Sets crop population and water-volume calculations.
Elevation	High and low points, slope direction	Affects pressure and drainage.
Soil variability	Texture, depth, compaction, drainage	Determines water-holding and irrigation frequency.
Water source	Location, capacity, seasonal reliability	Defines system flow and storage needs.
Power	Grid, solar, generator or hybrid	Constrains pump choice and operating window.
Access	Roads, pump access, chemical handling area	Supports safe operation and maintenance.
Expansion	Future blocks or additional water source	Prevents undersizing of strategic infrastructure.

2.2 Irrigation zoning

Create separate irrigation zones where crops, soil textures or elevation differ materially. A single valve controlling a large mixed block is difficult to manage precisely. Smaller logical zones permit different runtimes, easier fault isolation and staged pumping.

Field rule. Do not combine steeply different elevations in one uncontrolled drip zone unless the design specifically manages the pressure variation with pressure-compensating emitters, regulation or other hydraulic measures.

3. Soil, Root Zones and Plant-Available Water

Irrigation management begins with the soil profile. Water applied at the surface moves differently through sand, loam and clay. The same irrigation runtime can therefore create a deep narrow wetting pattern in coarse soil or a wider shallower pattern in fine soil.

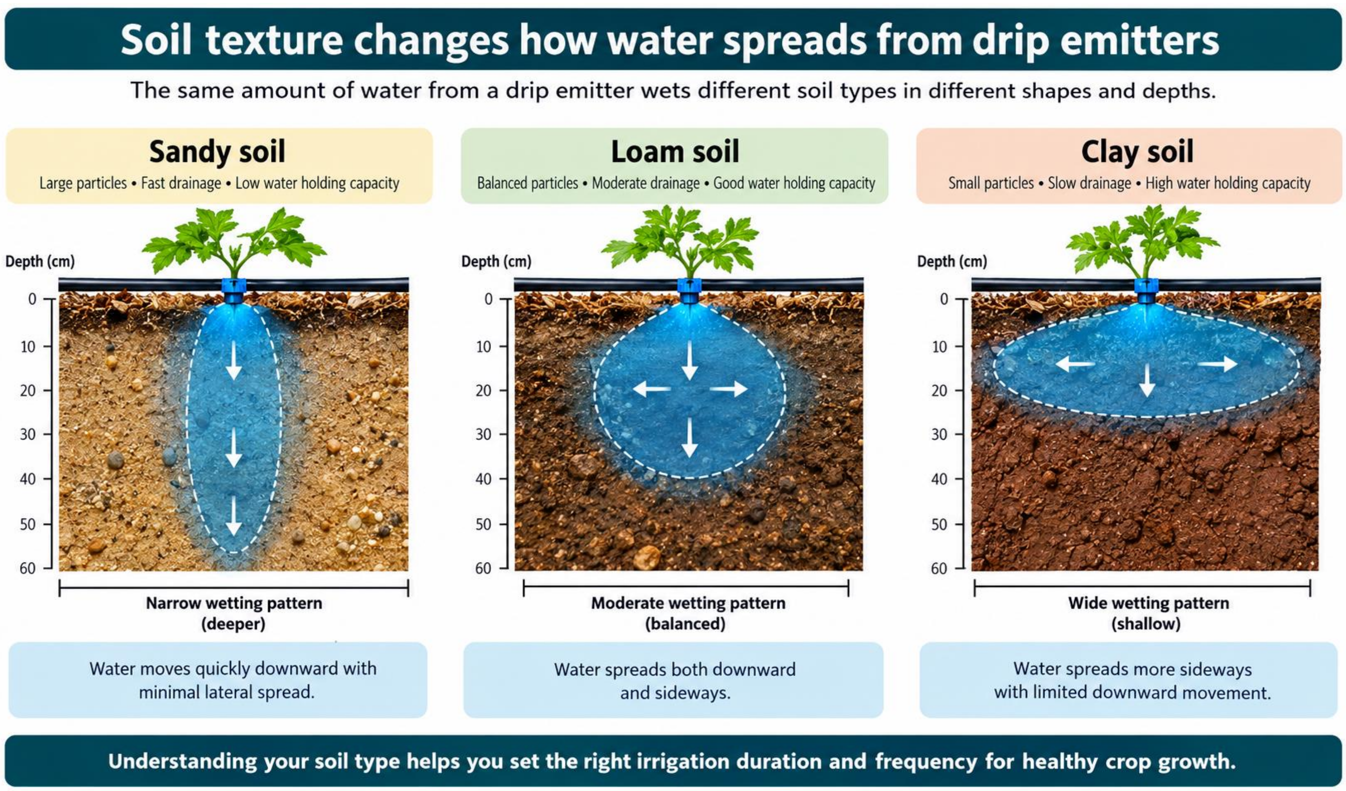

Figure 2. Typical wetting-pattern differences under drip irrigation. Actual shapes depend on soil structure, emitter discharge and irrigation duration.

3.1 Key soil-water terms

Term	Practical meaning
Saturation	Most pore space is filled with water; prolonged saturation can restrict root oxygen.
Field capacity	Water remaining after excess gravitational drainage has largely

Term	Practical meaning
	stopped.
Permanent wilting point	Soil-water level at which plants can no longer recover normal turgor.
Plant-available water	Water stored between field capacity and permanent wilting point.
Management allowable depletion	The chosen fraction of available water used before irrigation is triggered.

The objective is not to keep soil constantly wet. A healthy root zone must contain both water and oxygen. Excessive irrigation can reduce oxygen, encourage disease and move nutrients below active roots. Under-irrigation, especially during sensitive growth stages, can restrict growth and reduce yield or quality.

3.2 Field assessment

- Dig inspection pits before final design to confirm depth, layering and drainage.
- Observe whether compaction layers restrict roots or cause perched water.
- Use infiltration tests to understand how quickly water enters the soil.
- After drip installation, excavate across the wetting zone to verify actual spread rather than assuming a theoretical shape.

4. Water Sources, Storage and Security

The most technically advanced irrigation system cannot compensate for an unreliable water source. Before planting, establish the sustainable supply, the pumping rate, likely dry-season behaviour and the amount of storage required to cover interruptions or peak demand.

4.1 Source assessment

- Boreholes: conduct yield or pumping tests and monitor drawdown where appropriate.
- Dams and rivers: assess seasonal level change, sediment load and legal abstraction conditions.
- Municipal supply: confirm pressure, tariff, continuity and whether agricultural use is permitted.
- Harvested rainwater: calculate catchment area, expected rainfall capture, storage volume and first-flush management.

4.2 Storage sizing concept

Storage creates operating flexibility. It can separate a low but steady source from a higher short-term irrigation demand. For example, a borehole producing 4 cubic metres per hour continuously may replenish a reservoir while the field irrigation system operates at a higher flow for fewer hours. The storage calculation should include daily crop demand, refill rate, planned operating hours and a practical reserve.

Design caution. Do not size storage only from the physical tank cost. Consider how many hours or days of operational protection are required if a pump, borehole, grid supply or pipeline is interrupted.

5. Irrigation Water Quality

Water quality influences crop response, soil structure, fertigation performance and emitter reliability. A laboratory analysis should be completed before final system design and repeated when the source changes or problems appear.

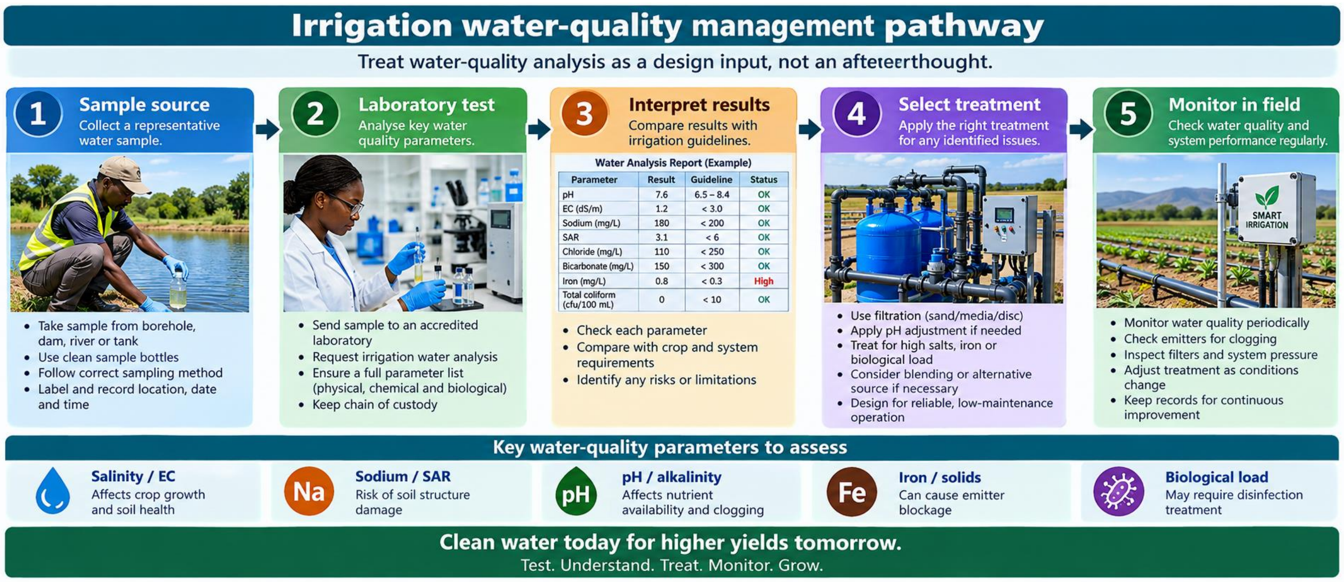

Figure 3. Water-quality management begins with representative sampling and ends with routine field monitoring.

5.1 Minimum analytical suite

- pH and electrical conductivity (EC).
- Total dissolved solids where relevant.
- Calcium, magnesium and sodium; sodium adsorption ratio (SAR) where appropriate.
- Chloride, bicarbonate, boron and nitrate where crop sensitivity or source conditions warrant.
- Iron, manganese and suspended solids where emitter blockage is a concern.
- Microbiological loading for surface or recycled water where biological clogging is likely.

5.2 Screening salinity risk

FAO guidance commonly uses irrigation-water electrical conductivity as a first screening indicator. Water below about 0.7 dS/m is generally considered to have no salinity restriction for many situations; roughly 0.7-3.0 dS/m indicates increasing management requirements, and values above about 3.0 dS/m can create severe restrictions depending on crop, soil, leaching and drainage. These are screening ranges, not universal crop limits.

Indicator	Lower concern	Increasing concern	High concern / specialist review
ECw (dS/m)	< 0.7	0.7-3.0	> 3.0
TDS (mg/L)	< 450	450-2,000	> 2,000

Always interpret salinity together with crop tolerance, soil drainage and leaching capacity. Sodium risk also depends on the interaction between SAR and EC, so it should not be judged from sodium concentration alone.

PART II - IRRIGATION ENGINEERING

6. Selecting an Irrigation Method

Method selection should be based on crop geometry, water quality, soil, topography, available pressure, labour, energy and the required level of control. No irrigation method is automatically best for every farm.

Method	Strengths	Limitations / watch points
Drip / microirrigation	High application efficiency; precise fertigation; low leaf wetting; easy zoning and automation.	Requires filtration, pressure control and regular flushing; emitters can clog.
Micro-sprinkler	Useful for orchards, nurseries and wider wetted area.	More evaporation and wind sensitivity than drip.
Solid-set / portable sprinkler	Flexible and familiar; can cover broad crop types.	Higher operating pressure; wet foliage; wind distortion.
Centre pivot / linear	Efficient mechanised coverage on large fields.	Capital intensive; field geometry and maintenance requirements.
Surface irrigation	Low technology and can suit some soils and water supplies.	Lower precision; levelling and runoff management are critical.

For many high-value botanical, vegetable and medicinal crops, drip irrigation is attractive because it targets the root zone and supports frequent fertigation. However, the expected benefit depends on correct design and maintenance.

7. Pumps, Energy and Total Dynamic Head

A pump is selected for a required flow at a required head. Selecting only by motor size or maximum advertised flow is a common mistake. The actual duty point must account for elevation, pipe friction, filtration losses, fittings and the pressure required at the field.

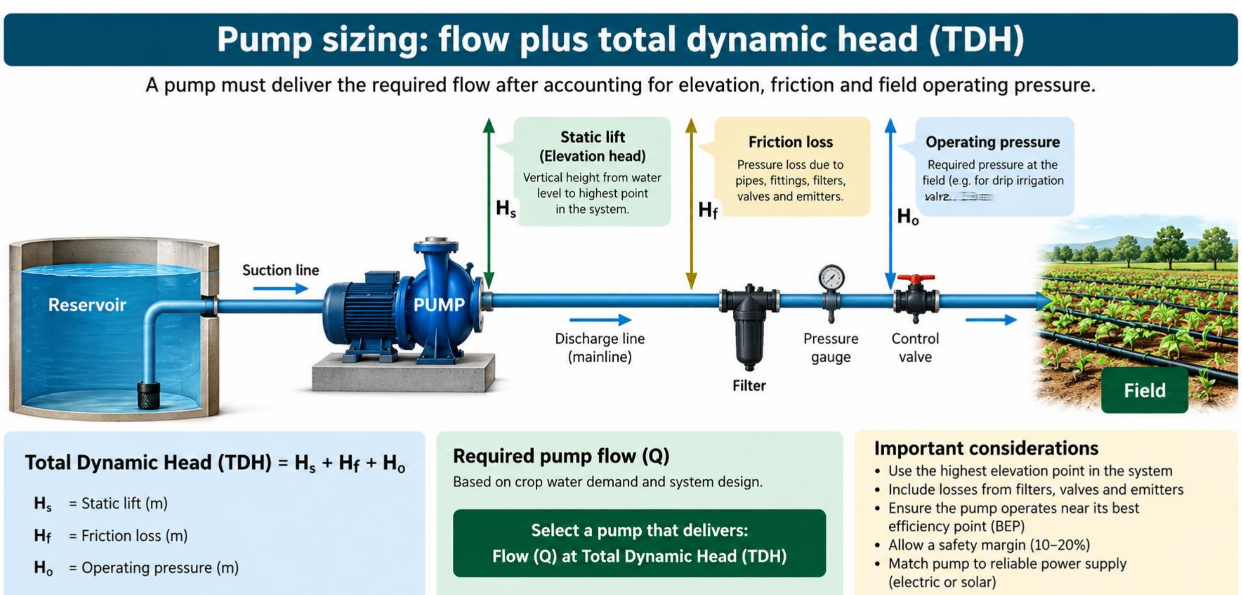

Figure 4. Pump sizing must account for flow and total dynamic head, not flow alone.

7.1 Total dynamic head concept

A simplified design expression is: Total Dynamic Head = static lift + friction losses + operating pressure head + losses through filters, valves and fittings. Suction conditions and source-water level must also be checked.

7.2 Energy choices

Energy source	Advantages	Management considerations
Grid electricity	Simple operation where reliable; easy automation.	Tariffs, outages and motor protection.
Solar PV	Low operating fuel cost; well suited to daytime pumping and storage.	Variable solar resource; battery or reservoir strategy may be required.
Diesel	Portable and independent of grid.	Fuel cost, maintenance, emissions and theft risk.
Hybrid	Improves resilience and operating flexibility.	Higher complexity and control requirements.

Pump stations should be designed for safe access, clear pressure monitoring and easy filter maintenance.

8. Drip Irrigation Design

A drip system should deliver the planned application uniformly across all active laterals while operating within the emitter and pipe pressure limits. Design begins with crop spacing and works backward through emitter demand, zone flow, pipe sizing and pump duty.

8.1 Design sequence

6. Define the crop row spacing, plant spacing and block area.

7. Select emitter type, emitter spacing and nominal discharge suited to crop and soil.
8. Calculate the number of emitters operating in each zone.
9. Calculate zone flow from emitter discharge multiplied by active emitters.
10. Check lateral length and pressure variation against manufacturer limits.
11. Size sub-mains and mains to limit friction loss and maintain acceptable velocity.
12. Confirm filtration, pressure regulation, flushing and fertigation requirements.
13. Confirm the pump can meet the combined flow and pressure duty.

8.2 Worked example - one hectare block

Illustrative example only: A 1 ha field has 1.0 m row spacing, 0.30 m emitter spacing and 1.6 L/h emitters. Row length is 100 m. The field contains about 100 rows and roughly 333 emitters per row, or approximately 33,300 emitters. If the entire hectare irrigates at once, theoretical emitter flow is about 53.3 m3/h. This would be a large instantaneous flow, so the field may be divided into smaller valve zones depending on pump capacity and desired management.

Why zoning matters. Dividing the block into four similar zones would reduce the theoretical operating flow to about one quarter of the full-block flow, while increasing the total hours required to irrigate all zones. The final zoning choice balances pump size, available hours, pressure uniformity and automation.

9. Hydraulics, Pressure Zoning and Valves

Water loses pressure as it moves through pipes, fittings, filters and valves. Elevation also changes pressure: lower points generally gain pressure and higher points lose it. Good hydraulic design therefore controls both friction and elevation differences.

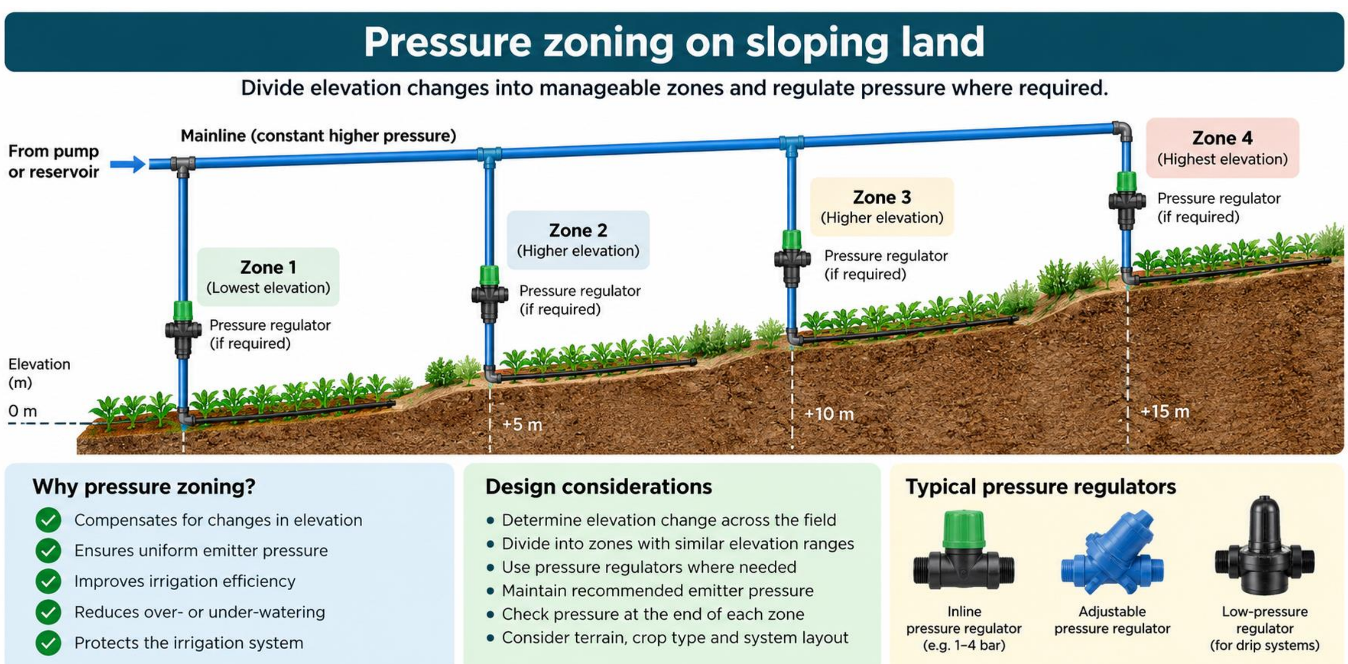

Figure 5. Pressure zoning helps maintain consistent emitter performance on sloping land.

9.1 Practical controls

- Use pressure regulators where downstream pressure must be stabilised.
- Install gauges before and after filters to observe pressure loss.

- Provide isolation valves so faults can be repaired without shutting down the entire farm.
- Use air-release or vacuum-relief equipment where high points or drainage conditions can trap air or collapse pipes.
- Place flush points at lateral and sub-main ends.

Do not assume that the pressure at the pump is the pressure at the last emitter. Commissioning should measure pressure at representative upstream, middle and downstream points under normal operating flow.

10. Filtration, Flushing and Clogging Control

Emitter clogging can be physical, chemical or biological. A good filtration strategy is based on the water source and the emitter opening rather than on a generic filter size.

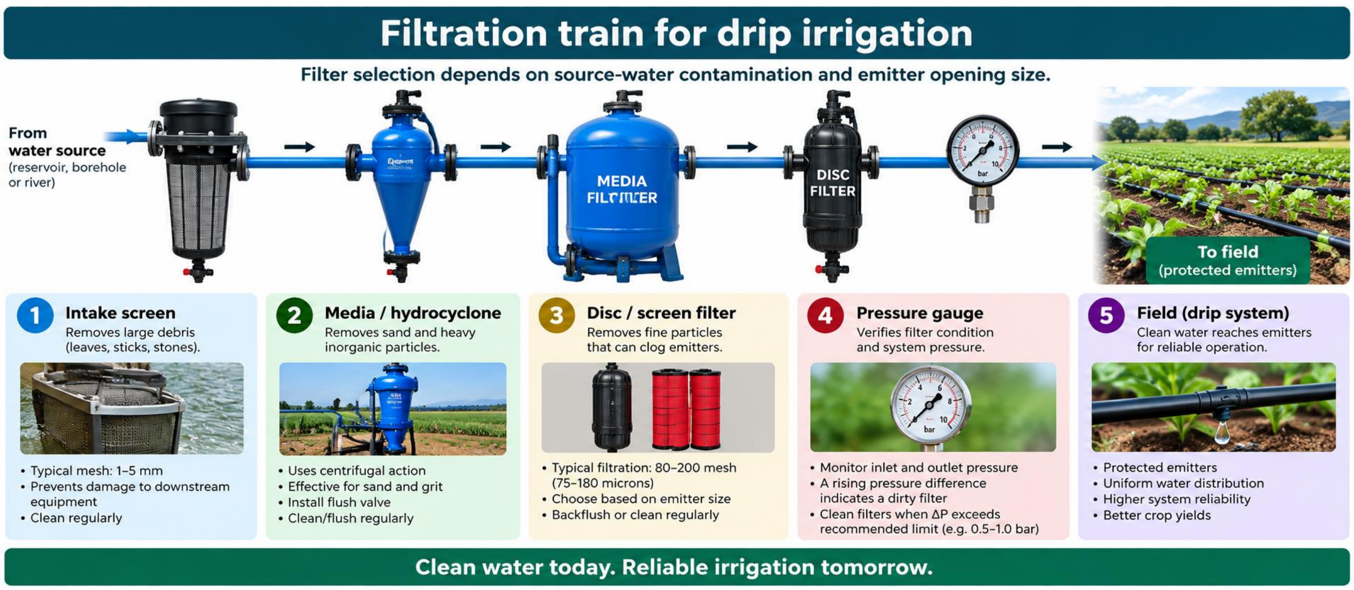

Figure 6. A typical filtration train progressively protects the drip system from different forms of contamination.

10.1 Clogging categories

Category	Examples	Control approach
Physical	Sand, silt, clay, organic debris	Source screening, settling, hydrocyclone/media filtration, screen/disc filtration.
Chemical	Mineral precipitation, iron deposits	Water analysis, pH management, treatment where justified, regular flushing.
Biological	Algae, bacteria, biofilm	Source protection, appropriate treatment, line flushing and sanitation procedures.

Filter pressure differential is a useful operating signal. A rising differential usually indicates loading and the need for cleaning or backwashing. Always follow the filter manufacturer’s allowable differential and maintenance procedure.

10.2 Flushing programme

- Flush new pipelines before connecting emitters or operating sensitive equipment.
- Flush mains and sub-mains after repairs, fertiliser incidents or heavy contamination.
- Flush laterals at a velocity sufficient to move settled material; practical requirements depend on pipe diameter and manufacturer guidance.
- Record flushing frequency so recurring contamination can be traced back to source-water or treatment problems.

11. Irrigation Scheduling and Water-Balance Methods

Scheduling determines when to irrigate and how much to apply. The strongest approach combines crop water use, recent rainfall, soil-water measurements, growth stage and system capacity. Fixed daily runtimes should be treated as provisional rather than permanent.

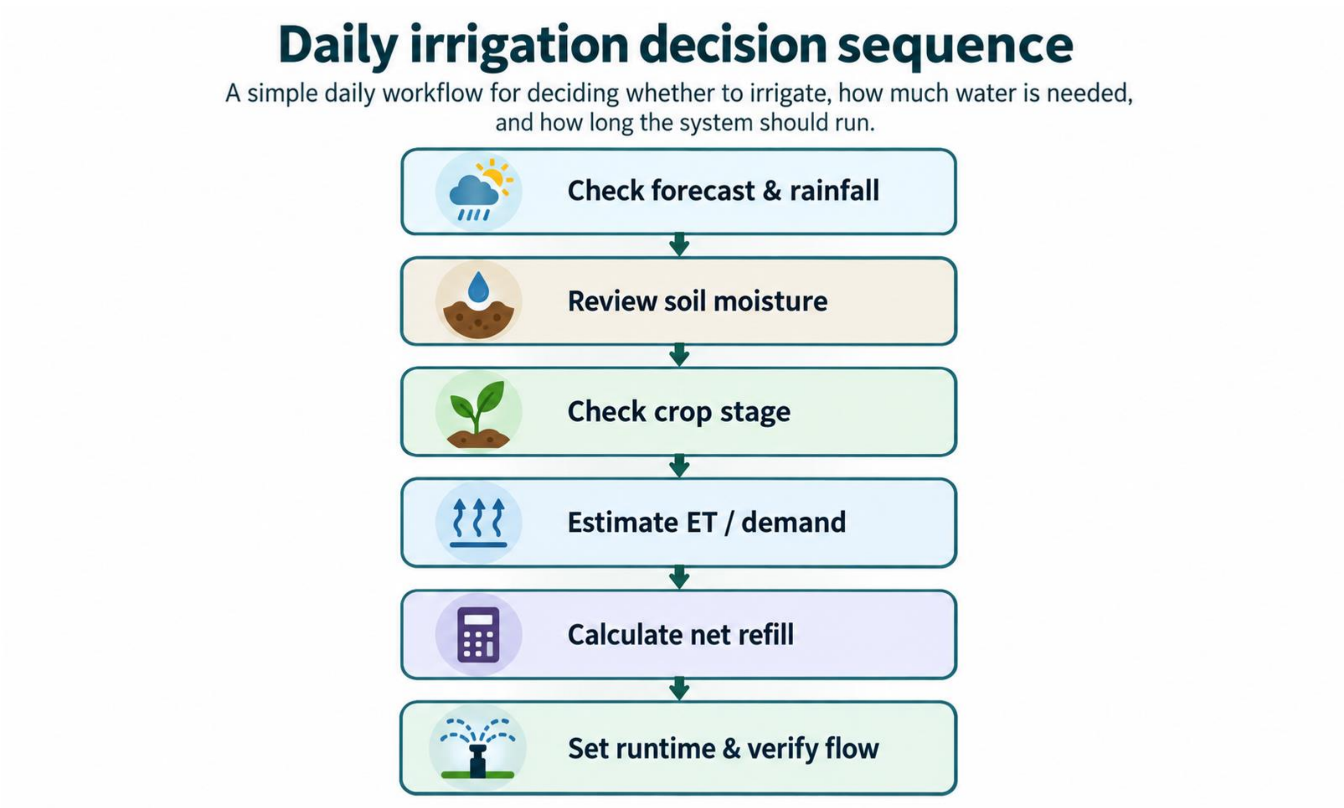

Figure 7. A repeatable daily decision sequence prevents irrigation from becoming a guess.

11.1 Evapotranspiration method

A common framework is $ETc = Kc \times ETo$, where ETo is reference evapotranspiration from weather data and Kc is a crop coefficient representing crop stage and canopy. The resulting crop evapotranspiration can be converted to a water volume because 1 mm applied over 1 hectare equals 10 cubic metres.

11.2 Worked daily water-volume example

Suppose estimated crop water use is 4.5 mm/day over 1 ha. Net crop water use is 45 m3/day. If the irrigation application efficiency used for planning is 90%, gross irrigation demand is approximately 45 / 0.90 = 50 m3/day. If the available irrigation window is 8 hours, the average required delivery rate is about 6.25 m3/h. This example does not include effective rainfall, leaching requirements or other project-specific adjustments.

11.3 Scheduling checks before starting a zone

- Has meaningful rainfall occurred since the previous irrigation?
- Does sensor data show the active root zone is approaching the chosen refill threshold?
- Is the crop at a sensitive establishment, flowering, bulking or harvest stage?
- Is the forecast likely to increase or reduce demand?
- Can the planned application be delivered without pushing water below the active root zone?

PART III - SMART MONITORING AND AUTOMATION

12. Soil-Moisture Sensors

Soil-moisture sensors convert an invisible root-zone condition into a management signal. They should support, not replace, field observation. Sensor type, placement, soil contact and interpretation determine whether the data are useful.

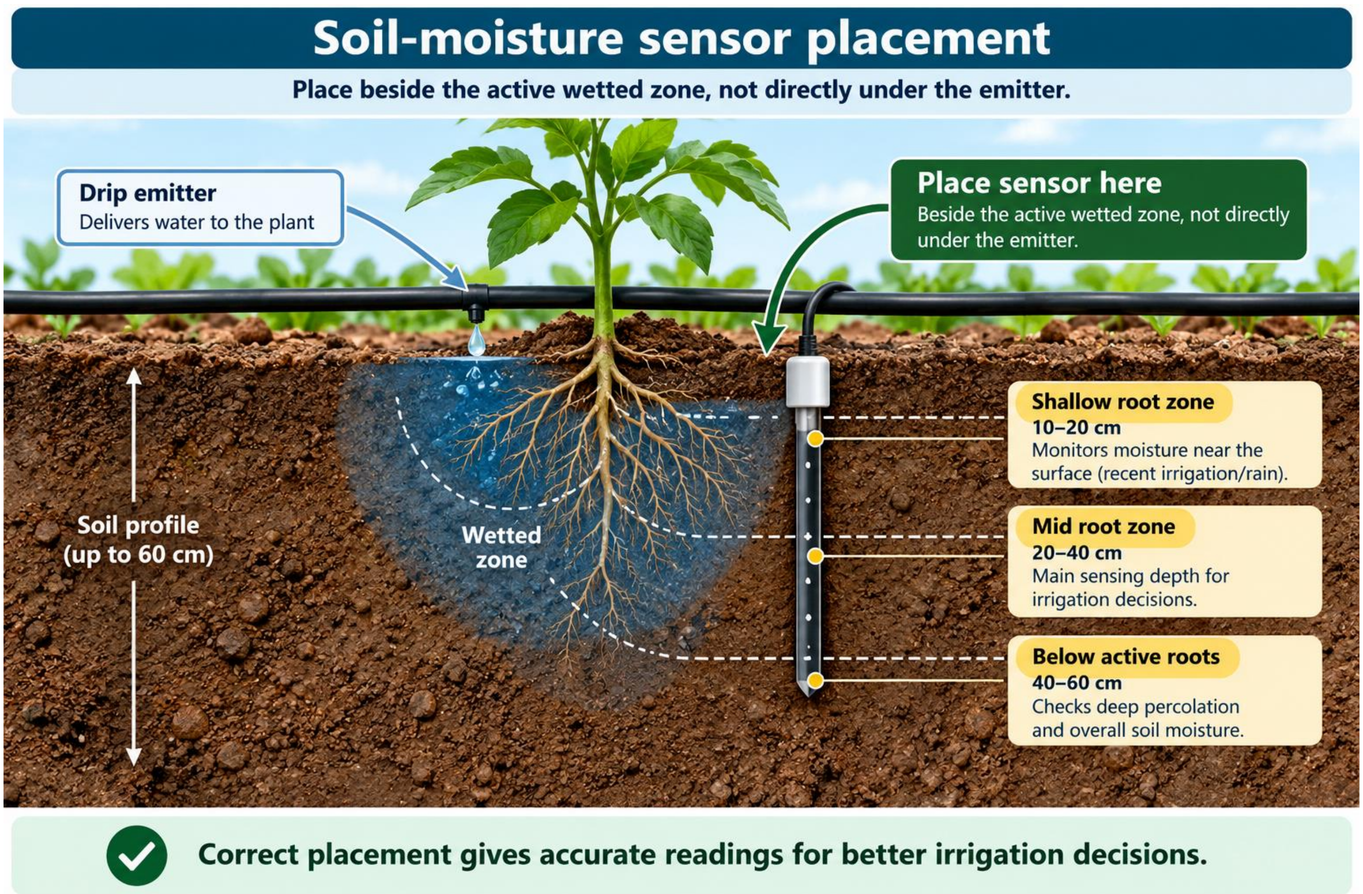

Figure 8. Multi-depth sensor placement helps show whether water is remaining shallow, filling the root zone or moving too deep.

12.1 Major sensor approaches

Approach	What it indicates	Strengths	Watch points
Volumetric water content	Water volume within a soil volume	Fast response; useful for trend and profile monitoring.	Requires correct calibration/interpretation for soil conditions.
Soil-water tension / matric potential	How strongly water is held by soil	Directly relates to plant extraction difficulty.	Operating range and maintenance vary by sensor type.
Manual feel and appearance	Approximate moisture status	Low cost; excellent verification skill.	Subjective and less suited to continuous remote monitoring.

12.2 Placement principles

- Use representative management zones rather than convenient locations near roads.
- Install at more than one depth so over-irrigation can be detected.
- Ensure good soil contact and avoid air gaps around probes.
- Place sensors relative to the emitter and root zone consistently across comparison sites.
- Label and map every sensor location and installation depth.

Interpret trends, not single numbers. A sudden reading can be caused by irrigation, rainfall, poor contact, salinity effects or sensor fault. Compare several days of data with irrigation logs and field inspection before changing a major schedule.

13. Weather Stations, ET and Climate Data

Weather data are most valuable when they lead to a farm action. Rainfall can reduce scheduled irrigation, high wind can change sprinkler performance, and periods of high temperature and solar radiation can raise crop water demand.

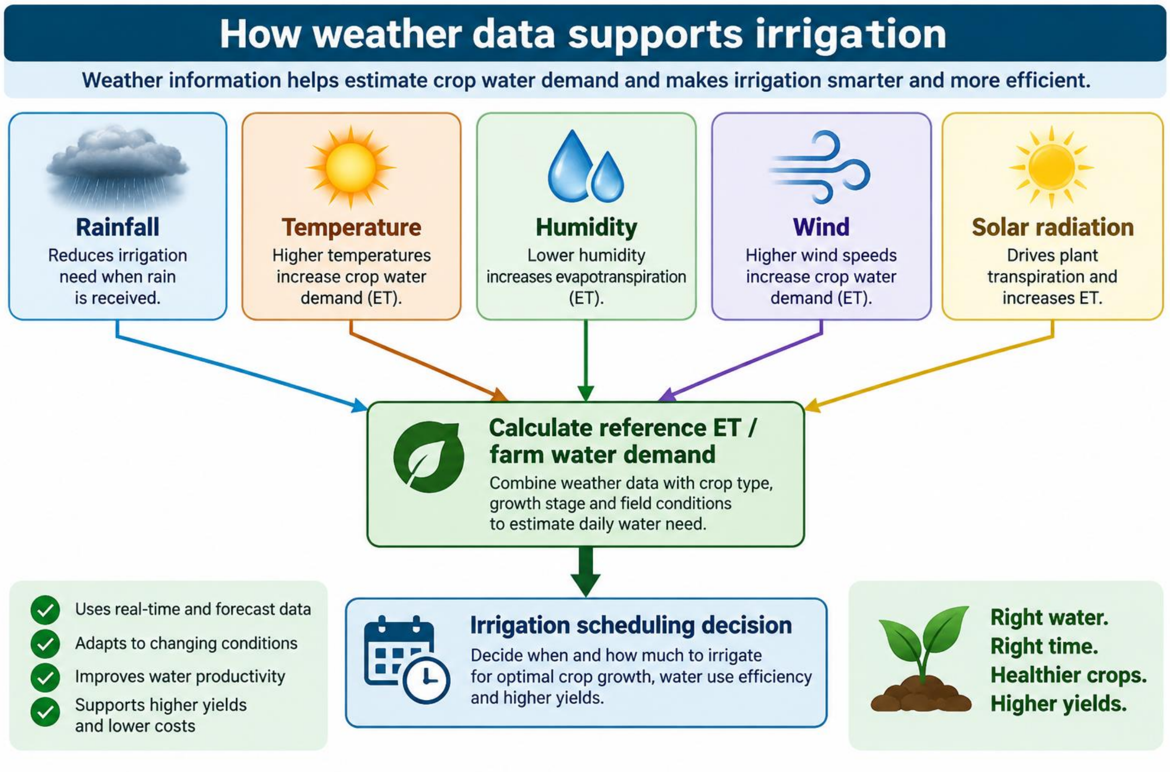

Figure 9. Weather observations feed evapotranspiration estimates and irrigation decisions.

A field weather station should be placed in a representative, open location and maintained like any other instrument.

13.1 Installation principles

- Keep sensors away from buildings, large trees, heat sources and irrigation spray that would bias measurements.
- Mount and level instruments according to manufacturer instructions.

- Inspect rain-gauge funnels, radiation sensors and moving parts routinely.
- Maintain a backup record of critical data or use a platform that can export records.

14. Flow, Pressure and System Diagnostics

A smart irrigation system needs direct measurements of what the water is doing. Flow and pressure measurements often reveal problems earlier than crop symptoms.

14.1 What changing readings can mean

Observed change	Possible causes	First checks
Flow higher than normal	Leak, open flush valve, broken lateral, more zones active	Walk the zone, confirm valve status and inspect mains.
Flow lower than normal	Blocked filter, partly closed valve, pump issue, clogging	Compare filter differential, pump pressure and zone valves.
Pressure low + flow high	Major leak or excessive open area	Isolate sections and inspect pipe network.
Pressure high + flow low	Restriction, closed valve or blockage	Check filter, valve position and downstream obstruction.
Normal head pressure but dry end rows	Lateral pressure loss, blockage, uneven elevation	Measure end pressure and perform emitter discharge checks.

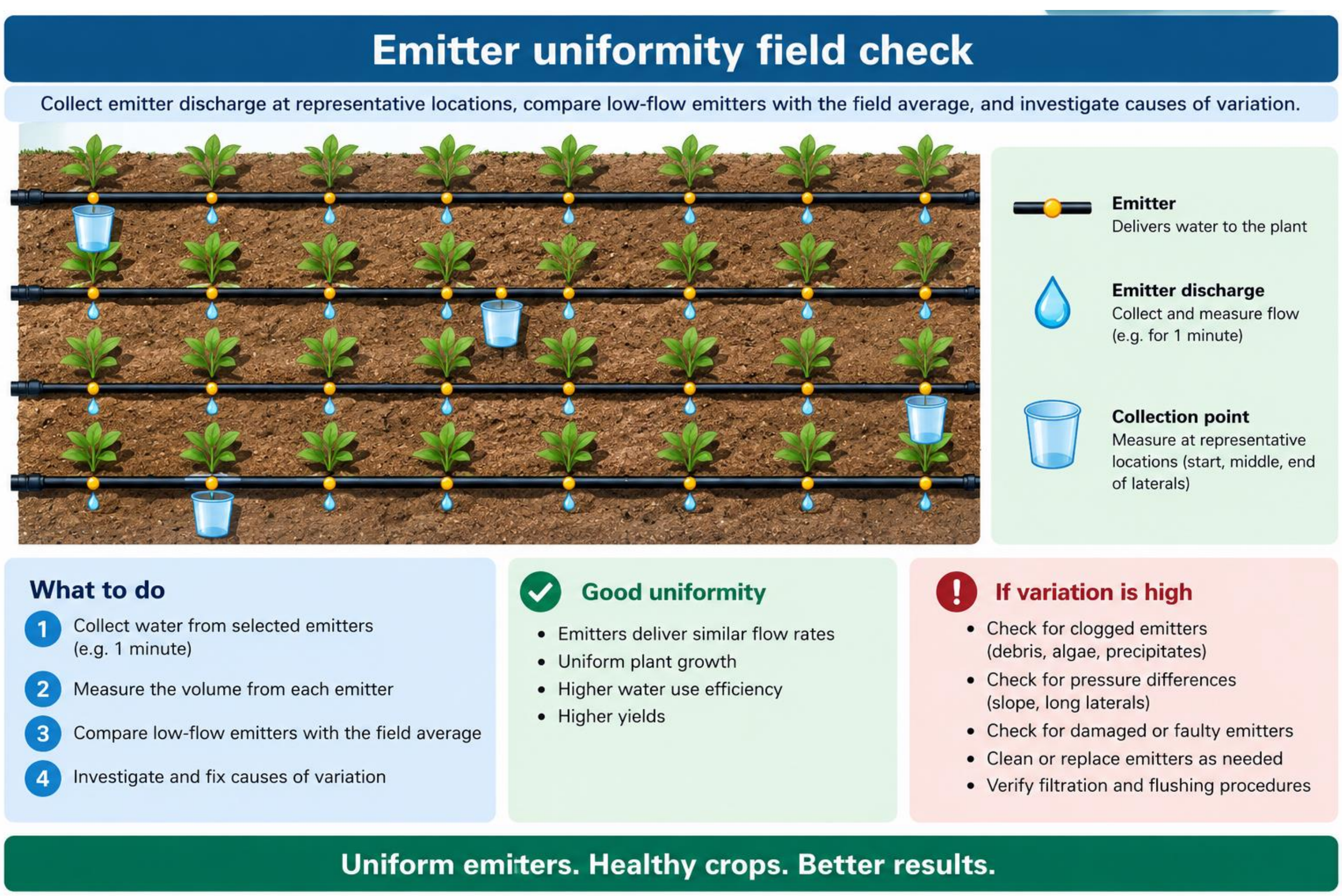

Figure 10. A simple emitter discharge test can identify field non-uniformity and guide corrective action.

14.2 Uniformity test method

14. Select representative laterals near the beginning, middle and end of the zone.
15. Collect water from a consistent set of emitters for the same measured time.
16. Convert collected volume to comparable discharge values.
17. Calculate the average discharge and the average of the lowest quarter of measurements.
18. Compare the low-quarter average with the overall average and investigate patterns of low flow.

15. Automation, IoT and Remote Control

Automation ranges from a timer opening one valve to a fully connected system combining weather, moisture, flow, pump status and remote alerts. The best architecture separates field equipment, measurement, control and decision layers so that faults can be diagnosed logically.

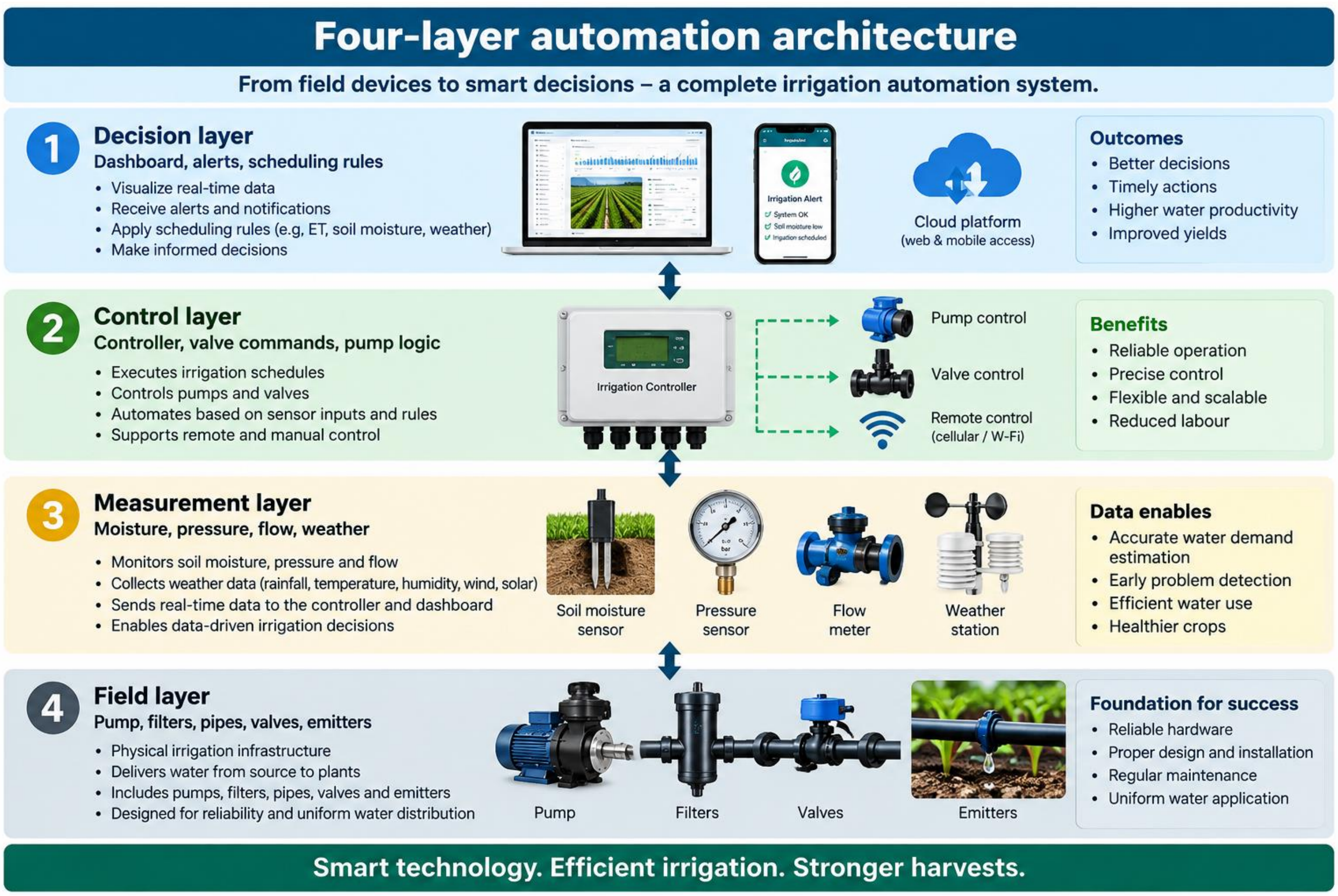

Figure 11. Smart-farm automation is most reliable when each layer has a clear role.

15.1 Useful automation functions

- Scheduled zone opening and closing.
- Pump start/stop interlocks and dry-run protection.
- High- and low-flow alarms.
- Pressure-loss alarms across filters.
- Rainfall or soil-moisture hold conditions.
- Remote valve status and manual override.
- Daily water-use reporting by zone.

Automation should fail safely. If communication is lost, the farm should have a defined operating state, local manual control and a documented recovery procedure. Critical irrigation should not depend on a single unprotected communication link.

PART IV - NUTRIENT AND CROP MANAGEMENT

16. Fertigation Systems and Nutrient Delivery

Fertigation delivers soluble nutrients through irrigation water. It can improve timing and placement, but it also introduces chemical compatibility, injection accuracy and system-protection requirements. Backflow prevention and safe chemical handling are essential.

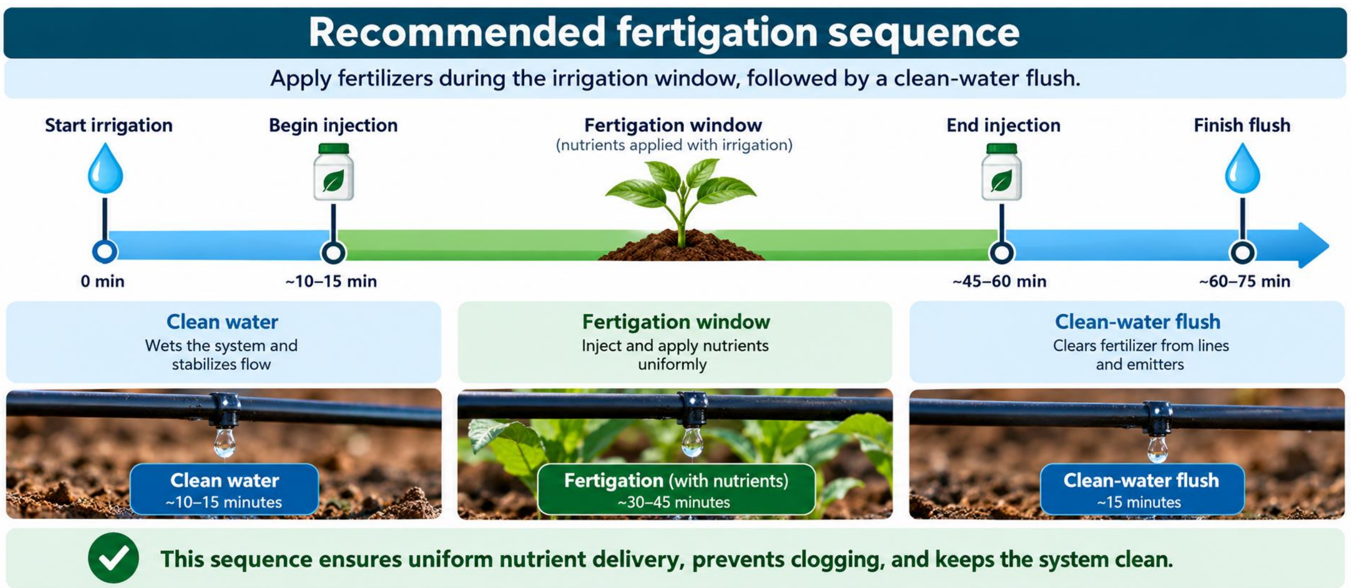

Figure 12. A practical fertigation event begins and ends with clean water so the system is pressurised first and flushed afterward.

16.1 Fertigation operating sequence

19. Confirm the correct irrigation zone and normal flow and pressure.
20. Ensure the selected fertiliser is completely soluble and compatible with the source water and other products.
21. Pre-irrigate with clean water so the system is fully pressurised.
22. Inject at a controlled rate while all emitters are operating normally.
23. Complete injection early enough to allow clean-water flushing before shutdown.
24. Record product, quantity, tank volume, injection time, zone and operator.

16.2 Compatibility and precipitation

Concentrated fertilisers can react with each other or with irrigation water. Calcium-containing products, phosphates and sulphates are common examples where incompatible mixing can produce precipitates. When uncertainty exists, use separate stock tanks, compatible injection points or a jar test under qualified agronomic guidance.

Never use the irrigation network as a chemical experiment. Any acidification, chlorination or corrective water treatment must use suitable equipment, personal protective equipment, backflow protection and a documented procedure. Follow product labels and local regulations.

17. Crop-Specific Application Notes

Crop water demand changes with climate, plant density, growth stage, soil and production system. The notes below are management priorities rather than fixed irrigation recipes. Local trials and calibrated scheduling should determine final runtimes.

Crop	Irrigation priorities	Smart-monitoring focus
Moringa	Strong establishment watering; avoid chronic waterlogging; maintain consistent moisture under intensive leaf production.	Track root-zone depletion between harvest cycles and compare irrigation with regrowth.
Hibiscus	Avoid severe stress during canopy development, flowering and calyx filling; maintain drainage.	Use moisture trends and weather demand during flowering and harvest windows.
Turmeric	Maintain reliable moisture in well-drained soil; mulching can reduce evaporation and temperature swings.	Monitor shallow and mid-root-zone moisture to prevent long dry periods.
Garlic	Even moisture during establishment and bulb development; avoid prolonged wetness near maturity.	Use shorter controlled events and watch disease-prone wet conditions.
Black carrot	Uniform moisture supports root shape and quality; avoid alternating severe drying and saturation.	Use consistent soil-moisture thresholds and uniformity checks across beds.

17.1 High-density moringa production

Where moringa is grown at high density for leaf or biomass production, the irrigation system must be matched to the unusually high plant population and repeated harvest cycle. Designers should calculate water demand from planted area and crop response rather than multiplying a notional demand by individual tree count. Drip-line spacing, emitter spacing and fertigation strategy should be validated in field blocks before expansion.

After each harvest or cutting cycle, monitor regrowth, root-zone moisture and nutrient response. If new growth is slow while soil remains wet, the issue may be nutrition, compaction, temperature or root health rather than insufficient irrigation.

PART V - INSTALLATION, OPERATIONS AND QUALITY CONTROL

18. Installation and Commissioning

Commissioning is the point where a drawing becomes an operating irrigation system. Every valve, pressure zone, filter, sensor and controller function should be tested under realistic flow conditions before the system is accepted.

18.1 Installation sequence

25. Survey and mark mains, sub-mains, blocks, valves and control points.
26. Install pump, power system and primary protection equipment.
27. Install mainline, sub-mains and valve manifolds.
28. Install filtration, fertigation and monitoring instruments.

29. Flush mains and sub-mains before connecting sensitive downstream components.
30. Install laterals and emitters according to design spacing and orientation.
31. Pressure-test, repair leaks and flush laterals.
32. Program controller, label valves and verify manual override.
33. Install sensors and map exact positions and depths.
34. Run each zone and record baseline pressure and flow values.

18.2 Commissioning acceptance sheet

Item	Verification	Baseline / result
Pump duty	Required zone flow achieved at operating pressure	___________
Filter condition	Clean differential recorded	___________
Zone pressure	Head, middle and end readings acceptable	___________
Zone flow	Metered flow compared with design	___________
Leak test	No visible leaks under operating pressure	Pass / Fail
Flushing	Mains, sub-mains and laterals flushed	Complete / Incomplete
Controller	All programs, interlocks and manual functions tested	Pass / Fail
Sensors	Positions, depths and IDs recorded	Complete / Incomplete
Training	Operator startup, shutdown and emergency steps demonstrated	Complete / Incomplete

19. Preventive Maintenance

Maintenance should be planned around risk, not only around breakdowns. The highest-cost irrigation failures often begin as small changes in pressure, flow, filter loading or emitter discharge that were not acted upon.

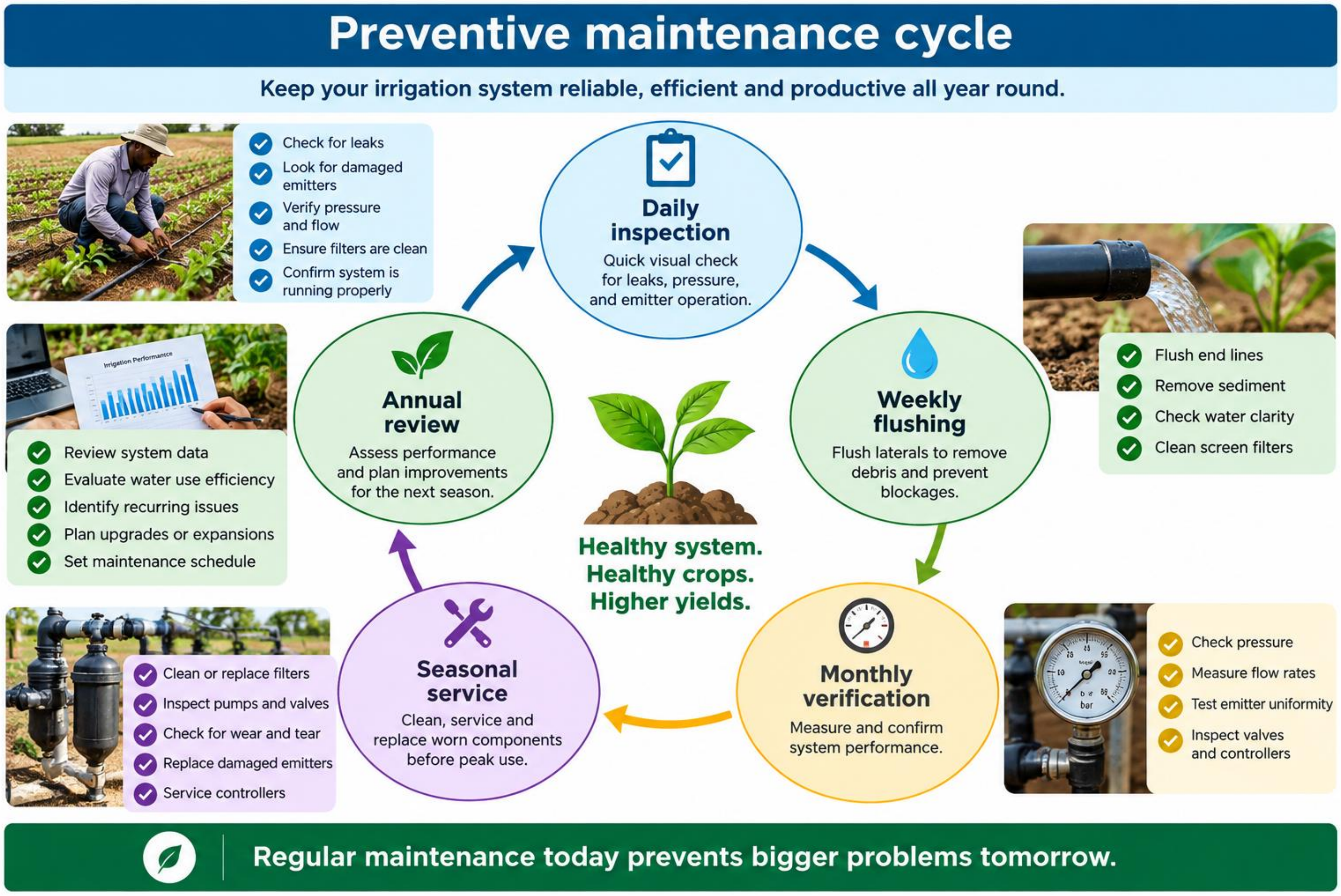

Figure 13. Preventive maintenance works best as a repeating cycle rather than an emergency response.

19.1 Suggested maintenance calendar

Frequency	Tasks
Each irrigation day	Check source level, pump sound, leaks, zone pressure, flow and controller alarms.
Weekly	Inspect and clean filters as required; flush representative laterals; inspect valves and exposed pipe.
Monthly	Compare current pressure/flow with commissioning baseline; test selected emitter discharge; inspect sensor condition.
Seasonally	Service pump and power equipment; clean storage structures; inspect mainline supports; review calibration and settings.
Annually / before season	Review water analysis, irrigation design assumptions, expansion requirements and operator training.

Keep spare gaskets, connectors, emitters, repair couplings, valve parts and filter elements appropriate to the installed system. Downtime during hot weather can cause crop damage much faster than during cool conditions.

20. Troubleshooting

Troubleshooting should move from measurement to cause. Do not immediately change irrigation runtime because crops look stressed. First determine whether the problem is water supply, pressure, distribution, roots, nutrition, temperature, disease or sensor error.

Symptom	Likely causes	Diagnostic sequence
Whole zone dry	Valve failure, pump issue, controller output, closed isolation valve	Check controller command -> valve actuation -> upstream pressure -> zone flow.
End of laterals dry	Excessive lateral length, low inlet pressure, clogging, elevation	Measure inlet/end pressure -> flush -> sample emitter flow -> review design.
Filter blocks rapidly	High solids, algae, undersized filter, damaged intake	Inspect source -> check prefiltration -> verify filter capacity -> adjust maintenance.
Pressure oscillates	Air, pump control instability, varying open zones	Inspect air release -> pump controls -> valve sequence.
Crop yellowing despite irrigation	Nutrient imbalance, root disease, waterlogging, salinity	Check root zone -> review fertigation -> test soil/water -> inspect drainage.
Sensor shows wet but plants wilt	Poor sensor placement/contact, salinity effect, roots elsewhere	Manual soil check -> inspect roots -> verify sensor installation/calibration.

20.1 The baseline principle

The best troubleshooting reference is the system's own commissioning baseline. If a zone originally operated at a certain pressure and flow and the values later change materially, the direction of change provides a strong diagnostic clue. This is why baseline records should be protected and retained.

21. Safety, Environmental Protection and Resilience

Irrigation systems combine water, pressure, electricity, rotating equipment and sometimes concentrated chemicals. Safety procedures must therefore be part of normal operations, not added after an incident.

- Lock out or isolate electrical equipment before maintenance where required.
- Use guards and safe access around pumps and moving machinery.
- Relieve pressure before opening filters, fittings or pressurised lines.
- Use appropriate personal protective equipment for fertilisers, acids, chlorine products or other treatment chemicals.
- Install backflow prevention so chemicals cannot enter water sources or potable systems.
- Contain spills and prevent nutrient-rich flush water from entering sensitive waterways.
- Provide backup water, power or emergency procedures for high-risk crop stages.

21.1 Climate resilience

Resilience planning should ask what happens if the farm experiences a longer hot period, reduced borehole output, power interruption or delayed spare parts. Practical responses may include reservoir capacity, spare pump components, solar backup, additional water sources, drought-priority zoning and heat-response irrigation rules.

22. Records, KPIs and Continuous Improvement

Smart farming depends on records that can be compared. A dashboard is useful only if the underlying data are reliable and tied to identifiable blocks. Start with a small set of indicators that managers actually use.

22.1 Core irrigation KPIs

Indicator	How to use it
m3 water applied per hectare	Compare blocks and seasons after adjusting for crop stage and rainfall.
Pressure by zone	Detect drift from the commissioning baseline.
Flow by zone	Detect leaks, restrictions and abnormal valve conditions.
Irrigation hours	Track workload and verify schedules.
Filter pressure differential	Trigger cleaning and diagnose source-water loading.
Uniformity test result	Verify that emitters are delivering consistently.
Yield per hectare	Connect water and nutrient management with commercial output.
Water productivity	Compare production achieved per unit of water used.

22.2 Digital record structure

Use consistent identifiers: Farm -> Block -> Zone -> Crop -> Planting date. Every irrigation, fertigation, spray, sensor and harvest record should reference these identifiers. This allows later analysis without trying to reconstruct where an activity occurred.

APPENDICES

Appendix A - Essential Calculations

Calculation	Formula / relationship	Example
Area conversion	1 ha = 10,000 m2	2.5 ha = 25,000 m2
Depth to volume	1 mm over 1 ha = 10 m3	5 mm over 3 ha = 150 m3
Crop ET	ETc = Kc x ETo	If ETo 6 mm and Kc 0.8, ETc = 4.8 mm/day
Gross irrigation	Gross depth = Net depth / application efficiency	4.5 mm / 0.90 = 5.0 mm
Zone flow	Emitter flow x active emitters	1.6 L/h x 8,000 = 12.8 m3/h
Runtime	Required volume / zone flow	25 m3 / 12.5 m3/h = 2 h
Uniformity concept	Low-quarter average / overall average x 100	Use measured emitter discharge values

Appendix B - Daily Irrigation Log

Date	Zone	Crop	Start	Stop	Flow	Pressure	Rain	Observation / action

Appendix C - Sensor Inspection Sheet

Sensor ID	Block / zone	Depth	Reading trend	Physical condition	Action required

Appendix D - Fertigation Record

Date	Zone	Product	Quantity	Stock volume	Injection time	Operator	Notes

Appendix E - Pre-Season Readiness Checklist

- Water source tested and sustainable flow confirmed.
- Reservoir cleaned and structurally inspected.
- Pump serviced and motor protection tested.
- Filters inspected; media/screens/discs in serviceable condition.
- Pressure gauges and flow meters functioning.
- Mains and sub-mains pressure-tested and flushed.
- Valves labelled and manual override verified.
- Drip laterals repaired and flushed.

- Sensors checked, batteries replaced where necessary and communication restored.
- Weather station inspected and cleaned.
- Controller schedules backed up and alarms tested.
- Fertigation equipment calibrated and backflow protection checked.
- Spare parts and PPE stocked.
- Operators briefed on emergency procedures.

Appendix F - Glossary

Term	Meaning
Application efficiency	The fraction of diverted or delivered irrigation water that is beneficially stored in the crop root zone.
Emitter	A device that releases water from a drip lateral at a controlled discharge.
ETo	Reference evapotranspiration, representing atmospheric evaporative demand from a standard reference surface.
ETc	Crop evapotranspiration, often estimated as ETo multiplied by a crop coefficient.
Fertigation	Application of soluble nutrients through the irrigation system.
Field capacity	Soil-water content after excess gravitational water has largely drained.
Head	Energy per unit weight of water, commonly expressed as metres of water.
Hydraulic zone	A part of the irrigation system operated under similar flow and pressure conditions.
Kc	Crop coefficient used with ETo to estimate crop evapotranspiration.
SAR	Sodium adsorption ratio, used with salinity information to assess sodium-related infiltration risk.
Total dynamic head	Combined head that a pump must overcome, including elevation, pressure and friction losses.

Appendix G - Technical References

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About the Author

Elfas Mcloud Zadzagomo Shangwa Hunter is the author of this technical guide. The manual has been prepared for practical agricultural training, farm implementation and project development under Hunter's Global Network / Farmers Pride International.

Author note. This edition is structured as a living technical manual. Site-specific crop schedules, engineering drawings, standard operating procedures and project-specific specifications can be added as field data and operating experience accumulate.

Operator Competency Checklist

Competency	Demonstrated	Supervisor sign-off
Start and stop the pump safely	Yes / No	___________
Identify and isolate an irrigation zone	Yes / No	___________
Read pressure gauges and flow meters	Yes / No	___________
Clean or backwash filters correctly	Yes / No	___________
Flush mains, sub-mains and laterals	Yes / No	___________
Run a normal fertigation event	Yes / No	___________
Interpret basic soil-moisture trends	Yes / No	___________
Respond to high-flow / low-flow alarms	Yes / No	___________
Record irrigation and maintenance activities	Yes / No	___________

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WATER SMARTER
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ABOUT THIS MANUAL

This field handbook brings together practical irrigation engineering, soil-water management, smart sensors, automation, fertigation, climate data, maintenance, commissioning and farm performance management in one operational guide. It is designed for growers, schools, cooperatives, project developers, technicians and farm managers working with high-value crops in water-constrained environments.

Practical irrigation design	Smarter water-use decisions	Field-ready management tools

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