PACE Execution

Website · print edition

Proper and adverse borehole completion

Includes the website pages and expertise descriptions, expanded focus-area observations, the modular infrastructure drawing and both finished borehole diagrams.

Working draft · Revision 06

Live site: https://pace-execution.ccope43672.chatgpt.site

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Diagram sheets follow the website pages. Interactive controls are represented as explanatory text in this print edition.

Home

Practical Action for Capital Efficiency

Turn investmentinto lastingservice.

Help water and development organizations continually increase desired outcomes per resource input.

Explore how we help

↗

CONNECTED WATER SYSTEMS

FIELD NOTES

Hover over a component to highlight its system. Select it to explore the corresponding PACE expertise. On touchscreens, tap once to highlight and tap again to open.

Explore the full drawing ↗

Concept illustration · not a construction design

Implementer + operator

Design together. Improve together.

Implementer

Operator

WATER, SANITATION & HYGIENE

DEVELOPMENT OPERATIONS

CAPITAL DEPLOYMENT

From intention to implementation

Good plans needthe capacity to deliver.

A project can stall between funding and field delivery. PACE looks across technical decisions, organizational handoffs, and costs to find what needs to change—and what to do first.

01 / UNDERSTAND

Find the constraint.

Identify where projects lose time, resources, or clarity through focused reviews and field diagnostics.

Diagnostics & reviews ↗

02 / IMPROVE

Make delivery simpler.

Prioritize improvements in design, equipment, workflows, and accountability.

Explore focus areas ↗

03 / FOLLOW THROUGH

Build lasting capacity.

Support teams through implementation, organizational transitions, and sustained operational improvement.

Fractional support ↗

Practical improvement · an illustrative example

Small changes.Lasting consequences.

Standardization can turn a recurring procurement problem into a more manageable service model. The design evolves around what teams need in the field.

EXISTING APPROACH / EXAMPLE

A different pump.A different spare.

Equipment selected one project at a time can leave teams supporting a wide range of parts, tools, and procedures.

→

△ REV 01 / PROPOSED IMPROVEMENT

A shared core.Clear exceptions.

Review pump curves, align compatible spares, and retain a defined range for projects with different requirements.

Illustrative approach, not a measured client result. The red cloud identifies the proposed change.

Focused expertise. Connected thinking.

The right scopefor the problem.

Begin with a consultation or a bounded review. Expand into an office-and-field engagement when the problem calls for it.

See engagement options ↗

A practical starting point

What’s getting in the wayof your next step?

Start with a focused conversation about your organization, your priorities, and the decisions ahead.

Start a conversation ↗

About us

About PACE

Practical expertise.Purposeful execution.

PACE Execution is an advisory practice focused on helping organizations translate resources, plans, and technical knowledge into reliable delivery.

Who we are

Our approach

Our network

Better use of capital.Better service to people.

Our work connects engineering, operational leadership, and financial thinking. We examine the whole delivery process—from the first investment decision to the service people actually receive.

Our focus is practical: identify constraints, prioritize improvements, and help teams act on them.

Who we are

Experience behind the work.

CC

PORTRAIT TO BE ADDED

Chris Cope

Founder & Principal

Chris brings engineering, project, and operational experience across the private and nonprofit sectors, including petroleum engineering and international water programs.

His background includes a B.S. in Petroleum Engineering, an M.S. in Civil Engineering with a water resources management focus, and a Professional MBA.

01

PORTRAIT TO BE ADDED

Board member

Profile forthcoming

Space reserved for name, role, relevant experience, and photograph.

02

PORTRAIT TO BE ADDED

Board member

Profile forthcoming

Space reserved for name, role, relevant experience, and photograph.

Our approach · proposed language

Our mission

Help water and development organizations continually increase desired outcomes per resource input.

Our theory of change

If organizations identify delivery constraints, simplify repeatable work, and align decisions with service outcomes, they can use time and capital more effectively. When teams implement and sustain those improvements, more resources can reach the people they serve.

How that change happens

The logic model connects our work to the results we seek.

01 / INPUTS

Expertise + evidence

Client knowledge, project records, technical expertise, and field observations.

02 / ACTIVITIES

Diagnose + prioritize

Review costs, designs, workflows, and capacity. Identify changes with practical value.

03 / OUTPUTS

Decisions + action

Prioritized opportunities, reviewed designs, clear responsibilities, and an implementation roadmap.

04 / OUTCOMES

Stronger delivery

Less avoidable delay, better use of resources, and more reliable service.

These outcomes depend on implementation, local capacity, adequate resources, and continued operational follow-through. Progress should be measured against an agreed baseline.

A network shaped around the need

Specialist experience.Shared purpose.

Our collaboration model brings together experienced consultants across WASH, development, and capital deployment, with expertise matched to the requirements of each engagement.

Consultant and partner profiles will be added as relationships are confirmed for publication.

A practical starting point

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Start a conversation ↗

Services

Services

Start focused.Go deeper where it matters.

A typical engagement can move from an initial conversation to a desk review, then into a focused office-and-field assignment. Each stage has its own purpose and scope.

Proposed engagement framework · USD

01

Initial consultation

45–90 minutes

Discuss the challenge, clarify priorities, and identify whether a targeted review or a broader engagement would be useful.What you receive: A shared problem statement and recommended next step.

$50

Proposed fixed fee

02

Desk review

Four hours of review

Review an agreed set of organizational, financial, or project documents to identify where further attention could have the most value.What you receive: A list of opportunities, key questions, and suggested follow-up that you can prioritize for further engagement and grant proposals.

$1,000

Defined document scope

03

Focused engagement

Four or seven weeks

Combine office discussions, document analysis, field observation, and synthesis around an agreed set of questions.What you receive: Findings, prioritized recommendations, and an implementation roadmap.

Scoped fee

Based on assignment

Draft prices for discussion. Four-hour reviews require a complete, agreed document package and a bounded scope. Travel, additional analysis, and implementation support would be addressed in the

proposal.

A separate technical entry point

Focused design review

A four-hour review of a complete design package, scoped to the technical disciplines and decisions that need attention.

$1,000 proposed fixed fee

Deliverable: prioritized comments, material gaps, questions to resolve, and recommended next actions.

A bounded advisory review; scope and required professional sign-off are agreed before work begins.

Support beyond a short engagement

Fractional leadership& execution support

Recurring support for a transition, a capacity gap, or a sustained operational improvement effort.

Assignments may include fractional COO responsibilities, support to a COO or chief of programs, delivery oversight, or implementation support.

Structure: agreed responsibilities, time commitment, milestones, and a monthly fee. Duration follows the work.

What a focused engagement can include

LISTEN

Office review

Understand objectives, records, decisions, and constraints. Engage with office staff.

OBSERVE

Field assessment

Compare documented processes with conditions on the ground. Engage with field staff.

CONNECT

Synthesis

Connect technical, organizational, and financial findings.

ACT

Roadmap

Provide multiple actionable options from which leadership may enact.

A practical starting point

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Start a conversation ↗

Focus areas

Areas of focus

Specific challenges.Connected solutions.

Explore the technical and organizational areas where PACE can help. These working initiative names describe areas of support; modular equipment concepts remain in development.

Planning & people

PACE Plan

Evergreen jurisdictional master planning

Maintain a living master plan for entire water-service jurisdictions, including existing systems, rather than piecemeal development. Combine demand, service boundaries, funding and phased investment.

Bottleneck → proposed improvement

THE BOTTLENECK

Piecemeal investments proceed without a shared service boundary, demand picture or funding sequence.

△ PROPOSED IMPROVEMENT

Use population mapping, field assessments and funding scenarios to maintain an evergreen master plan with actionable phases.

Planning & people

PACE Performance

Outcomes, investment & shared incentives

Benchmark outcomes per investment and make them visible to support shared interdisciplinary goals and incentives.

Bottleneck → proposed improvement

THE BOTTLENECK

Spending is visible, but its relationship to service outcomes and shared incentives is unclear.

△ PROPOSED IMPROVEMENT

Compare desired outcomes per resource input alongside service reliability, lifecycle costs and replacement needs.

Planning & people

PACE People

Roles & delivery capacity

Clarify responsibility, authority, communication and the resources teams need to execute.

Bottleneck → proposed improvement

THE BOTTLENECK

Decisions stall when responsibility, authority and capacity do not align.

△ PROPOSED IMPROVEMENT

Take a handful of delayed decisions and trace them through the organization to identify ownership, handoffs and capacity constraints.

Infrastructure

PACE Penetration

Drilling & borehole completion

Connect drilling, aquifer characterization, casing, screens and annular isolation to a reliable water source.

Bottleneck → proposed improvement

THE BOTTLENECK

Wandering holes, misplaced screens and inadequate seals compromise yield and quality.

△ PROPOSED IMPROVEMENT

Compare proper and adverse completion, and use depth-indexed yield and water-quality records to inform completion.

Compare borehole completions ↗

Infrastructure

PACE Purify

Water quality & treatment

Connect source-water findings to treatment, monitoring and operational accountability.

Bottleneck → proposed improvement

THE BOTTLENECK

Water-quality findings and treatment decisions are disconnected.

△ PROPOSED IMPROVEMENT

Review treatment requirements, chlorination arrangements, bypasses and verification responsibilities.

Infrastructure

PACE Pipe

Transmission, distribution & hydraulics

Connect drop pipes, transmission, storage connections and distribution to demand and phased expansion.

Bottleneck → proposed improvement

THE BOTTLENECK

Pressure constraints and expansion needs emerge after the network is committed.

△ PROPOSED IMPROVEMENT

Review pressures, pipe sizing, network layouts and service connections across the master plan.

Infrastructure

PACE Pump

Pump curves & standardization

Match pump curves to system requirements while simplifying equipment families, spares and field support.

Bottleneck → proposed improvement

THE BOTTLENECK

A dispersed pump inventory increases spare-parts and support requirements.

△ PROPOSED IMPROVEMENT

Compare pump curves and shared equipment configurations to define a manageable inventory and exception range.

Infrastructure

PACE Power

Solar & electrical systems

Coordinate solar generation, electrical protection, controls, cables and pump motors.

Bottleneck → proposed improvement

THE BOTTLENECK

Power, controls, protection and pumping requirements are designed as disconnected pieces.

△ PROPOSED IMPROVEMENT

Review power demand, generation and pump curves together; develop repeatable electrical packages.

Infrastructure

PACE Pier

Structures & modular expansion

Explore shared lattice supports, buildings, tank platforms and reservoirs that can expand with demand.

Bottleneck → proposed improvement

THE BOTTLENECK

Fixed structure layouts make later expansion difficult or capital-intensive.

△ PROPOSED IMPROVEMENT

Compare staged capacity and structural modules through site-specific engineering.

Infrastructure

PACE Pulse

Monitoring, telemetry & response

Combine operational measurements and remote communications so teams receive useful information and act on it.

Bottleneck → proposed improvement

THE BOTTLENECK

Measurements arrive too late or without a clear response process.

△ PROPOSED IMPROVEMENT

Define flow, storage, quality and equipment data, reporting intervals, connectivity, alerts and response responsibilities.

Infrastructure

PACE Piezometric

Water levels & artesian well control

Use water-level evidence, hydraulic response and artesian well control to understand and manage source behavior.

Bottleneck → proposed improvement

THE BOTTLENECK

Limited hydraulic evidence and inadequate control leave well behavior poorly understood.

△ PROPOSED IMPROVEMENT

Review static levels, drawdown, recovery, observation arrangements, dry-run protection and artesian containment.

Customer connections

PACE Premises

On-premises meters & taps

Connect household service to accessible, maintainable metering and tap assemblies.

Bottleneck → proposed improvement

THE BOTTLENECK

Customer connections can undermine service accountability and maintainability.

△ PROPOSED IMPROVEMENT

Review meter boxes, yard taps, access and service verification at each premises.

Delivery support

PACE Purveyance

Procurement & supply chains

Connect purchasing, logistics, suppliers and spares to field service needs.

Bottleneck → proposed improvement

THE BOTTLENECK

Fragmented purchasing delays equipment and spares.

△ PROPOSED IMPROVEMENT

Standardize repeat purchases and specifications while preserving suitable exceptions.

Delivery support

PACE Project

Design & project delivery

Improve multidisciplinary reviews, documentation, decision gates and handoffs.

Bottleneck → proposed improvement

THE BOTTLENECK

Missing inputs surface late in implementation.

△ PROPOSED IMPROVEMENT

Review inputs, assumptions, sequencing and responsibilities.

Delivery support

PACE Projections

Forecasts & investment scenarios

Make demand, costs and growth assumptions visible.

Bottleneck → proposed improvement

THE BOTTLENECK

Unclear assumptions prevent meaningful scenario comparisons.

△ PROPOSED IMPROVEMENT

Compare staged scenarios and test changing demand and operating costs.

A practical starting point

What’s getting in the wayof your next step?

Start with a focused conversation about your organization, your priorities, and the decisions ahead.

Start a conversation ↗

Our work

Our work

Show the work.Explain the value.

A portfolio should connect the original challenge, the work performed, and the evidence of change. This draft establishes that structure without presenting unverified outcomes.

Working white papers

Explore the technical work.

Pump standardization

Why Africa Only Needs Four Pumps: standardizing complete pumping systems.

Read the paper ↗

Modular water systems

Plan for Growth, Build in Stages: modularity and incremental development.

Read the paper ↗

Borehole completion

The Ounce of Prevention Is Worth a Pound of Cure: completion and artesian well containment.

Read the paper ↗

Selected areas of work

From analysisto practical decisions.

The examples below summarize approaches developed in PACE’s working material. They are not claims of completed client engagements or measured results.

01 / APPROACH IN DEVELOPMENT

Pump inventory simplification

A wide range of equipment can create spare-parts, procurement, and training burdens.

Explore the approach

Work: Compare pump curves and shared motor configurations to identify a smaller, serviceable core inventory.

Evidence to track: Equipment records, pump-curve checks, procurement costs, repair time, and service reliability.

02 / APPROACH IN DEVELOPMENT

Demand-led expansion

Building ahead of verified demand can tie up capital and increase operating obligations.

Explore the approach

Work: Combine settlement mapping with field assessments, then compare phased coverage and investment options.

Evidence to track: Verified connections, demand, phase costs, coverage, and service performance.

03 / APPROACH IN DEVELOPMENT

Capital efficiency visibility

Project spending alone does not explain the service delivered.

Explore the approach

Work: Compare capital cost per verified customer and investigate differences across a project portfolio.

Evidence to track: Consistent customer definitions, project costs, operating costs, and reporting periods.

Client & collaborator profiles

Relationships behindthe work.

This space is reserved for approved client and collaborator profiles, with a clear description of each relationship.

Future case studies can distinguish PACE engagements from Chris’s earlier professional experience and identify whether work is completed or ongoing.

A practical starting point

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Tools & insights

Tools & insights

Make the decisionclearer.

Tools coming soon. Explore the approaches being developed.

Coming soon

Population & service maps

Use settlement patterns, field assessments and jurisdictional water-service boundaries to maintain master plans and define phased service coverage.

Coming soon

Implementation phases

Connect master-plan priorities with sequenced investments, funding requirements, decision gates and operational readiness.

Coming soon

Value waterfall

Connect project spending to a clearly defined service benchmark, keeping benchmark value distinct from actual cash flow.

Coming soon

Cost per reliable safe water customer

Compare costs using consistent customer, reliability, water-quality and cost definitions. Include operating and replacement costs alongside capital investment.

Coming soon

Scorpion plot business intelligence

Rank projects by cost per reliable safe water customer, compare cumulative spending and customers served, and investigate differences across the portfolio.

A practical starting point

What’s getting in the wayof your next step?

Start with a focused conversation about your organization, your priorities, and the decisions ahead.

Start a conversation ↗

Contact

Start a conversation

Tell us whereyou want to go.

A useful first conversation starts with the challenge, the decision ahead, and the kind of help your team needs.

A focused first step.

Use this draft inquiry builder to outline your needs. It creates a message you can copy; it does not submit or send your information.

Initial consultation45–90 minutes · proposed fee of $50

Contact details and scheduling will be connected before public launch.

Your name

Organization

What are you interested in?

What would you like help with?

Your inquiry

Your inquiry has not been sent.

Modular infrastructure

Field notes

Connected systems.Shared purpose.

Explore each component system and its corresponding PACE expertise.

Hover over a component to highlight its system. Select it to explore the corresponding PACE expertise. On touchscreens, tap once to highlight and tap again to open.

PACE Penetration

PACE Penetration / Borehole completion

Two completions.Different outcomes.

Explore proper and adverse drilling and completion using the finished PACE borehole diagrams. Switch views to compare the source from the surface downward.

Proper completion: centered casing, planned screens, annular isolation and a sealed wellhead.

Open proper diagram ↗

Open adverse diagram ↗

Download all website pages · PDF ↓

Conceptual comparison with exaggerated width and abbreviated depth intervals. The adverse example illustrates failure mechanisms, rather than describing every borehole in any region.

Read the borehole completion white paper ↗

Completion observations

Compare the details.

Element | Proper example | Adverse example

Wellhead | Top plate well seal, protected cable route and surface apron. | Loose plate, open penetrations and exposed cable.

Casing & trajectory | Casing extends through the target intervals, with centralizers and a casing shoe. | Wandering borehole and eccentric casing; the casing hangs up on a ledge or dogleg.

Screen placement | Selected screens correspond to the target aquifers. | Alternating screened and plain casing admits water from unwanted zones; deeper targets remain unreached.

Annular materials | Surface sanitary seal, intermediate seals and selected filter pack isolate intervals. | Shallow seal and bridged gravel leave unfilled annular space below.

Water quality | Completion aims to isolate unwanted contributing zones. | Shallow turbidity, iron-oxidizing bacteria and pathogens, plus iron, hardness and salinity from other zones, illustrate potential mixing.

Downhole condition | Pump, dry-run sensor and water level are shown in the completed source. | Drawdown, cascading inflow and iron oxide floc fill illustrate an adverse operating condition.

From drilling to verification

Know which zones contribute.

Log drilling progress, water strikes, driller’s yield, conductivity and water-quality samples by depth. Use those records, borehole geometry and formation conditions to plan casing, screens, filter pack and seals. Verify the completed source with development, pumping tests and water-quality testing.

Explore all PACE focus areas ↗

Borehole completion white paper

Read the completion and artesian containment paper ↗

PACE expertise

PACE Plan

Evergreen jurisdictional master planning

The opportunity

Maintain a living master plan for entire water-service jurisdictions, including existing systems, rather than piecemeal development. Combine demand, service boundaries, funding and phased investment.

The bottleneck

Piecemeal investments proceed without a shared service boundary, demand picture or funding sequence.

Proposed improvement

Use population mapping, field assessments and funding scenarios to maintain an evergreen master plan with actionable phases.

Modular water systems paper ↗

All expertise ↗

A practical starting point

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Start a conversation ↗

PACE Performance

PACE expertise

PACE Performance

Outcomes, investment & shared incentives

The opportunity

Benchmark outcomes per investment and make them visible to support shared interdisciplinary goals and incentives.

The bottleneck

Spending is visible, but its relationship to service outcomes and shared incentives is unclear.

Proposed improvement

Compare desired outcomes per resource input alongside service reliability, lifecycle costs and replacement needs.

All expertise ↗

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PACE People

PACE expertise

PACE People

Roles & delivery capacity

The opportunity

Clarify responsibility, authority, communication and the resources teams need to execute.

The bottleneck

Decisions stall when responsibility, authority and capacity do not align.

Proposed improvement

Take a handful of delayed decisions and trace them through the organization to identify ownership, handoffs and capacity constraints.

All expertise ↗

A practical starting point

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PACE Purify

PACE expertise

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Water quality & treatment

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Connect source-water findings to treatment, monitoring and operational accountability.

The bottleneck

Water-quality findings and treatment decisions are disconnected.

Proposed improvement

Review treatment requirements, chlorination arrangements, bypasses and verification responsibilities.

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Transmission, distribution & hydraulics

The opportunity

Connect drop pipes, transmission, storage connections and distribution to demand and phased expansion.

The bottleneck

Pressure constraints and expansion needs emerge after the network is committed.

Proposed improvement

Review pressures, pipe sizing, network layouts and service connections across the master plan.

Modular water systems paper ↗

All expertise ↗

A practical starting point

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PACE expertise

PACE Pump

Pump curves & standardization

The opportunity

Match pump curves to system requirements while simplifying equipment families, spares and field support.

The bottleneck

A dispersed pump inventory increases spare-parts and support requirements.

Proposed improvement

Compare pump curves and shared equipment configurations to define a manageable inventory and exception range.

Pump standardization paper ↗

All expertise ↗

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Solar & electrical systems

The opportunity

Coordinate solar generation, electrical protection, controls, cables and pump motors.

The bottleneck

Power, controls, protection and pumping requirements are designed as disconnected pieces.

Proposed improvement

Review power demand, generation and pump curves together; develop repeatable electrical packages.

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PACE Pier

Structures & modular expansion

The opportunity

Explore shared lattice supports, buildings, tank platforms and reservoirs that can expand with demand.

The bottleneck

Fixed structure layouts make later expansion difficult or capital-intensive.

Proposed improvement

Compare staged capacity and structural modules through site-specific engineering.

Modular water systems paper ↗

All expertise ↗

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PACE Pulse

Monitoring, telemetry & response

The opportunity

Combine operational measurements and remote communications so teams receive useful information and act on it.

The bottleneck

Measurements arrive too late or without a clear response process.

Proposed improvement

Define flow, storage, quality and equipment data, reporting intervals, connectivity, alerts and response responsibilities.

All expertise ↗

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PACE expertise

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The opportunity

Use water-level evidence, hydraulic response and artesian well control to understand and manage source behavior.

The bottleneck

Limited hydraulic evidence and inadequate control leave well behavior poorly understood.

Proposed improvement

Review static levels, drawdown, recovery, observation arrangements, dry-run protection and artesian containment.

Completion and artesian containment paper ↗

All expertise ↗

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PACE Premises

On-premises meters & taps

The opportunity

Connect household service to accessible, maintainable metering and tap assemblies.

The bottleneck

Customer connections can undermine service accountability and maintainability.

Proposed improvement

Review meter boxes, yard taps, access and service verification at each premises.

All expertise ↗

A practical starting point

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PACE Purveyance

PACE expertise

PACE Purveyance

Procurement & supply chains

The opportunity

Connect purchasing, logistics, suppliers and spares to field service needs.

The bottleneck

Fragmented purchasing delays equipment and spares.

Proposed improvement

Standardize repeat purchases and specifications while preserving suitable exceptions.

All expertise ↗

A practical starting point

What’s getting in the wayof your next step?

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Start a conversation ↗

PACE Project

PACE expertise

PACE Project

Design & project delivery

The opportunity

Improve multidisciplinary reviews, documentation, decision gates and handoffs.

The bottleneck

Missing inputs surface late in implementation.

Proposed improvement

Review inputs, assumptions, sequencing and responsibilities.

All expertise ↗

A practical starting point

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Start a conversation ↗

PACE expertise

PACE Projections

Forecasts & investment scenarios

The opportunity

Make demand, costs and growth assumptions visible.

The bottleneck

Unclear assumptions prevent meaningful scenario comparisons.

Proposed improvement

Compare staged scenarios and test changing demand and operating costs.

All expertise ↗

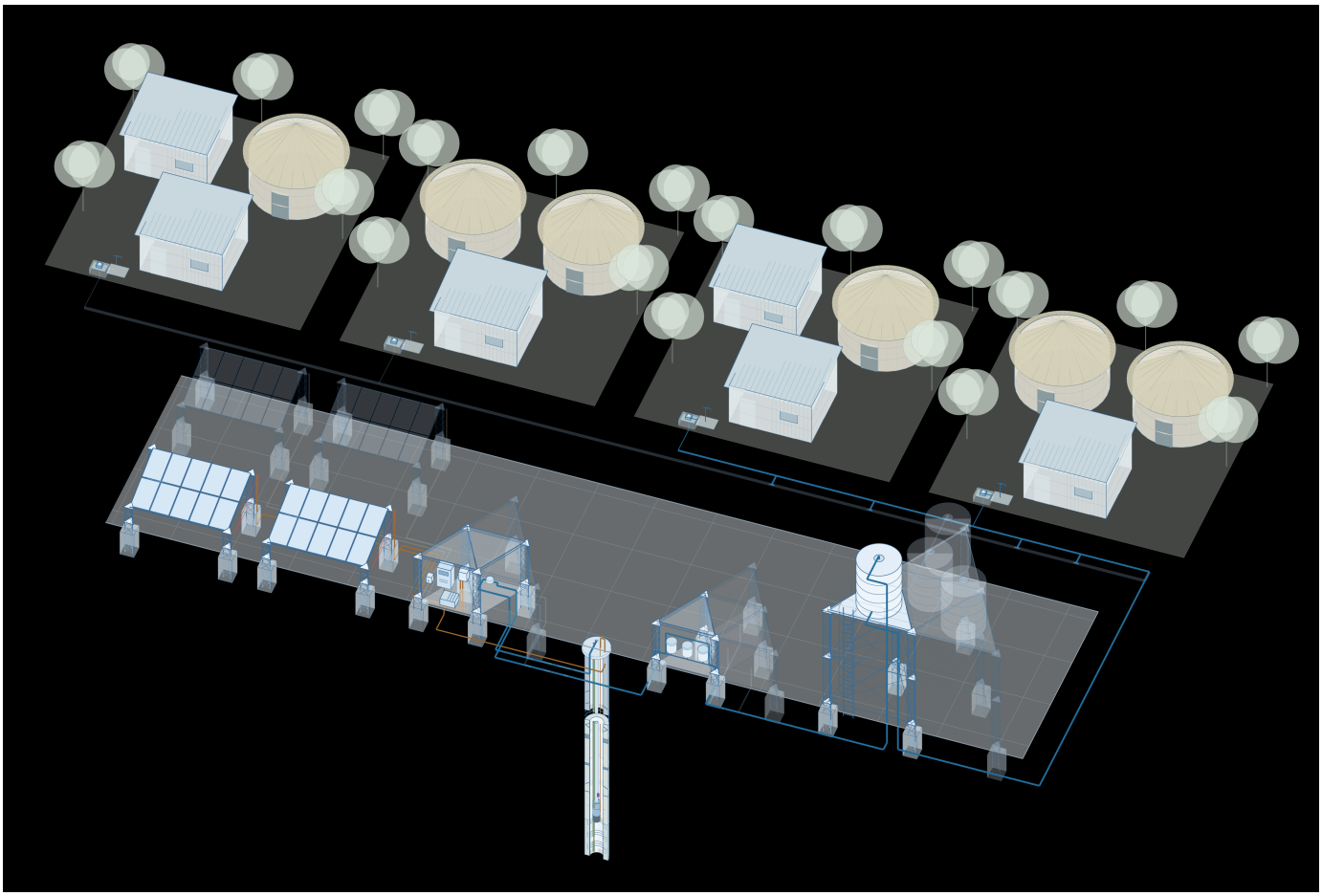
A practical starting point

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Start a conversation ↗

Modular infrastructure

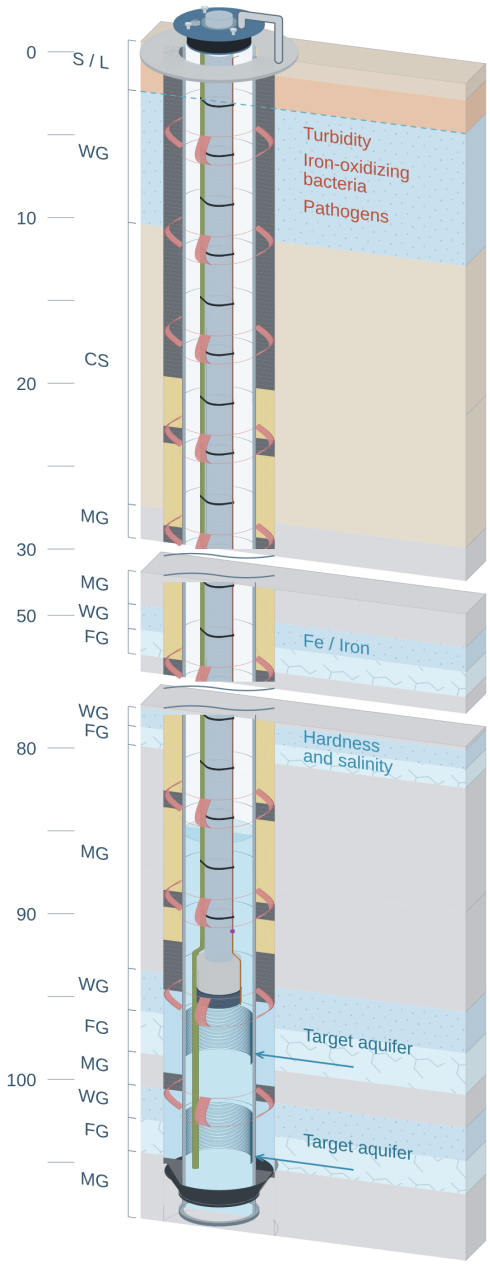


Proper borehole completion

Borehole — proper completion

Horizontal exaggeration: 28×

10-inch hole · 6-inch PVC casing · horizontally exaggerated



Completion observations

Sealed wellhead plate

0–20 m surface annular seal
(bentonite / cement)

Continuous annular backfill

Shallow water isolated
by plain casing and sanitary seal

Straight bore; centered casing
Flat-bar centralizers every 6 m

3 m casing sticks
1 m annular seals every 6 m
between backfilled intervals

30–48 m abbreviated

High-iron zone isolated
by plain casing and annular seals

54–78 m abbreviated
High dissolved-solids zone
isolated from target aquifers

Dynamic water level

Plain casing above target zones

Pump above screens
3 m annular seal

Target: desirable
yield and water quality

Target: desirable
yield and water quality

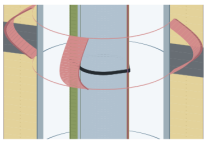
Shale trap; seal above
Casing shoe at 108 m

Component details



Top plate well seal

Bolted seal; separate sealed ports
¾-inch metal conduit; support collar



Flat-bar centralizer / backfill

Centered casing; complete annular fill
Bentonite seals separate intervals

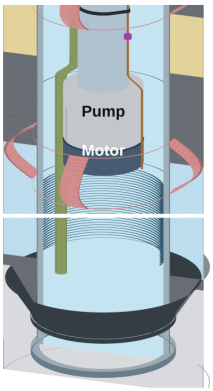


Black retaining strap

Cable + slotted observation pipe
held snugly to the drop pipe
Strap at each drop-pipe connection

Dry-run sensor / pump assembly

Sensor above wet end
Intake between pump and motor



Shale trap / casing shoe

Cutaway seal below fractured aquifer
Formation fill outside and below
Shoe clear of borehole bottom

Geology key

- S Topsoil
- L Lateritic residual soil
- MG Massive granite / granodiorite
  Sealed fractures; low permeability
- CS Clay-rich saprolite / clay-filled joints
  Low permeability
- WG Weathered granite
  Storage; lower permeability
- FG Fractured granite aquifer
  Connected fractures transmit water

Drawing key

- Centralizer
- Shale trap
- Dry-run sensor
- Motor
- Gravel
- Observation pipe
- Drop pipe
- Bentonite / cement
- Power cable
- Pump

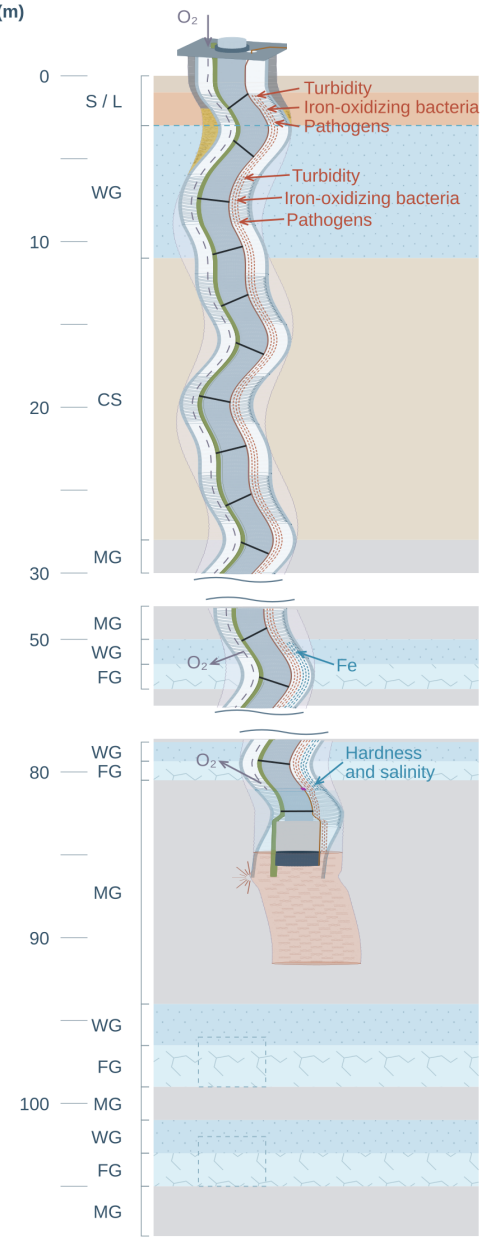
Illustrative completion · same depth windows, geology and scale as alternate

Adverse borehole completion

Deviated borehole — adverse completion

8-inch hole · 6-inch PVC casing · horizontally exaggerated

Horizontal exaggeration: 28×



Completion observations

Unsealed wellhead plate

0–2 m surface annular seal (bentonite / cement)

Gravel pack bridging

Shallow inflow (water table): turbidity + iron-oxidizing bacteria + pathogens

Wandering bore; eccentric casing; severe doglegs

Indiscriminate casing design: alternating screened and plain casing all the way to surface

30–48 m abbreviated

Middle contributing zone: high iron; screens displaced above targets

54–78 m abbreviated

Middle contributing zone: high total dissolved solids; screens displaced above targets

Casing hung up on borehole wall / ledge (dogleg severity)

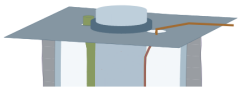
Open hole continues 5 m below casing

Total drilled depth short of target aquifer

Unreached target: desirable yield and water quality

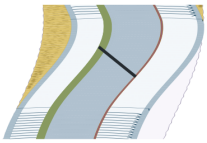
Unreached target: desirable yield and water quality

Component details



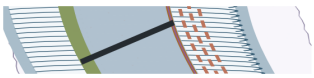
Unsealed wellhead plate

Loose top plate; open penetrations
Exposed cable above top plate



Gravel pack bridging

Bridges between casing and wall; unfilled annulus below

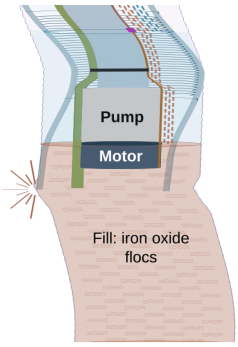


Black retaining strap

Cable + blank observation pipe held by strap; no centralizers or deeper annular seals

Dry-run sensor / pump assembly

Sensor: 2 m above wet end
Intake between pump and motor



Casing hung up on wall / ledge (dogleg severity)

Geology key

- S Topsoil
- L Lateritic residual soil
- MG Massive granite / granodiorite
  Sealed fractures; low permeability
- CS Clay-rich saprolite / clay-filled joints
  Low permeability
- WG Weathered granite
  Storage; lower permeability
- FG Fractured granite aquifer
  Connected fractures transmit water

Drawing key

- Unfilled annulus
- Iron-oxide flocs
- Dry-run sensor
- Motor
- Gravel
- Observation pipe
- Drop pipe
- Bentonite / cement
- Power cable
- Pump

IOB: iron-oxidizing bacteria · Fe: iron · O_2: oxygen

Why Africa Only Needs Four Pumps

Standardizing complete pumping systems to improve lifecycle cost and reliable water service

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PACE Execution

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The Journal of the Accord Network

This manuscript examines complete pumping system standardization as a practical application of lifecycle costing. It combines an internal East African portfolio screening, published research, and explicitly identified practitioner observations. Technical checks and submission preparation notes remain in the separate author review appendix.

Why Africa Only Needs Four Pumps

Standardizing complete pumping systems to improve lifecycle cost and reliable water service

Abstract

Water service costs connect initial construction, capital maintenance, and routine operation. This paper examines whether four pump models, organized into two standardized system families, could improve lifecycle performance across an East African portfolio. An internal screening yields preliminary coverage of 90 percent when marginal SP applications and assumed-suitable SQFlex records are included. The proposed intervention standardizes motors, drives, electrical protections, photovoltaic configurations, racks, and working procedures alongside pumps. Municipal water practice, packaged treatment, international standards, and energy-sector learning curves establish precedents for combining repeatability, purchasing scale, and accumulated experience. These sources support the mechanisms without establishing savings for the proposed kits. The paper therefore proposes testing complete configurations against service requirements, lifecycle cost per customer, reliability, and maintainability, while retaining engineered exceptions.

Keywords: solar pumping; standardization; component commonality; inventory; water service; lifecycle cost

Water service requires an integrated lifecycle

A pump purchase commits a water service provider to a chain of future decisions. The selected hydraulic assembly determines compatible motors, electrical equipment, operating limits, spare parts, and aspects of installation and maintenance. A decision recorded as a saving in the construction budget may subsequently consume the operator's time, require repeated replacements, or interrupt water sales. The performance of that purchase therefore extends beyond the project and the organization that made it.

Capital expenditure (CapEx), capital maintenance expenditure (CapManEx), and operating expenditure (OpEx) are useful accounting distinctions. They describe initial assets, renewal and rehabilitation, and routine operation and minor maintenance. They do not describe independent systems. IRC's WASHCost framework already establishes the importance of costing sustained services, including support and the cost of capital.[1] This paper applies that lifecycle perspective to the consolidation of pumping equipment and its supply arrangements.

The same interdependence exists among community development, project management, and multidisciplinary design. Community engagement informs demand and willingness to use a service. Design establishes the service that can be delivered and maintained. Project management coordinates the resources needed to realize it. Operational experience should inform all three. Treating these responsibilities as a succession of handoffs without continuing feedback can leave each party meeting its own targets while the customer receives an unreliable service.

Common configurations can also improve cooperation among disciplines. A project manager can recognize an incomplete kit, a community-development practitioner can explain realistic restoration arrangements, and an operator can report a deviation in terms the designer understands. This working knowledge allows each discipline to inform the others without requiring every participant to acquire

[1] IRC. 2011. Life-cycle Costs Approach: Costing Sustainable Services. WASHCost Briefing Note 1a. https://www.ircwash.org/resources/briefing-note-1a-life-cycle-costs-approach-costing-sustainable-service.

the same specialist qualifications. The assembly of repeatable equipment can be standardized while the planning and delivery of water service remain interdisciplinary.

The proposition examined here is that four pump models, arranged within two standardized system families, could serve most recurring applications in a defined East African portfolio. Two SP hydraulic assemblies would share a qualified motor and drive platform. Two complementary SQFlex models would use a compatible motor and control architecture. Electrical protections, photovoltaic modules, rack modules, interfaces, documentation, and maintenance procedures would form complete pumping kits. This is pumping system standardization, extending through procurement and service.

The title states a hypothesis to test. The available analysis concerns an organizational portfolio in East Africa; it does not establish continent-wide coverage. A limited equipment portfolio should serve eligible applications, with deliberate engineering for exceptions. The objective is sustained, affordable water service at an acceptable lifecycle cost per customer. Health protection, reliability, and financial sustainability are connected outcomes, although health effects require their own evidence.

For Christian relief and development organizations, stewardship includes the consequences of initial decisions for the people who will operate and use the service. An organization's responsibility for a particular budget does not eliminate its influence on another organization's future costs. Shared service objectives, technical review, and feedback from operators can make those consequences visible before procurement.

An established practice applied to water service

Interchangeability has a long industrial history. Nineteenth-century firearms manufacture developed precise tooling, gauges, and inspection so that parts could fit across assemblies. This achievement emerged through several inventors and institutions; attributing it solely to Eli Whitney obscures that development. In 1913, Ford combined interchangeable components, divided tasks, and moving materials in automobile assembly. The transferable principle is the reduction of avoidable variation in interfaces and work, supported by verification that parts actually conform.[2]

Water infrastructure has its own history of common specifications. AWWA adopted its first standard for cast-iron water pipes and special castings in 1908. Standardized testing methods and equipment specifications provided shared reference points for an expanding sector.[3] Standardization should not be credited by itself with the health gains of filtration and disinfection. It helps make specified performance reproducible and verifiable. The present proposal extends that practical tradition to a portfolio of source-water pumping assemblies.

Safe water is a service whose value depends on quality, quantity, continuity, access, and affordability. Equipment variety is useful when it improves those outcomes or accommodates a real site requirement. Variety that merely multiplies interchangeable tasks, stock lines, and training burdens needs a different justification. This is compatible with respecting customer preferences about service arrangements and with maintaining diversity in community engagement and local governance.

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[2] Karyl Lee Kibler Hall and Carolyn Cooper, "Windows on the Works," Eli Whitney Museum & Workshop, https://www.eliwhitney.org/windows-works; The Henry Ford, "K–12 Research Guide: Assembly Line," https://askus.thehenryford.org/K12/faq/433848. These histories distinguish the development of interchangeability from the later moving assembly line.

[3] American Water Works Association, "About Us," historical timeline, entries for 1905 and 1908, https://awwa.org/who-we-are/.

The long tail of equipment variety

The 63-record SP evaluation contains 43 distinct model labels after spaces are normalized. Thirty-one labels occur only once. Those one-time labels represent 72.1 percent of the model list and 49.2 percent of the records. The five most frequent labels together account for only 18 records, or 28.6 percent. Figure 1 reconstructs the equipment long tail directly from the study table. These are frequencies of recorded pump models, not measurements of subsequent spare-parts demand.[4]

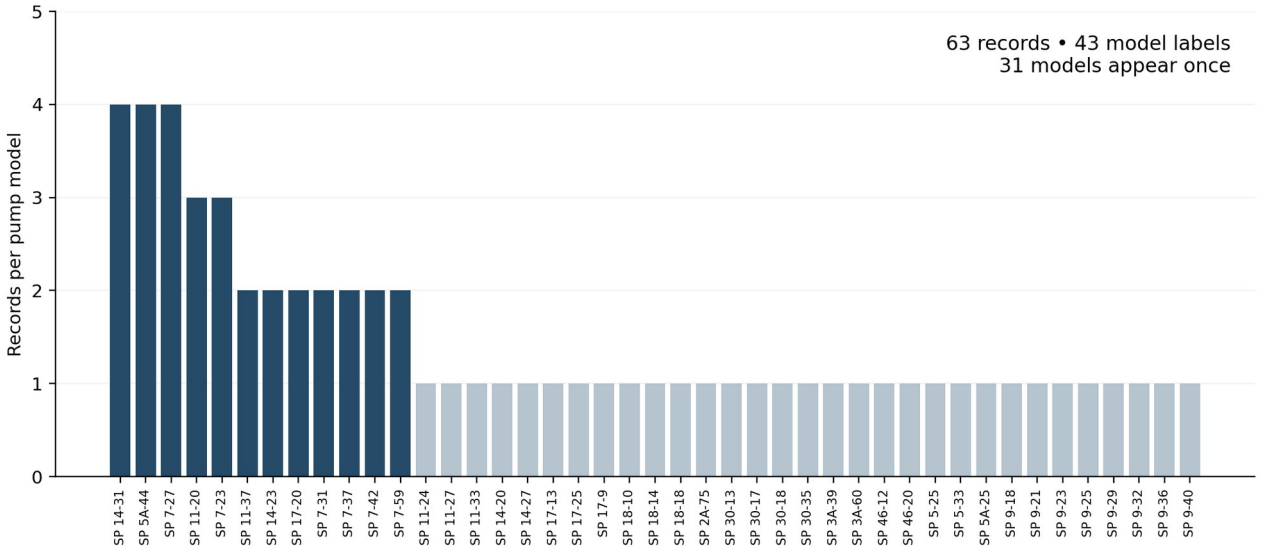


Figure 1. Long tail of SP model labels in the 63-record evaluation. Reconstructed from EA SP Pump Simplification, Curves & Duty Points, G40:G102. Only spaces were normalized; distinct names such as SP 5 and SP 5A were retained. This figure represents recorded equipment frequency, not replacement demand.

A long tail describes a distribution with many infrequently occurring items. In this portfolio, even the most frequent SP model appears only four times. Consequently, a policy of keeping a replacement for every recorded model would spread stock across many items with little individual repetition. Inventory expenditure alone would not show whether the correct replacement was available at the correct location. A warehouse could contain substantial value while a particular community still waited for its pump.

Long-tail items and long-lead-time items are related operational concerns but different quantities. The former are uncommon items in the portfolio; the latter take a long time to obtain. A rarely purchased model may be locally available, while a common model may have a long supply lead time. An inventory policy needs both frequency and lead-time information, together with the consequences of a stockout. The historical pump list establishes variety; it does not by itself establish stock requirements.

Research on component sharing provides a foundation for evaluating this tradeoff. Fisher, Ramdas, and Ulrich examine how organizations can offer different products while using fewer underlying components. Their automotive study treats commonality as a tradeoff involving design costs, variable costs, product requirements, and volumes. The application proposed here is analogous: different water schemes can retain different duties while drawing from a limited equipment architecture. Their results do not quantify savings for African water projects.[5]

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[4] Internal Pump Study. n.d.b. “EA SP Pump Simplification.” Unpublished engineering workbook, supplied by the author. Worksheets: Curves & Duty Points; 50 Hz Options Library. File: EA SP Pump Simplification(1).xlsx.

[5] Fisher, Marshall, Kamalini Ramdas, and Karl Ulrich. 1999. “Component Sharing in the Management of Product Variety: A Study of Automotive Braking Systems.” Management Science 45 (3): 297–315. https://doi.org/10.1287/mnsc.45.3.297.

The practical objective is to concentrate recurring demand on components that can substitute across many installations. A common motor may serve two hydraulic assemblies. A common drive enclosure may support both assemblies. A rack module may recur across several array sizes. This creates repetition at several levels even when the complete site designs differ. The long tail becomes an explicit set of exceptions whose performance requirements and supply arrangements are documented.

The East African screening study

The primary technical analysis selected SP 9-40 and SP 14-31 as complementary candidates and compared them with 63 SP pump records installed or planned during 2017–2025.[6,7] The first candidate provides greater head at lower flow; the second extends the flow range at lower head. The workbook includes duty points, source-yield information, original and substitute daily production estimates, solar-capacity changes, and suitability ratings. It is a retrospective engineering screening exercise rather than a controlled trial.

The presentation summarizes five rating levels. Eleven SP records are rated 0, four are rated 1, twelve are rated 2, eight are rated 3, and twenty-eight are rated 4. Categories 2 and 3 are grouped as requiring additional solar capacity. Category 4 is described as meeting the required demand or more with the same solar capacity. Category 1 can work but is not recommended under the study criteria; category 0 cannot provide the required demand. These categories convey the original analysis and do not substitute for a new site-by-site verification.

The resulting SP-only share in categories 2–4 is 48 of 63, or 76.2 percent. Including category 1 raises the potentially workable share to 52 of 63, or 82.5 percent. A broader worksheet calculation adds 47 SQFlex records to the denominator and places all of them in category 4. Under that assumption, 99 of 110 records fall outside category 0, giving exactly 90.0 percent. Excluding the four marginal SP records gives 95 of 110, or 86.4 percent. Table 1 makes these different definitions visible.

The 90 percent figure therefore has a traceable basis in the supplied analysis. Its interpretation depends on two conditions: the inclusion of marginal SP applications and the assumption that all 47 SQFlex records qualify. The latter has not been established for the particular pair of SQFlex models proposed here. The combined calculation also mixes SP records from 2017–2025 with SQFlex records from 2021–2025. It should be described as preliminary portfolio coverage under stated assumptions.

Population and acceptance rule	Covered / total	Share
SP only, ratings 2–4	48 / 63	76.2%
SP only, ratings 1–4	52 / 63	82.5%
SP plus assumed-suitable SQFlex, ratings 2–4	95 / 110	86.4%
SP plus assumed-suitable SQFlex, ratings 1–4	99 / 110	90.0%

Table 1. Coverage depends on population and acceptance rule. The 47 SQFlex records are assumed suitable in the combined screening, not individually validated for the proposed pair. Source: internal workbook, J40:J110.

[6] Internal Pump Study. n.d.a. “Pump Simplification—Focus: East Africa.” Version 3. Unpublished presentation, supplied by the author. File: Pump Simplification - V3.pptx.

[7] Internal Pump Study. n.d.b. “EA SP Pump Simplification.” Unpublished engineering workbook, supplied by the author. Worksheets: Curves & Duty Points; 50 Hz Options Library. File: EA SP Pump Simplification(1).xlsx.

A dot on a flow–head plot is useful evidence of the hydraulic requirement, but visual enclosure by a curve does not establish full kit suitability. Several records can occupy similar positions. An original duty point may also describe a peak flow that differs from the minimum flow needed over an available pumping day. Daily yield, seasonal irradiance, allowable abstraction, motor loading, and operating limits determine whether the substitute actually supplies the required volume. Figure 2 redraws the SP points and the tabulated candidate curves on common numerical axes.

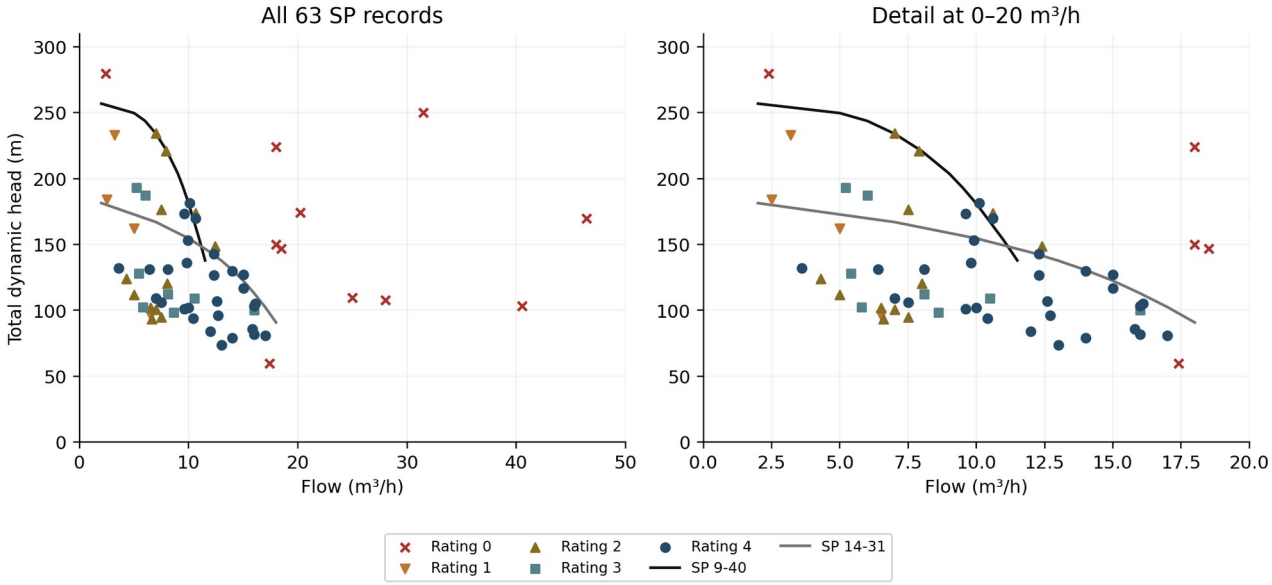


Figure 2. SP duty points and candidate 50 Hz curves, adapted from the study underlying presentation slide 12. All 63 records are plotted; overlapping points may conceal records. Right panel enlarges the common flow range. Source ratings are retained. Curves use tabulated workbook coordinates and are not full validated operating envelopes. SQFlex curves are omitted here because the plotted duty records are SP installations.

The workbook distinguishes production relative to the original design from production relative to stated water demand. These must remain separate. For example, the Chibelela row reports 103.8 cubic metres per day for the substitute with additional solar capacity, compared with 100.1 for the original design and stated demand of 171. The substitute slightly exceeds the original design output while supplying about 60.7 percent of the stated demand. This illustrates why final coverage should use a declared service requirement rather than a favorable replacement ratio alone.

A complete kit architecture

The proposed core portfolio comprises SP 9-40, SP 14-31, SQF 3-105, and SQF 7-55. The SQF pair represents the high-head, lower-flow and lower-head, higher-flow ends of the three 2.5 kW-class candidates in the workbook. SQF 5-70 remains a candidate for a fifth model if its intermediate duty range materially improves coverage, efficiency, or cost. This is a proposed selection for testing, not a completed optimization of the SQFlex portfolio.

For the SP family, the intended common motor is an appropriately specified 7.5 kW MS4000. The manufacturer-generated SP 9-40 sheet identifies that motor rating and gives rated currents of 18.4–18.8–19.6 A for its listed voltage configuration.[8] The exact motor product number, voltage, current, cable arrangement, and compatibility with both hydraulic assemblies must be fixed in the kit specification. Common motor naming alone does not establish interchangeability.

[8] Grundfos. 2018. “SP 9-40.” Grundfos Product Centre technical printout, version 2018.06.003, product 98699065. Manufacturer-generated document hosted by Lenntech. https://www.lenntech.com/uploads/grundfos/98699065/Grundfos_SP-9-40.pdf.

An 11 kW solar-compatible variable frequency drive is proposed as the common SP drive platform. Its selection must be confirmed against continuous output current, ambient-temperature and altitude derating, input voltage range, motor compatibility, and the intended photovoltaic array. The drive rating is distinct from the motor shaft-power rating and from the array nameplate capacity. These numbers do not need to be equal. They describe different parts of the energy-conversion chain.

The SQFlex family would use the compatible MSF3 motor platform and a common control-unit specification. Its integrated electronics make this a separate electrical architecture from the SP family. The proposal is one approved external drive platform for SP installations and one approved SQFlex controller platform, with common control functions where practical. It does not require routing SQFlex pumps through the SP drive. The workbook identifies the motor family, but the final component schedule must confirm exact variants and approved combinations.

The electrical kit should include a controlled bill of materials, enclosure arrangement, terminals, labels, and wiring diagram. It should define the isolation, overcurrent and surge-protection arrangements, earthing, dry-run protection, tank-level control, and any manufacturer-required output filtering. Standardization can reduce repeated design and assembly work, but protection ratings must follow the actual circuit configuration. Cable length, voltage drop, array current, and installation conditions remain parameters within approved limits.

Solar standardization should operate through repeatable modules. A program could select a qualified photovoltaic module specification, a limited set of string configurations, and a repeatable rack bay with standard fasteners and installation details. Projects would then use an approved number of bays and strings. Standard rack geometry does not eliminate checks for wind loading, foundations, corrosion exposure, shading, or land constraints. It reduces the number of details that must be redesigned while leaving site-dependent quantities explicit.

The same approach extends down the borehole and into commissioning. Approved pump connections, drop-pipe interfaces, cable joints, lifting provisions, and wellhead details can be grouped into a small set of compatible assemblies. Installation instructions can follow the physical kit. Commissioning records can use consistent fields for voltage, current, frequency, flow, water level, pressure, and controller settings. A technician who encounters a familiar system can draw on an established test sequence rather than reconstructing its design history.

Table 2 sets out the distinction between common equipment and site-dependent configuration. The kit should be understood as a bounded design with approved variants. Its boundaries are essential: a fixed kit that cannot accommodate a legitimate duty will force poor engineering decisions, while a kit with unrestricted variants will recreate the original equipment variety. Exceptions should record the failed eligibility criterion and the reason for selecting another assembly.

Subsystem	Common specification	Site-dependent configuration
SP assembly	SP 9-40 or SP 14-31; qualified common MS4000 motor	Duty, source yield, setting depth, cable length
SP drive and protections	Proposed 11 kW drive; approved electrical bill of materials	Verified current, derating, array and cable limits
SQFlex assembly	Proposed SQF 3-105 or SQF 7-55; compatible control platform	Daily delivery; optional SQF 5-70 evaluation
Solar generation	Qualified module and approved string/rack modules	Number of strings and rack bays within limits
Installation and maintenance	Standard interfaces, diagrams, checks, spare-parts schedule	Site civil works, hydraulic connections and local conditions

Table 2. Proposed standardization boundaries. Component ratings and combinations remain subject to manufacturer and site verification.

Efficiency at the pump and at the service level

Hydraulic efficiency remains important. The useful hydraulic power delivered to water is determined by flow, total dynamic head, water density, and gravitational acceleration. Electrical input also depends on pump, motor, and drive losses. A comparison between alternatives must hold the service requirement constant. Reporting lower electrical consumption while delivering less water or failing to reach the required storage elevation would not demonstrate an efficiency gain.

For illustration, lifting 100 cubic metres per day through 100 metres requires approximately 27.25 kWh per day of hydraulic energy, using water density of 1,000 kilograms per cubic metre and gravitational acceleration of 9.81 metres per second squared. At a combined electrical-to-hydraulic efficiency of 60 percent, electrical demand is 45.4 kWh per day. At 50 percent, it is 54.5 kWh per day, an increase of 20 percent. These are illustrative calculations, not measured results from the study. They demonstrate why a moderate efficiency penalty can matter.

Variable speed broadens the useful application range of a selected hydraulic assembly. It does not create unlimited flexibility. The Hydraulic Institute, Europump, and U.S. Department of Energy explain that static head materially changes the relationship between speed reduction, flow, and efficiency. In a high-lift water system, reducing speed can quickly reduce useful delivery as the available pump head approaches the static requirement. A simple cubic-power rule cannot establish the annual savings or daily production of these systems.[9]

Consequently, the proposed SP kit should be assessed across approved speed ranges with the actual system curve. A useful selection method would identify acceptable operating regions rather than shade the entire area below a maximum-speed curve as suitable. Minimum motor cooling, hydraulic operating limits, cable effects, and source yield should be incorporated into the eligibility test. Solar simulations should evaluate delivery across the day and through the limiting season, with storage considered alongside pumping.

[9] Hydraulic Institute, Europump, and U.S. Department of Energy. 2004. Variable Speed Pumping: A Guide to Successful Applications. Executive summary. https://www.energy.gov/sites/default/files/2014/05/f16/variable_speed_pumping.pdf.

The World Bank's Solar Pumping: The Basics treats solar pumping as an integrated system and emphasizes adaptation to local conditions.[10] That perspective supports evaluating the pump, power supply, and storage together. In the present proposal, standardization adds a portfolio dimension: equipment choices are also evaluated for their repeatability, supply arrangements, and maintainability across sites. The engineering requirement at each site remains the starting point.

Solar energy has no purchased fuel charge at the point of use, but an efficiency penalty still has costs. Additional photovoltaic modules may require more racking, foundations, cable, protection equipment, land, transport, and installation work. Components will eventually need maintenance or replacement. Conversely, additional energy demand does not necessarily require an equal percentage increase in array capacity because daily production depends on the changing available power and system operating point. Those effects require simulation or measured performance.

Electrical reliability is part of the pumping decision

UNICEF's 2016 assessment, authored by Emily Bamford and Djani Zadi, examined experience in Nigeria, Mauritania, Uganda, and Myanmar. Figure 9 attributes 43 percent of reported malfunction causes to wiring and electrical components and 25 percent to motor issues, including silting. Together these categories account for 68 percent of the plotted causes. These are shares of malfunction causes, not failure rates for all installations, and the motor category should not be relabeled as a verified pump-hydraulic failure category.[11]

The assessment also reports that only about one-third of minor repairs were completed within three days; limited local technical capacity and spare-parts access could prolong interruptions for weeks. This supports evaluating equipment, installation, and repair supply together.[12]

The joint Water Mission and UNICEF design and installation guide provides a technical foundation for qualifying the proposed kits, covering source assessment, pump selection, electrical design, installation, and commissioning.[13] Standardization would concentrate that engineering effort into repeatable, documented configurations. It would not remove the need to assess each source or correct poor well construction.

Outlay costs and economies of scale

The following cost categories describe mechanisms within the lifecycle: outlay, transactions, enforcement, and foregone opportunities. They cut across CapEx, CapManEx, and OpEx rather than forming additional accounting totals. For costing, each actual expenditure should be allocated once; opportunity effects should be reported separately with their assumptions.

Richard Westney provides a useful organizing framework: portfolio cost reduction arises through the interaction of standardization, economies of scale, and experience curves. His argument extends

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[10] World Bank. 2018. Solar Pumping: The Basics. Washington, DC: World Bank. https://documents.worldbank.org/curated/en/880931517231654485/pdf/123018-WP-P159391-PUBLIC.pdf.

[11] Bamford, Emily, and Djani Zadi. 2016. Scaling Up Solar Powered Water Supply Systems: A Review of Experiences. New York: UNICEF. See p. 18, figure 9. https://www.pseau.org/outils/ouvrages/unicef_scaling_up_solar_powered_water_supply_systems_a_review_of_experiences_2016.pdf.

[12] Bamford, Emily, and Djani Zadi. 2016. Scaling Up Solar Powered Water Supply Systems: A Review of Experiences. New York: UNICEF. See p. 18, figure 9. https://www.pseau.org/outils/ouvrages/unicef_scaling_up_solar_powered_water_supply_systems_a_review_of_experiences_2016.pdf.

[13] Water Mission and UNICEF. 2021. Solar Powered Water Systems: Design and Installation Guide. February 2021 English edition, 02-2021_SPG_E_002. https://globalwatercenter.org/wp-content/uploads/2024/04/Solar_Powered_Water_Systems_Guide_02-2021_English.pdf.

beyond repeated equipment to designs, work processes, specifications, and commercial arrangements. Common designs make aggregated purchasing possible; repeated execution gives teams opportunities to improve. He also identifies a management problem: a choice that benefits the portfolio may appear less attractive to an individual project judged only against its own immediate targets.[14]

Outlay costs should be assessed along the entire supply and service chain. A pump's advertised unit price does not capture volume purchasing, shipping, warehouse handling, installation labor, or the cost of waiting for missing equipment. A kit that appears more expensive when priced as an isolated purchase may become less expensive when recurring demand supports a different production and distribution arrangement. That possibility should be evaluated with actual quotations and order commitments.

For manufacturers, concentrated demand can support longer production runs, more predictable component requirements, and fewer configuration changes. Distributors may carry fewer slow-moving items, turn stock more frequently, and spread technical support and order-processing costs over more units. Consolidated shipments can reduce freight and handling per unit. Implementers may reduce repeated mobilization, incomplete deliveries, field storage, and labor spent waiting for equipment. These are mechanisms for potential savings at successive stages; they do not guarantee that every participant's cost or price will fall.

The relevant purchasing scale may span several organizations and utilities. An organization with a modest water portfolio may buy too few pumps to justify favorable stock commitments on its own. Several buyers using the same technically qualified components could provide a distributor with a recurring market. The purchasing group need not share every project design or use identical ownership arrangements. Agreement on equipment specifications, forecasts, and commercial responsibilities may be sufficient to aggregate compatible demand.

Applied here, the portfolio may extend across organizations. A shared technical platform could create a recurring market large enough to support stocked components and repeated installation practice. That is a coordination proposition: compatible demand, credible commitments, common technical controls, and records of performance must connect the buyers. Merely publishing a preferred pump list would leave most of the mechanism unfinished.

Volume purchasing works only if the apparent discount survives financing, inventory, obsolescence, warranty, and distribution costs. Competitive procurement can establish framework agreements with approved suppliers, volume price tiers, call-off orders, stock commitments, and delivery targets. Savings in production or distribution create room for lower prices; commercial terms determine how much is passed to purchasers. Supplier concentration also introduces exposure to shortages or defects, so qualified alternatives and an exception process remain important.

Last-mile delivery here means the final stage of delivering equipment to its destination, irrespective of whether the destination is urban, rural, or ultra-rural. It is a logistics function, not a label for the most remote community. Organizations that transport equipment from a distributor to installations already perform part of this function. Shared depots, scheduled routes, complete-kit dispatch, and coordinated deliveries could improve it. Remote communities are described as ultra-rural where appropriate; their actual transport and service costs should be measured.

[14] Richard Westney, "A Strategy For Driving Step Change Reductions in Capital Project Cost," Oil and Gas Facilities, March 17, 2015, Society of Petroleum Engineers, https://jpt.spe.org/strategy-driving-step-change-reductions-capital-project-cost. Practitioner framework; see the sections on standardization, economies of scale, experience curves, and portfolio versus project incentives.

The same advantages apply to capital maintenance. A qualified common motor could be stocked at a service depot or carried by a maintenance team serving compatible installations. With diagnostic capability, lifting equipment, approved replacement procedures, and authority to use the stock, the team could restore service without beginning a new procurement cycle. Utility-owned, distributor-held, or consigned stock are possible arrangements. Ownership, replenishment, payment, and accountability must be established in advance.

The internal Muatineni comparison illustrates why equipment consolidation still requires a complete cost comparison. In its retained-filter scenario, pumping-related outlay rises from approximately US$26,068 to US$29,363, or 12.6 percent. The pump becomes cheaper, but solar modules rise from 42 to 56 and rack assemblies from three to four.[15] This historical, project-level estimate does not include negotiated portfolio purchasing benefits and is not evidence that standardization either raises or lowers total lifecycle costs. Any proposal to remove an output filter requires separate technical verification.

A historical water-treatment comparison shows why capital and operating effects belong in the same assessment. An EPA study of package treatment plants estimated construction costs of US$488,236 against US$1,124,000 for conventional treatment at one million US gallons per day. Its annual treatment operation and maintenance estimates were US$40,409 and US$62,571, respectively—approximately 57 percent and 35 percent lower for the package alternative. These are historical modeled comparisons, not current prices or an isolated measurement of standardization. They nevertheless demonstrate that repeatable treatment assemblies have been evaluated for both initial and continuing costs in small-community water provision.[16]

Replacement costs across the asset life

Consider two hypothetical pumps providing the same required service. One costs P and lasts eight years; the other costs P/3 and lasts six months. Over an eight-year interval, with purchases at commissioning and each replacement date before year eight, the first requires one purchase. The second requires sixteen, costing 16P/3, or 5.33P. Thus, a two-thirds reduction in unit price can produce more than five times the undiscounted equipment expenditure.

For illustration, if P is US$3,000, the purchases total US$3,000 and US$16,000 respectively. Discounting the sixteen US$1,000 payments at an effective annual rate of 8 percent gives approximately US$12,178 in present purchase costs, compared with US$3,000 paid initially for the durable option. Both alternatives are assumed exhausted at the end of year eight. Labor, transport, retrieval, reinstallation, and service interruptions are excluded. The assumed lifespans are illustrative and are not claims about a particular brand or model.

This comparison explains how a lower CapEx allocation can create higher CapManEx and OpEx. It also demonstrates why comparing purchase prices without an analysis period is inadequate. Equipment quality is only part of the result: poor installation, unsuitable duty, ineffective protections, problematic source conditions, or incorrect drive settings may shorten the life of an otherwise suitable pump and motor. A standardized installation must therefore include the electrical system and the conditions under which the assembly is approved to operate.

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[15] Internal Pump Study. n.d.c. “EA Pump Simplification More Analysis.” Unpublished engineering workbook, supplied by the author. Worksheets: Analysis; Cost-Benefit Analysis. File: EA Pump Simplification More Analysis(1).xlsx.

[16] Richard G. Stevie and Robert M. Clark, Package Water Treatment Plants, Volume 2: A Cost Evaluation, EPA-600/2-80-008b (U.S. Environmental Protection Agency, July 1980), table 7, p. 44, and figures 22–25, https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=500013XO.TXT. Percentage differences calculated from the report’s historical cost estimates; the comparison is at the 1 MGD boundary of the applicable models.

The economic test is the discounted cost of supplying the same required service. Include equipment, installation, administration, maintenance, replacements, support, and any applicable residual value. Show provider revenue effects separately from expenditure and distinguish financial effects from customer and health consequences. Cost classifications should clarify the analysis rather than allow the same technician hour, outage, or lost sale to be counted more than once.

Established standards provide methods for making this comparison consistently. ISO 15686-5 addresses lifecycle costing of constructed assets and their parts, with an explicit analysis period and scope extending from acquisition through operation to disposal. ASTM E917 covers lifecycle costs of buildings and building systems; ASTM E964 addresses discounted benefit-to-cost and savings-to-investment ratios.[17] Their relevance is methodological: the proposed kit should be assessed against an alternative providing equivalent service, with the same horizon, discount assumptions, replacement treatment, and system boundary. The existence of an evaluation standard does not itself establish a percentage saving from standardization.

Transaction costs and repeat purchasing

Transaction costs arise in specifying a purchase, obtaining and evaluating quotations, negotiating terms, approving orders, coordinating suppliers, administering imports, and resolving contractual discrepancies. Physical storage and installation are direct resource costs; arranging and administering them creates additional transaction costs. Repeating the entire purchasing process for uncommon configurations can consume substantial staff time even when the equipment price is modest.

Complete, released specifications allow purchasing staff to order a known assembly against established terms. Routine orders can refer to an approved bill of materials, verified substitutions, and agreed inspection requirements. Engineering effort is then concentrated on qualification, site eligibility, and exceptions. This also makes a supplier's commitment clearer: delivering a nominally similar pump does not satisfy an order for a compatible and documented kit.

Predictable demand is valuable only when suppliers can trust the commitments behind it. Buyers need confidence in authenticity, delivery, and warranty support; suppliers need confidence in payment and realistic forecasts. Clear bid procedures and appropriate protection of proprietary quotations help maintain that relationship. Transparent competition can coexist with durable supply agreements. Recurring renegotiation and opportunistic substitution can undermine both. The conditions vary by market and should be documented rather than presumed from geography.

International-standard adoption also has a directly relevant African water example. An ISO-supported study of Sénégalaise des Eaux assessed management, abstraction, treatment, distribution, sales, engineering, and maintenance. It estimated annual benefits attributable to standards at about XOF 1.4 billion, or 1.9 percent of annual sales. The study also attributed a 1.54 percent reduction in energy costs to improved planning and operational control under its management system. These are case-study estimates involving management and technical standards, not a controlled test of pump commonality or a discounted whole-life result.[18]

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[17] ISO 15686-5:2017, Buildings and constructed assets—Service life planning—Part 5: Life-cycle costing, public scope, https://www.iso.org/standard/61148.html; ASTM E917-17(2023), Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems, public scope, https://store.astm.org/e0917-17r23.html; ASTM E964-15(2026), Standard Practice for Measuring Benefit-to-Cost and Savings-to-Investment Ratios for Buildings and Building Systems, public scope, https://store.astm.org/e0964-15r26.html. These are evaluation methods, not estimates of savings caused by adopting standards.

[18] International Organization for Standardization, "Water Senegal, Senegal," Economic Benefits of Standards, vol. 2 (2012), chap. 10, especially the business-function impact tables and conclusion, https://www.iso.org/iso/2012_economic_benefits_of_standards_2_senegal_water_senegal_en.pdf. Study conducted July–December 2011 using 2010 financial indicators. ISO's case-study factsheet reports rounded annual benefits of XOF 1.4 billion, equivalent to 1.9% of sales: https://www.iso.org/iso/ebs_case_studies_factsheets.pdf.

The Senegal example supports a narrower and more useful conclusion than a universal savings percentage: common procedures, defined responsibilities, monitored indicators, and technical requirements can have measurable economic value within water service itself. A small pump portfolio should sit inside that management structure. Equipment commonality, conformity to international standards, and organizational process standardization are related interventions, but their effects should be identified separately when evaluating results.

Scope must be defined through the service objective before equipment purchasing becomes the dominant decision. Budgets and schedules are real constraints, but delivering within both does not establish that the appropriate service was built. Where funding is insufficient, changes in service level, phasing, or coverage should be explicit and assessed with the operator and community. Quietly reducing essential equipment quality or protections transfers costs and risk into the operating period.

There is also a risk of inventory-driven design. Suppliers stock what has sold, organizations buy what is available, and designers adapt projects to the resulting stock. This feedback can perpetuate an unsuitable selection. Consolidation should begin with verified duties, source conditions, service requirements, and lifecycle performance; purchasing commitments should then support the selected portfolio. Ubiquity alone does not establish suitability.

Opportunity costs of delay and repeated failure

A specialized component with a long lead time can become the constraint on completing a project. The internal presentation reports pump procurement periods of three to four months, sometimes followed by further delays.[19] Where this waiting lies on the critical path, readily available kits could allow earlier commissioning and earlier deployment of the same team on its next project. The benefit depends on whether another activity would still constrain completion.

Waiting also creates direct costs: idle labor, accommodation, supervision, storage, and remobilization. Staff may remain away from families longer, increasing welfare and supervision burdens. The corresponding opportunity cost is the work those people and that capital could otherwise accomplish. More unfinished projects create more simultaneous commitments, coordination, and changes of attention. A portfolio can therefore lose throughput even while every team appears occupied.

Late completion can jeopardize grant milestones and delay revenue, but the consequences extend beyond financial schedules. Community contributions, training, and mobilization are often organized around an expected service date. Long delays may weaken participation and confidence in promised service. They can also affect working relationships with public authorities and future service-area assignments or approvals. These are plausible consequences to investigate in the relevant jurisdiction, not assured financial benefits of standardization.

During operation, an outage can reduce current sales and cause customers to resume using previous sources. Some may not return when service resumes; others may permanently reduce purchases. The economic analysis should distinguish immediate lost sales from persistent customer attrition and reduced use. Lost revenue is relevant to cash planning; lost contribution after avoidable costs is the appropriate starting point for estimating the financial benefit of restored sales. Claims about the scale or permanence of attrition require customer records.

Reliable and predictable supply also protects the value of community engagement and use of the service. A technically functioning asset does not recover those benefits automatically after a long

[19] Internal Pump Study. n.d.a. “Pump Simplification—Focus: East Africa.” Version 3. Unpublished presentation, supplied by the author. File: Pump Simplification - V3.pptx.

interruption. Customer confidence, collection patterns, tariffs, alternative sources, and actual demand all affect recovery. Service restoration should therefore be followed by evidence of resumed use, not simply confirmation that the pump runs.

Repeated maintenance can consume the capacity needed to improve the service. In an informal ten-seed allocation exercise conducted by the author, one operator responsible for several systems placed eight seeds against pump replacement, pump cleaning, and well flushing associated with iron oxide problems. Only two seeds represented all other duties. This was an elicited estimate from one operator, not a timed work study. It illustrates how one recurring technical problem can dominate a service organization's workload.

The operator's labor is an operating expenditure. Leak detection, investigation of unauthorized connections, chlorine replenishment, preventive maintenance, and improvement work displaced by that labor are foregone opportunities. Standardizing equipment would not itself solve iron precipitation or poor borehole development. It could simplify diagnosis and repair while freeing attention for source-specific investigation and a durable corrective intervention. Root-cause work remains essential.

Funds repeatedly consumed by pump and electrical replacements are unavailable for network improvements, planned renewal, or expansion. Where policy and financing arrangements permit, improved performance may also leave more resources for subsidizing rural and ultra-rural service. Those resources are not automatically available as cash: organizations must distinguish reduced spending, released staff capacity, and revenue recovered, then decide deliberately how each will support better service.

Repetition and continuous improvement

Repeated execution can release capacity as well as reduce purchasing costs. In a 2024 geothermal study, El-Sadi and colleagues examined Fervo Energy's first eight horizontal enhanced-geothermal-system wells, including wells at Project Red and Cape Station. They reported more than a 60 percent reduction in drilling days normalized by total measured depth. Their sequential performance and learning-curve charts document the application of technical and operational learning across wells.[20] This is a geothermal construction result, not a water-pumping savings forecast. Its relevance is the ability to retain and apply learning where recurring work shares sufficiently similar conditions.

A corresponding petroleum example is Coletta, Arias, and Mendenhall's Eagle Ford drilling campaign, whose SPE/IADC paper reports more than a 52 percent reduction in drilling time and 45 percent in cost over two and a half years. The improvements involved several changes in technology, execution, and management rather than repetition alone.[21] A Total Argentina presentation similarly illustrates a declining well-cost curve alongside standardization and a change in drilling fluids.[22]

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[20] Kareem El-Sadi, Brittany Gierke, Elliot Howard, and Christian Gradl, "Review of Drilling Performance in a Horizontal EGS Development," Proceedings, 49th Workshop on Geothermal Reservoir Engineering, Stanford University, February 12–14, 2024, SGP-TR-227, pp. 1–2, figures 1–2, https://pangea.stanford.edu/ERE/db/GeoConf/papers/SGW/2024/Elsadi.pdf. The charts show sequential well-delivery performance and learning curves; the reported reduction concerns drilling days normalized by total measured depth.

[21] Claudio J. Coletta, Camilo Arias, and Scott Mendenhall, "Drilling Improvements in Pursuit of the Perfect Well in the Eagle Ford—More Than 52% Reduction in Drilling Time and 45% in Cost in Two and a Half Years," SPE/IADC-178897-MS (2016), https://doi.org/10.2118/178897-MS, as summarized by Adam Wilson, "Drilling Improvements Work Toward the Perfect Well in the Eagle Ford," Journal of Petroleum Technology 68, no. 9 (2016): 104–105, https://doi.org/10.2118/0916-0104-JPT. The publisher's summary was consulted; the full conference paper was not available for review. The conference paper was not peer reviewed.

[22] Jean-Yves Lansot, "Total Argentina Gas Shale Wells—Implementation of Clean Based Fluids," AADE Fluids Management Group presentation, February 21, 2019, slides 8–9, https://www.aade.org/download_file/force/3228/510. The well-cost learning

These examples establish the plausibility of substantial accumulated improvement in commodity infrastructure; they do not establish a transferable percentage or prove that component consolidation caused the entire reduction.

For water programs, the corresponding learning record would connect each installation to engineering hours, procurement time, field labor, commissioning defects, repair duration, and actual service delivery. Teams need enough continuity to apply what they learn, and the authority to revise the approved configuration when evidence warrants it. Standardization should preserve successful improvements in the next released design. Repeating an unsuitable design or a recurring failure is repetition without learning.

Enforcement costs and focused technical proficiency

Enforcement costs, as used here, are the resources required to verify and sustain conformity with approved requirements. They include checking the authenticity and compatibility of supplied equipment, inspecting installation, witnessing commissioning, reviewing maintenance, and controlling changes. A supervisor can verify a familiar assembly against a released drawing and test procedure more readily than reconstruct the requirements of a different system at every visit.

Municipal practice provides a close precedent. Dea and Gans's ASCE paper on the Washington Suburban Sanitary Commission describes a design manual, standard specifications, standard detail drawings, field reports of design deficiencies, and retained design files. The stated purposes included shorter and less costly design and construction, reduced inventory costs, and greater staff flexibility across facilities; the authors reported that experience supported those objectives.[23] The important connection is between standard details and operational feedback. Designers, contractors, operators, and supervisors use common requirements while contributing different expertise.

This applies during both initial construction and capital maintenance. Replacement should preserve the approved configuration or follow a documented engineering review of the proposed change. The process can preauthorize equivalent components and routine replacements while reserving new combinations for the responsible designer. A field technician should not need to invent a pump–motor pairing or redesign electrical protections to restore service. Replacing like for like is also insufficient when recurring failures indicate that the original selection or installation was unsuitable.

A qualified kit can include preconfigured drive parameters, wiring diagrams, protection settings, installation photographs, inspection points, and commissioning limits. Site-specific cable lengths, source conditions, and other variable inputs remain explicit. Incorrect installation or programming can damage even high-quality equipment, so the kit must preserve the connection between the hardware and its approved operating instructions. Configuration changes should update the asset record and maintenance guidance.

Verification can itself be organized more efficiently. The National Research Council's Safe Water From Every Tap observed that repeated pilot testing could erode package-plant savings; manufacturers reported testing additions exceeding 30 percent of equipment costs. It recommended independent certification to reduce duplicative testing while retaining appropriate site evaluation.[24]

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curve annotates a 63% reduction alongside casing-architecture standardization and a drilling-fluid change. This industry presentation is an additional illustration, not an independently controlled estimate of standardization's contribution.

[23] Stanley J. Dea and Roger L. Gans, "Design Standardization Program of WSSC," Journal of Management in Engineering 2, no. 2 (1986): 111–123, https://doi.org/10.1061/(ASCE)9742-597X(1986)2:2(111). The accessible publisher abstract describes the program and reports success against its objectives; no quantified savings estimate is claimed here.

[24] National Research Council, Safe Water From Every Tap: Improving Water Service to Small Communities (Washington, DC: National Academy Press, 1997), Summary, https://www.nationalacademies.org/read/5291/chapter/2. The reported testing-cost increase was supplied by manufacturers, not a controlled average across all package plants.

For pumping kits, the analogous proposal is to qualify recurring assemblies once under a defined process, then verify that each installation falls within the approved conditions. Shared qualification cannot replace borehole assessment, source-water evaluation, or commissioning.

Research supports a nuanced approach to repetition. Staats and Gino, using two and a half years of transaction data from a Japanese bank, found that specialization within a day was associated with improved productivity, while variety in experience across days also improved productivity. The implication proposed here is to combine repeated practice on approved pumping configurations with planned development across other water-service responsibilities. The study does not identify an optimal number of pump models or quantify savings for water technicians.[25]

The sporting analogy is a limited repertoire of well-rehearsed plays, with clear responsibilities and known responses to common situations. It illustrates execution discipline rather than proving that four or eight plays is universally optimal. Collins's hedgehog concept offers a related illustration of sustained organizational focus.[26] Neither analogy substitutes for evidence about installation defects, repair times, or learning in the actual workforce.

A technician may need competence in several essential functions without mastering every pump, drive, motor, and electrical arrangement in the market. Deliberate repetition within a few applications can reduce unnecessary variation in training and troubleshooting. Specialist engineers and electricians should remain available for work beyond the technician's approved scope. Standardization makes that division of labor more practical; it should not lower professional expectations or treat brief training as equivalent to specialist qualification.

Staff turnover makes documented configurations, supervised practice, and competency assessment particularly important. Training investment should be tested through demonstrated tasks and retained performance. An organization seeking growth in dependable service needs expertise and time for continuous improvement. The aim is to develop a capable workforce supported by repeatable systems, with investment judged against service quality and long-term performance.

Remote oversight and comparable performance

Remote oversight begins with a known installation record: the pump and motor, drive model and parameters, array capacity, setting depth, hydraulic arrangement, commissioning performance, and available water-level information. A small approved equipment portfolio reduces the number of configurations that analysts must understand. Monitoring then tests whether a known installation behaves as expected.

Production trends, together with available electrical and source data, can help flag underproduction, abnormal starts and stops, or changes in energy use. Adequate time resolution is needed to detect cycling; daily totals can conceal frequent interruptions. Irradiance, tank demand, operating speed, head, and source behavior affect interpretation. The purpose is to prioritize investigation and direct the next measurement, not to infer a unique fault from production alone.

With suitable instrumentation, engineers can compare observed behavior with expected operation and investigate electrical faults, borehole deterioration, changing drawdown, or abstraction exceeding approved limits. Static water level requires an appropriate nonpumping measurement; it should not be inferred directly from a daily production total. Alerts may shorten detection delays and reduce reliance on customers or operators first reporting a problem.

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[25] Staats, Bradley R., and Francesca Gino. 2012. "Specialization and Variety in Repetitive Tasks: Evidence from a Japanese Bank." Management Science 58 (6): 1141–1159. https://doi.org/10.1287/mnsc.1110.1482.

[26] Collins, Jim. n.d. "The Hedgehog Concept." Accessed November 2, 2026. https://www.jimcollins.com/concepts/the-hedgehog-concept.html.

Comparable equipment and consistent records make comparisons across systems more meaningful, provided head, demand, irradiance, and source constraints are accounted for. Statistical or machine-learning tools could support anomaly detection as data accumulate, but their performance must be checked against field findings. Monitoring has value when someone is assigned to review an alert, investigate, authorize action, and verify the result. Sensors without a response process simply record the outage.

Inventory and the availability of complete kits

Component commonality can allow one spare to satisfy several possible needs. Baker, Magazine, and Nuttle analyze safety-stock decisions with common components and a service-level constraint. Their specialized model provides a theoretical basis for evaluating pooled requirements; it does not imply a universal percentage reduction in stock. For water programs, the value depends on the extent of genuine interchangeability, the distribution of failures, replenishment times, and the locations where equipment is needed.[27]

A common SP motor could be held as a spare for either standard hydraulic assembly, provided the approved interfaces and ratings match. This may permit replacing a failed motor while retaining a serviceable hydraulic assembly. The saving depends on the actual failure mode and the ability to retrieve, diagnose, repair, and reinstall the equipment. A motor in stock cannot resolve a failed borehole, damaged drop pipe, unavailable lifting equipment, or a fault that has not been correctly identified.

Complete-kit availability is a more useful readiness measure than pump availability alone. An SP pump and motor may be ready while the drive, cable splice, surge protector, or compatible connector remains unavailable. A program should therefore count how many complete, deployable kits it holds and identify the component limiting that number. Procurement schedules should account for the longest replenishment requirement among the necessary components. Standardizing that surrounding equipment is central to the proposed service benefit.

The supplied stocking proposal uses budget limits, country stock caps, and preferred pump allocations to explore inventory decisions.[28] Its four-SP-model list addresses a different stocking alternative from the two-SP-plus-two-SQFlex architecture advanced here. Its weighted quantity objective should not be interpreted as proof of maximum service coverage. A revised model could select pump families and country stock levels subject to verified technical eligibility, expected demand during lead time, and a target service level.

A practical first implementation can use transparent reorder rules before introducing an optimization model. Record each withdrawal, replenishment date, emergency transfer, and stockout. Separate planned project demand from repair demand. Establish supplier commitments for the standard components and identify a qualified substitute for critical items where feasible. Commonality concentrates demand and may improve purchasing leverage, but it can also concentrate exposure to a supplier interruption or a defect affecting an entire component family.

Validation and application beyond the initial portfolio

The first validation task is to establish one clean evaluation register. Each record should identify the scheme, pump position, country, installation or planning date, required daily volume, total dynamic

[27] Baker, Kenneth R., Michael J. Magazine, and Henry L. W. Nuttle. 1986. “The Effect of Commonality on Safety Stock in a Simple Inventory Model.” Management Science 32 (8): 982–988. https://doi.org/10.1287/mnsc.32.8.982.

[28] Internal Pump Study. n.d.d. “Pump Stocking MILP Model Proposal.” Unpublished working document, supplied by the author. File: Pump Stock MILP Proposal - Ben-tern.docx.

head, source constraints, and existing power arrangement. Repeated schemes, upgrades, multiple pumps, and alternative model names should be distinguished. The denominator should count a declared unit, such as pumping installations, rather than interchangeably using projects, pumps, or communities.

Next, evaluate each record against the proposed four-model portfolio using consistent acceptance criteria. For SQFlex, compare SQF 3-105 and SQF 7-55 and quantify the incremental contribution of SQF 5-70. For SP, retain the original rating as historical information and calculate new pass or fail results against the required service and approved kit limits. A marginal design should remain visible rather than silently joining the accepted category. Report the cost of exceptions alongside their number.

Temporal and geographic differences deserve separate reporting. The presentation shows a shift toward SP pumps and larger community-system motors in recent years, while some large systems serve refugee settlements. Adding older small-system records can raise an overall coverage percentage without showing how well the portfolio fits new work. Report results for the same date window across both families and for relevant application groups. Any exclusions must be declared before claiming coverage for the remaining population.

A prospective comparison should follow eligible standardized installations and comparable conventional installations through procurement, commissioning, and operation. Useful outcomes include installed cost, engineering hours, order-to-site time, incomplete deliveries, daily water production, electrical energy per cubic metre, stockout days, repair duration, and days meeting the service requirement. Differences in head, demand, source yield, country logistics, and system age should be considered before attributing results to standardization.

For broader application, other organizations could contribute anonymized equipment and duty-point records using the same fields. This would test whether the candidate kit covers a recurring regional need or mainly reflects one organization’s project mix. The approach is transferable even if the specific pump models change. A common evaluation method can support competitive procurement and equivalent products while preserving the benefits of repeatable interfaces, electrical assemblies, and installation procedures.

Customer outcomes and aligned incentives

The performance measure should connect expenditure to actual service. Report lifecycle cost per customer served at a declared service level over a stated analysis period, alongside reliability, quality, affordability, and use. Define whether a customer is a person, household, connection, or institution. Connection counts and the population within a service area are not interchangeable with verified users.

For comparisons over time, annualized lifecycle cost per customer-year can be useful if customer counts reflect the period actually served. Compare systems within relevant groups, including settlement density, remoteness, income, source conditions, and required service level. Report subsidies separately so that a low tariff is not mistaken for a low cost of service. A portfolio should not improve its reported unit cost merely by excluding expensive rural and ultra-rural customers.

Count-based equipment coverage should be accompanied by demand-weighted coverage and the population associated with eligible schemes. Uncommon large installations may account for a substantial share of water production. An additional pump model can be justified by its incremental service coverage, lower energy requirement, or reliability benefit, even if it adds few installations. Those gains should be compared with its inventory, training, documentation, and support burden.

Procurement, construction, engineering, community development, and operations need performance measures that recognize their joint effect on customers. Purchase price, budget compliance, and commissioning dates remain useful, but they should sit alongside sustained service and renewal costs. Donor agreements and organizational targets can support this by budgeting for lifecycle requirements, documenting handover responsibilities, and requiring operational feedback to inform subsequent designs.

An initial standardized-kit pilot should track order-to-site time, complete deliveries, engineering and procurement hours, field labor, installation defects, daily delivery, energy per cubic metre, repair time, customer retention, and actual expenditures. Comparable conventional installations should be evaluated over the same period, with differences in duty and context recorded. This would test whether consolidation improves execution and service rather than merely reducing the number of equipment labels.

Conclusion

The East African portfolio provides a specific starting point for pumping system standardization: 63 SP records contain 43 model labels, and the broader screening reaches 90 percent preliminary coverage under stated assumptions. Two SP hydraulic assemblies, a common qualified motor and drive, and two complementary SQFlex assemblies offer a testable basis for a much smaller set of complete pumping configurations.

Municipal standardization, historical package-treatment comparisons, ISO's Senegal water-utility case, and geothermal and petroleum learning curves place this proposal within a substantial history of practice. Westney's portfolio framework explains how common designs, aggregated demand, and accumulated experience can reinforce one another. The contribution here is a specific pumping-system architecture and a method for testing it against water-service outcomes, rather than a claim to have originated these principles.

The evidence also sets boundaries. Annual economic benefits, historical capital comparisons, drilling-time reductions, and lifecycle present costs are different measures. They cannot be added together or imported as a forecast for African water systems. The proposed portfolio must demonstrate its own savings, reliability, and service coverage through technically qualified installations and transparent operating records.

CapEx, CapManEx, and OpEx are interdependent parts of the cost of sustained service. Community engagement, project management, and multidisciplinary design likewise contribute to the same customer outcome. Equipment consolidation is valuable when it improves that outcome over the full lifecycle, including the capacity to maintain, renew, and expand service. Four pumps is a concrete proposition for testing how much dependable water service a simpler, better-supported system can deliver.

Plan for Growth, Build in Stages

Modularity and incremental development of water delivery systems

PACE Execution • Working white paper • Draft 4 • November 2, 2026

Abstract

Water systems must serve populations whose size, location, purchasing behavior, and service expectations change over time. Forecasts are necessary, but building immediately for a distant forecast can leave an operator with extensive assets, limited sales, high maintenance obligations, and poor water turnover. This paper proposes an alternative: master-plan the full system, deliver a complete and financially supported first phase, and expand through standardized modules as measured demand justifies investment. Modularity applies to source development, pumping, solar generation, treatment, storage, structural supports, distribution, and customer connections. Its purpose is to make growth affordable while preserving service quality. Factory fabrication and interchangeable components support that purpose; they are part of a broader strategy for matching capital commitments to demonstrated needs.

1. From infrastructure targets to functioning service

The central sizing problem is not simply how many people live within a proposed service area. It is how many will use the service, how much they will purchase, where and when they will need it, and whether revenue and committed subsidies can sustain delivery. Population growth, migration, seasonal incomes, competing water sources, connection costs, and confidence in reliability can all change the relationship between population and demand.

A grant can finance infrastructure faster than an operator can establish a customer base. Where funding rewards installed capacity or projected beneficiaries more heavily than sustained service, there is an incentive to build for optimistic future uptake. The resulting system may look complete on a construction schedule while remaining incomplete as a service: the source, tank, and mains exist, but household connections, customer acquisition, or operating finance are missing.

This is a proposed explanation of a recurring implementation problem, not a claim that all funders use these incentives or that beneficiary reporting is wholly unregulated. Established frameworks exist. The WHO/UNICEF Joint Monitoring Programme, for example, defines safely managed drinking water through accessibility on premises, availability when needed, and freedom from contamination. Project reporting should complement such service measures with verifiable operational and commercial data. [1]

At minimum, distinguish the population potentially reachable; households and institutions physically connected; active purchasing accounts; people actually using the service; and people receiving the intended quality and continuity. A customer account and a consumer are different units: one paying account can serve several people. Neither a design population nor a connection count establishes actual consumption or safe service.

The first phase should therefore be a complete service to an achievable initial market. Where on-premise connections are the intended model, their installation and commissioning belong in the phase budget.

Expansion should increase the number of people receiving a reliable service, rather than merely enlarge the population described as potentially served.

2. Incrementalism as an investment strategy

The Freakonomics episode “In Praise of Incrementalism” provides an accessible introduction to progress through accumulated improvements. Its discussions of cities, saving, and performance improvement emphasize the consequences of repeated decisions and small gains. That perspective is useful here, although the episode does not itself establish an optimal water-system investment strategy. [2]

Water-sector research provides a more direct analytical foundation. Basupi and Kapelan examine flexible distribution-system design under uncertain future demand. Erfani, Pachos, and Harou develop a multistage real-options approach to water-supply capacity expansion under uncertain climate conditions. These studies address different planning settings, but both place value on adapting investments as uncertainty resolves. Their results should not be treated as measured savings for the schemes proposed here. [3,4]

The applicable economic concept is the value of flexibility: preserving an affordable future choice can be preferable to committing immediately to one forecast. A modular system makes that choice practical. Standardized expansion interfaces, reserved sites, accessible connections, and approved configurations reduce the cost and disruption of responding to new information.

Incremental development still requires an overall plan. Otherwise, small investments can accumulate into an incompatible system. The master plan should identify likely growth corridors, source constraints, future pressure zones, ultimate structural limits, and the sequence of upgrades. It should also distinguish investments that are expensive to change later from equipment that can be added economically.

Land, rights of way, certain foundations, and difficult road crossings may justify provision for future capacity from the outset. Additional tanks, solar racks, treatment units, and some distribution branches can often be staged. The decision is asset-specific: compare the cost of unused early capacity with the expected cost of later expansion, disruption, and service risk.

3. Complete phases, measured expansion

A practical development sequence starts with a serviceable core and expands through defined decision points. Before construction, establish a demand baseline and scenarios rather than a single growth prediction. Include anticipated connection uptake, measured purchases where available, affordability, seasonal demand, institutional users, source yield, and non-revenue water.

The first phase should include the entire chain required to deliver water: source, energy, pumping, treatment, storage, distribution, usable connections, metering, operating staff, and maintenance arrangements. For the PACE proposition, this supports the principle of completing on-premise connections within each funded service area. A phase is complete when its intended customers can use the service, not when the upstream equipment has been installed. [5]

Expansion decisions should combine several indicators:

- Demand: active accounts, purchased volume, connection waiting lists, and sustained peak requirements.
- Service: pressure, continuity, water quality, complaints, and capacity constraints observed during demanding conditions.

- Source and assets: seasonal yield, drawdown, pumping performance, tank turnover, and remaining equipment capacity.
- Finance: cash collected, operating expenditure, maintenance reserves, arrears, and the funding available for the next phase.

Thresholds should be set during design and reviewed using actual operating data. A short demand spike should not automatically trigger permanent expansion. Conversely, known lead times mean procurement may need to begin before existing capacity is exhausted. The objective is timely investment supported by evidence.

Two practitioner accounts illustrate why this matters. One concerns a substantial water investment whose consumption and collections reportedly fell far below expectations. The other concerns a network reportedly designed around on-premise connections without funding to deliver those connections. Both describe a gap between installed infrastructure and a functioning customer service. They are hypotheses for case-study investigation, not independently verified findings; the author's recalled project details appear in the editorial note at the end.

Selecting the first service area

The first phase requires explicit decision criteria of its own. Population density, settlement pattern, and the location of likely customers should inform where service begins. Average population density across a large administrative area can conceal compact settlements separated by substantial distances. Planning should therefore examine household locations, potential connections per kilometer of distribution, expected purchased volume per kilometer, and the distance and elevation between customers and the source. Population density is an input to this assessment; the density of actual or reasonably expected demand is the more direct operating consideration.

The master plan should distinguish the authorized service territory, the area intended for eventual service, and the boundary of the first funded phase. These boundaries need not coincide. The first-phase boundary should identify the specific households and institutions to be connected, the infrastructure needed to serve them, and the interfaces for later expansion. It should be defined through multidisciplinary review with the operator, relevant authorities, and affected communities, and documented spatially rather than left as a broad beneficiary estimate.

Candidate first-phase areas should be compared against a consistent set of criteria:

- Service need: current water quality, reliability, access difficulties, and the consequences of delayed service.
- Demand concentration: settlement density, likely connection uptake, seasonal use, and expected purchased volume along the proposed network.
- Technical feasibility: source capacity, topography, pressure requirements, water turnover, access, land availability, and feasible construction routes.
- Financial support: the cost of complete connections, expected collections, operating and maintenance obligations, and committed affordability support.
- Operational readiness: staffing, practical skills, supervision, access for inspection and repair, and the complexity of operating the proposed phase.
- Expansion value: whether the initial assets and boundary support logical, affordable extensions without stranding infrastructure or obstructing later service.

Criteria and their relative importance should be agreed before selecting the preferred area. A scoring matrix can make tradeoffs visible, but it should not substitute for engineering judgment or turn uncertain demand estimates into apparent precision. Basic feasibility and service requirements should be treated as prerequisites. Compare the remaining alternatives under plausible uptake scenarios and explain why the

selected boundary offers a complete, manageable first phase. The densest or most affluent settlement should not automatically win: service need, committed support, and the pathway to less concentrated areas also belong in the decision.

Building operator capacity through successive phases

Phased development also provides a practical way to build operator capacity. A smaller initial system gives a team repeated experience with the full service cycle: producing and treating water, maintaining pressure and continuity, reading meters, collecting revenue, inspecting assets, responding to faults, managing spares, and communicating with customers. Standardized equipment and recurring procedures make these repetitions transferable to later phases.

The principle is progressive responsibility matched to demonstrated capability. Operators bring differing levels of experience, and the initial scope should reflect that experience, available supervision, and local support. Simpler initial configurations can provide a manageable setting for practice and improvement while still meeting the same water-quality and service requirements expected of the expanded system.

Each phase should therefore include an operating-capacity plan alongside the engineering and financial plans. Provide practical training, supervised commissioning, written procedures, essential tools, reliable records, and access to technical assistance. Review performance across representative operating conditions, including fault response and seasonal changes where relevant. Useful evidence includes consistent treatment and monitoring records, timely preventive maintenance, reconciled meter and collection records, appropriate handling of alarms, and the ability to diagnose and escalate problems.

Expansion should account for the team's demonstrated capacity and the additional workload it will create. Where gaps remain, the response may be targeted training, additional staffing, simpler controls, or stronger technical support. Urgent service needs may justify expansion with that support in place rather than waiting for every skill to be developed internally. The intended progression is that physical capacity, customer demand, operating capability, and financial resources grow together.

4. Cash flow is part of system design

An oversized scheme imposes obligations immediately. Operators must inspect longer networks, read more meters, maintain more assets, manage treatment, and respond to failures even when sales remain small. Capital expenditure may be grant-funded, but operating expenditure and capital maintenance expenditure continue after construction.

A useful management measure is cash available after routine operating costs and an explicit provision for major maintenance. Collections, rather than invoices alone, determine the cash available to pay staff, buy chemicals, repair equipment, and retain essential spares. A scheme that appears affordable only because it postpones maintenance has not demonstrated sustainable operation.

For a simplified planning model:

Operating cash margin = cash collected from water sales + reliable operating support − routine operating cash costs − maintenance reserve contribution.

This measure should be tracked separately from expansion expenditure, debt service, and other financing flows. A sound operating business can have negative total cash flow during a funded expansion. Equally, a positive bank balance produced by an unspent construction grant does not demonstrate a viable operating service.

Research on business liquidity supports attention to cash management without supplying a universal profitability timetable. Afrifa's study of UK small and medium-sized enterprises examines relationships among working capital, cash flow, and performance. JPMorgan Chase Institute research finds an association between irregular cash-flow patterns and higher business exit rates. These are useful adjacent findings, not causal proof that a particular water scheme will succeed if it reaches a specified margin. [6,7]

The proposed objective is to establish a financially supported operating base early and test the incremental economics of each expansion. Where tariffs cannot cover socially necessary service, a dependable subsidy is part of the financing model. Positive operating cash flow must not become a reason to exclude households unable to pay; affordability support should be explicit and funded.

No universal rule establishes that significant income begins in year five. The more defensible point is that adoption and operational improvement take time. A multiyear funding framework can accommodate that process better than a construction deadline that assumes customers will appear immediately.

5. Hydraulic right-sizing protects water quality

Oversizing affects more than cost. A large pipe or tank operated at low demand can retain water for longer periods. EPA guidance identifies oversized infrastructure, low use, and dead ends among conditions associated with excessive water age and loss of disinfectant residual. Stagnation can create additional water-quality management burdens. [8,9]

The geometry is straightforward: stored pipe volume increases with the square of its internal diameter. A one-kilometer pipe with a 100-millimeter internal diameter contains approximately 7.85 cubic meters; one with a 75-millimeter internal diameter contains approximately 4.42 cubic meters. The larger pipe holds about 78 percent more water. At the same through-flow, its idealized displacement time increases correspondingly. This illustration is not a pipe-sizing recommendation: actual residence times depend on network topology, flow reversals, mixing, and demand patterns.

Free chlorine decays as it reacts; it does not have a single fixed expiration time. Higher water age, temperature, and chlorine demand can reduce residual before water reaches consumers. A low residual signals reduced protection and requires investigation, but does not by itself prove that the water is contaminated. Nor does all consumed chlorine become combined chlorine. Taste, odor, and disinfection by-products depend on chemistry and operating conditions; increasing the dose alone may leave the underlying residence-time problem unresolved.

Storage should be operated for the demand actually being served. Where permitted by the design, adjusting operating levels can improve turnover. Such changes must retain required treatment contact time, pressure, emergency reserves, and acceptable pump cycling. Tank layout, mixing, temperature, and the location of treatment also matter. [8,9]

Distribution expansion should be modeled for each stage, including the different demand patterns of communal taps and on-premise connections. Extended-period hydraulic and water-quality analysis can test pressure, water age, and residual management as customer uptake changes. Flushing remains an operating tool, but recurring flushing consumes water, chemicals, and labor; its costs belong in the lifecycle comparison.

6. Applying modularity across the system

Sources and boreholes

Preserve realistic pumping options when developing a source. Borehole and casing dimensions, pump clearance, access for rehabilitation, and sanitary protection can be expensive to change later. A larger drilled hole with an appropriately designed casing may preserve upgrade options, but the proposed ten-inch hole and six-inch casing are examples, not universal specifications. Geology, annular space, gravel packing, sealing, sustainable yield, water quality, and local requirements govern the design. More pump capacity cannot overcome an inadequate source.

Storage, head, and structural supports

Factory-made column segments, bolted interfaces, bracing, and tank platforms can form a repeatable structural family. Fabrication in jigs, controlled welding, inspection, and hot-dip galvanizing after fabrication offer a way to reduce inconsistent field work. Installation then centers on foundations, alignment, approved connections, and documented acceptance checks. This carries forward the standardization logic of the earlier PACE pump and structures papers. [5,10,11]

A triangular plan allows neighboring storage bays to share supports. In a simple chain of edge-sharing triangles, the first bay uses three support locations; each added bay adds one support location and two plan edges. Thus n bays use n + 2 support locations and 2n + 1 distinct plan edges. These counts describe geometry, not the complete bill of materials or structural capacity. Shared supports receive greater loads, and bracing, foundations, platforms, and access still require design.

The appropriate description is modular expansion with shared components and declining average support count per bay—not exponential growth. The marginal cost may be lower than constructing another independent tower, but savings require a complete engineered and priced comparison.

Height can also be an expansion dimension when the structural family and original foundations are designed for approved future configurations. Raising the operating water level by three meters adds approximately 29.4 kilopascals of static pressure. Whether this permits service to more distant or higher customers depends on friction losses, topography, minimum and maximum pressures, pumping capability, and source capacity.

Height increases require a designed lifting and reconstruction method, temporary stability provisions, and service-continuity arrangements. Adding segments is not automatically safe, and increasing height does not inherently increase stability. Ordinary telecommunications sections are precedents for manufacturing and assembly; their suitability for elevated water loads must be established separately. Directly embedding tower sections in concrete likewise requires a designed foundation and corrosion detail, rather than an assumed substitution for reinforcing steel.

Treatment and equipment spaces

Treatment can expand through additional validated units or parallel trains where the process permits. Buildings can preserve space and connections for future filters, dosing equipment, or contact capacity. Expansion must account for throughput, contact time, chemical storage, backwashing, maintenance access, and process reliability.

Electrical rooms may accommodate substantial capacity growth within an initial footprint if clearances, ventilation, cable routes, and equipment arrangement are planned. Geometry still matters: a three-meter-square room has nine square meters of floor area, while an equilateral triangle with three-meter sides has approximately 3.90 square meters. Triangular modules can combine into larger spaces, but equipment requirements should determine the useful shape.

Solar generation and standardized racks

Solar arrays illustrate repeatable expansion particularly well. The proposed module is a ten-position rack arranged as five columns by two rows, with panels in portrait orientation: their long dimension follows the slope, and their short edges lie uphill and downhill. Adjustable mounting provisions can accommodate an approved range of panel dimensions and loads. A nominal wattage does not define physical interchangeability.

One position can hold a secured, electrically isolated spare. At an illustrative 350 watts per panel, nine connected panels provide 3.15 kilowatts of nameplate capacity; the tenth is inventory, not generating capacity. Adding racks adds both active capacity and spares. This is a maintenance strategy, not automatic electrical redundancy. Compatibility, storage exposure, replacement testing, and safe isolation still require attention.

Mechanical rack boundaries need not define electrical strings. Series and parallel arrangements must meet the selected controller's voltage, current, and power limits under expected temperatures. Parallel strings may extend useful production during lower irradiance, subject to the pumping and source constraints. They do not guarantee a proportional increase in delivered water.

Grundfos documentation lists a 300-volt DC maximum for the referenced SQFlex range. A nominal operating voltage near that ceiling is not sufficient protection: cold-weather open-circuit voltage must remain within the applicable limit. RSI drives and SQFlex control equipment serve different motor arrangements and must not be treated as interchangeable. A later pump upgrade may reuse a compatible rack while requiring a different electrical design. [12]

Rack height and access should support safe cleaning, drainage, security, and maintenance. Elevation alone cannot prevent damage from thrown objects. Standardizing the rack should simplify installation while allowing site-specific wind, foundation, electrical, and security requirements.

Distribution and future loops

A staged network can reserve corridors and provide engineered, isolated future connection points. As demand develops, additional branches, parallel routes, or loops may relieve bottlenecks and improve continuity. Their locations should follow the master plan and hydraulic model, rather than a universal tee spacing or pipe diameter.

Loops can create useful alternative flow paths, but do not automatically eliminate low-flow areas or water-age problems. Each expansion requires review of demands, pressures, valve arrangements, flushing, and water quality. Unused connection provisions should avoid creating unnecessary stagnant branches. Some trunks should be sized for longer-term needs immediately; other sections can grow economically as demand becomes visible.

7. Established precedents for reusable engineering

The Bailey bridge demonstrates how a demanding structural function can be delivered through interchangeable manufactured parts and approved configurations. The Federal Highway Administration describes transportability, rapid assembly, and adaptation to different spans and loads among the system's requirements. The relevant lesson is that engineering can be embodied in a reusable product family and retained across many installations. [13]

Commercial radio towers offer a related precedent. ROHN markets recurring tower families and factory-fabricated, galvanized components. The engineering of a product family can be reused, while site loads, foundations, and permitted configurations still receive attention. This supports standardization; it does not establish that one tower form is universally least-cost or suitable for water storage. [11]

Westney's discussion of capital-project cost reduction and Fisher, Ramdas, and Ulrich's research on component sharing provide complementary perspectives on standardization. Common parts can reduce repeated design and procurement work, although excessive commonality can impose performance or material penalties. The aim is a small, useful family of compatible components rather than one component forced into every application. [10,14]

Geoffrey Moore's "Crossing the Chasm" offers an additional commercial analogy: adoption requires a complete solution for a defined customer group. Applied here, the implication is to establish dependable service in an achievable initial area and then extend it. This is an analogy from technology marketing, not a timetable or an empirical model of rural water adoption. [15]

8. Funding a progression rather than a construction event

A five-year funding framework is worth testing as an alternative to a single short construction cycle. It could finance the master plan, a complete first phase, early operating support where needed, monitoring, and subsequent capital tranches. Five years is a proposed program structure, not a universal requirement or a promise of profitability.

Later tranches should follow agreed evidence: sustained use, service quality, source performance, financial reporting, maintenance provision, and a credible demand case for expansion. The framework must also fund the monitoring and engineering needed to make those decisions. Operators should not be left carrying an oversized scheme while waiting indefinitely for a donor's next decision.

There are legitimate reasons to build ahead of observed purchases: urgent public-health needs, population displacement, long procurement lead times, indivisible infrastructure, and affordability constraints that suppress current demand. These should be explicit scenarios in the master plan. Incremental development succeeds when it preserves future access and responds promptly, not when it becomes an excuse to defer necessary service.

9. A practical validation program

The proposal should be tested through a limited portfolio with common reporting. Compare staged and conventional alternatives using lifecycle cost, time to functioning service, connection uptake, purchased volume, quality and continuity, cash collected, operating cost, major maintenance, and expansion disruption. Record engineering and manufacturing costs separately so that genuine repetition benefits can be distinguished from subsidy or omitted scope.

For structures, qualify a bounded family of configurations and document fabrication tolerances, inspection, coatings, connections, foundations, and expansion methods. For hydraulics and treatment, validate each phase against the intended service. For solar and pumping, define approved mechanical and electrical combinations. Track replacement-part availability and actual operator workload across the portfolio.

The proposed development model is therefore straightforward: plan the whole service, establish a complete operating base, preserve affordable upgrade paths, and commit additional capital as evidence supports it. Modularity makes incremental growth physically possible. Reliable service and financial discipline make that growth useful.

Editorial note: practitioner cases awaiting verification

The author recalls a Madagascar project costing approximately US$6 million, with consumption and payments around 10 percent of expectations. The comparison periods, forecast denominators, project scope, records, and permission to identify the project have not been verified. These figures are not used as quantitative evidence in this draft.

The author also recalls a Tanzanian well project where planned on-premise connections were not included in the funded scope. This account is not independently verified. The general implementation lesson is to align the service design, funded connections, and operating requirements.

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The Ounce of Prevention Is Worth a Pound of Cure

Proper Borehole Completion and Artesian Well Containment

Christopher Cope, PE | PACE Execution | Draft 2 | 4 November 2026

The most difficult asset to inspect

A solar rack can be inspected after installation. A water tower can be surveyed, electrical connections can be tested, and a pump can be retrieved. A borehole presents a different problem. Once the casing, filter pack, and seals have been installed, much of the construction is concealed permanently. A camera can show the inside of the casing; it cannot directly show whether the gravel reached the intended depth, whether grout surrounds the casing continuously, or whether the borehole has connected aquifers that should remain separate.

Specialist logs and hydraulic tests can investigate some concealed defects, but they do not recreate the opportunity to observe construction. Even when a defect is identified, repair may require expensive intervention, recompletion, or abandonment. The practical window for quality assurance is therefore the drilling and completion operation itself.

As a colleague put it, “You don’t get what you expect; you get what you inspect.” The drilling saying that “you can hide a thousand sins down a borehole” captures the corresponding risk. A completed installation can look satisfactory at the surface while concealing the causes of years of poor water quality, pump fouling, lost production, and groundwater leakage.

This paper argues for a straightforward change in emphasis: procure a documented, properly completed water source, supported by competent owner-side supervision, rather than accepting discharge alone as evidence of success. The water sector already has guidance for this approach. RWSN’s supervision manual and UNICEF’s drilling toolkit explicitly address oversight, contracting, and construction verification. [1,2]

One construction problem, two consequences

Poor completion can allow undesirable water into a well; it can also allow valuable groundwater to escape from its intended aquifer. Sanitary protection and artesian containment belong in the same discussion because both depend on controlling hydraulic connections. A well must admit water from approved producing intervals while sealing pathways that compromise water quality, service reliability, or the surrounding groundwater system.

Prevention requires more than purchasing better materials. It requires suitable equipment on site, an adaptable completion design, time to place and verify materials correctly, and someone with the competence and authority to stop unacceptable work before it is concealed. These are particularly consequential where maintenance services, laboratories, replacement parts, and rehabilitation equipment are difficult to obtain.

1. A productive borehole can still be a defective well

A short pumping test answers only part of the acceptance question. A well may produce the specified flow while drawing from an unsuitable shallow interval, transporting fines, mixing incompatible waters, or allowing leakage outside the casing. Conversely, a properly constructed well can encounter naturally poor groundwater. Construction quality and aquifer quality must be evaluated separately.

Contamination pathways and treatment consequences

Unsealed wellheads, open cable penetrations, poorly sealed casing joints, shallow screens, and incomplete annular seals can create pathways for contaminated runoff or shallow groundwater. Relevant hazards depend on local land use: faecal microorganisms; nitrate and nitrite associated with sanitation, manure, and fertilizer; pesticides; and organic chemicals associated with fuels, solvents, or other activities. A sanitary seal interrupts a pathway. It cannot remove contaminants already present throughout the producing aquifer.

“Organic matter” and “volatile organic compounds” are not interchangeable. VOCs are one subset of organic chemicals. Natural organic matter includes compounds derived from vegetation and other biological material. When chlorine reacts with natural organic matter, it can form disinfection byproducts, including trihalomethanes (THMs, reported collectively as total THMs or TTHMs) and haloacetic acids (HAAs). Their formation depends on water chemistry and treatment conditions; an open wellhead alone does not establish that they are present. [3]

The response is to protect the source and manage treatment appropriately, including relevant testing. Necessary disinfection should not be withheld because byproducts are possible. Nor should chlorination be treated as a repair for uncontrolled source contamination.

Iron fouling: distinguish the deposit from its cause

Iron may originate naturally in the formation and enter as dissolved ferrous iron. Contact with oxygen, changes in chemistry, and microbial activity can promote formation of iron-rich precipitates and biofilms. These deposits can obstruct screens, pumps, and pipework. Iron-oxidizing bacteria may occur naturally or be introduced during drilling and servicing; visible rust-coloured material does not by itself demonstrate bacterial activity or surface contamination. [4]

There is a relevant published analogue: Burte and colleagues documented geothermal-well clogging associated with mixing shallow oxygen- and nitrate-bearing groundwater with deeper anoxic water containing dissolved iron and manganese. Microbial activity aggravated deposition. This establishes a credible mechanism for concern about mixed inflows, but does not diagnose any particular African borehole. [5]

Christopher Cope reports frequent pump fouling in western Rhino Camp, including Amogu5, with pumps removed for cleaning or replacement, equipment sent to Kampala, and wells flushed to remove iron-rich deposits. These observations illustrate a recurring operational burden. The relative contributions of formation chemistry, casing corrosion, microbial activity, shallow inflow, and maintenance practices remain to be established at each site.

Air-based rehabilitation can introduce oxygen and temporarily change precipitation conditions. Nevertheless, flushing, surging, or airlifting can be appropriate rehabilitation methods. Their net effect depends on the procedure and subsequent removal of deposits. A useful investigation would combine maintenance histories, deposit examination, dissolved and total iron, dissolved oxygen, pH, microbiological assessment, and depth-resolved inflow information. Repeated cleaning without investigating the source of recurrence may leave the principal failure mechanism intact.

2. Completion must be designed and verified

A drilling programme should begin with an expected geological sequence, target intervals, contamination risks, and an initial completion design. It must also allow documented changes as actual conditions become known. Reaching the planned depth is not an end in itself: stopping early or drilling deeper can be justified, but only by an authorized decision based on recorded evidence. Unrecorded shortfalls are not an acceptable substitute for that decision.

Control drill-string loading and deviation

A drill bit needs a controlled load against the formation. “Drilling under tension” therefore does not mean removing all compression from the bottom-hole assembly. In conventional vertical rotary drilling, stiff drill collars provide weight on bit while the more flexible drill pipe above remains in tension. The transition between tension and compression should remain within the assembly designed to carry that load. [14]

Excessive feed or allowing too much drill-string weight onto the bit can bend the rods and increase lateral forces. The bit may then cut away from the intended trajectory. Boart Longyear identifies excessive feed pressure as a cause of deviation and also identifies ground conditions, setup, and equipment wear as contributing factors. A straight hole depends on the complete drilling system, not tension alone. [15]

The US Army Corps of Engineers’ water-well manual specifically emphasizes drill collars and controlled pullback for alignment, including with down-the-hole hammers. Its warning is directly relevant to water projects: excessive curvature can prevent installation of screens, casing, or pumps. [16]

Aggressive feeding may appear to save rig time, but an initially faster penetration rate is not necessarily a lower cost per completed well. Deviation, doglegs, wall contact, and poor hole cleaning can increase drag and complicate advancement, retrieval, and casing installation. They can leave a drilled interval that cannot be completed as planned. These problems increase the risk of failing to reach or complete the target interval and can erase the apparent saving in drilling time.

Match the method to the formation

Rotary mud drilling is often preferable to unsupported air-hammer drilling in loose, unconsolidated formations because a properly managed fluid system can support the hole and transport cuttings. The US Army Corps manual distinguishes mud-rotary applications in unconsolidated formations from air-drilling applications in consolidated rock. [16] Temporary casing, casing-advancement systems, or other methods may also be appropriate where fluids alone cannot provide stability.

Unconsolidated and poorly consolidated aquifers are important in Africa, including the Lake Chad Basin and sedimentary areas of Turkana. British Geological Survey country profiles describe these settings. They should not be treated as negligible exceptions, nor should a regional name substitute for a site-specific geological assessment. [17,18]

Blanket avoidance of drilling mud can limit the ability to stabilize the hole and install a proper completion. Conversely, unsuitable fluids or inadequate development can impair performance. The programme should specify compatible fluids, clean construction water, circulation capacity, solids management, and development. A drilling-fluid pump and a grout-placement pump serve different operations; the equipment must be suitable for each duty.

Inspect capability before mobilization

Verify the available bits, drill collars and stabilizing equipment, casing and screen quantities, jointing tools, centralizers, tremie equipment, grout mixer and pump, test equipment, and contingency materials. Log drilled depths, lithology, water strikes, losses, and depth-indexed conductivity and water-quality observations where practicable. Samples collected during drilling may be mixed or affected by drilling fluids; their provenance must be recorded.

Completion details: clearance, joints, and support

Provide usable annular clearance

For the lowered, packed-and-sealed completion discussed here, PACE proposes a nominal design starting point of 2 inches (50.8 mm) of radial clearance around the casing body: a borehole diameter 4 inches (101.6 mm) greater than the actual casing outside diameter. California guidance provides a comparable 2-inch annular-space recommendation when a tremie is used. [6] This is a starting specification, not a universal standard for every well-construction method.

For example, a casing body with an actual 6.0-inch outside diameter in a 10.0-inch hole has 2.0 inches of nominal clearance on each side when centred. If a coupling has a 7.0-inch outside diameter, clearance at that coupling is only 1.5 inches. Where a full 2-inch clearance is required around the coupling, the corresponding hole diameter is at least 11.0 inches. Nominal pipe size must not be substituted for actual outside dimensions.

Adequate clearance reduces the likelihood of casing hanging up and provides space for the tremie, pack, and seals. It does not guarantee that the casing will reach depth. Check the largest coupling diameter, centralizer geometry, tremie outside diameter, deviations, ledges, and hole condition together. Centralizers preserve stand-off but cannot straighten an inadequately drilled hole. Hole enlargement must also remain compatible with the rig's circulation and cuttings-removal capability.

Treat plain casing and its joints as a hydraulic barrier

Plain casing must exclude water along intervals intended to remain isolated. A joint that merely holds the next casing length is inadequate: it must also meet the specified watertightness and structural requirements. Make this function explicit in drawings, specifications, inspection criteria, and acceptance. Weld gaps, pinholes, or defective threaded seals can bypass an otherwise sound completion. Minnesota's well-construction requirements provide one clear example of an explicit watertight-joint requirement. [19]

Welded steel casing can perform well when square, properly prepared ends are aligned and joined using a suitable welding procedure. Poorly aligned joints can create local bends and projections that hinder installation. Remove slag and dress obstructive irregularities as the procedure permits; do not grind away required weld reinforcement or reduce the casing wall merely to produce a smooth appearance. Ontario guidance illustrates controlled steel-casing welding and alternative joint systems. [20]

Where field welding quality is difficult to assure, factory-threaded steel casing with suitable threaded couplings is a practical procurement option. It reduces dependence on repeated field butt welds and makes connection requirements more repeatable. Threads still require compatible components, inspection, correct engagement and make-up, and the specified potable-water-compatible sealing arrangement. A screwed connection is not automatically watertight. Coupling outside diameter and joint strength must be included in the design.

A suitable guide shoe or rounded bottom fitting can protect the leading edge and help it pass minor irregularities. It does not replace centralizers or correct a severe dogleg. A drive shoe for driven steel casing performs a different duty from a guide fitting on a lowered string. Select the component for the installation method and required bottom closure. [7,20]

Completion details: materials, pack, and seals

Select PVC or steel for the actual loads

Purpose-made PVC well casing and screens can be attractive around 100 m depth because of corrosion resistance and handling advantages. Boode, for example, offers engineered PVC well products with specified connection and collapse properties, including products for substantially greater depths. That demonstrates feasibility, not the suitability of any PVC pipe for any 100 m well. Select the particular casing, screen, and connection system from verified ratings. [21]

Check suspended weight and joint tensile capacity, bending during installation, external differential pressure, screen strength, temperature, and compatibility with grouting and future rehabilitation. Forcing PVC into a tight or crooked hole can damage it, but collapse is not exclusively an installation-friction problem. External pressure can exceed internal pressure during grouting, pumping, or development. Grout heat and uneven external support may also matter. Monitoring-well guidance from California DTSC describes these structural considerations; production-well design must use the applicable product and operating loads. [22]

Steel may be preferable where impact, driving, structural loads, or pressure requirements justify it. It also requires an assessment of corrosion and long-term wall loss. The selection should address the whole completion and service life rather than assuming steel is always stronger in practice or PVC is always sufficient below a particular depth.

Support the casing deliberately

For a casing-and-screen string lowered into an oversized borehole, the US Army Corps manual describes clamping and suspending the string at the top before placing filter material. [16] A rated support arrangement should preserve the intended installation depth and avoid uncontrolled axial compression from stacking the string on an irregular bottom.

Suspension can help keep a flexible string extended, but it cannot remove a dogleg or overcome wall contact. Check the capacity of the support, casing joints, and screens for the suspended load, and account for buoyancy or uplift during grouting. Use suitable handling equipment; Ontario guidance recommends proper casing elevators. [20] The design must identify both temporary installation support and the final load path. Driven casing seated in rock and other engineered arrangements require support provisions appropriate to those methods.

Place the pack and seals where the design requires them

Screens need specified slot dimensions and open area matched to the formation and filter pack. Uncontrolled torch-cut or saw-cut openings cannot be assumed to meet those requirements. Select and place the pack through a controlled procedure, checking for bridging and settlement. Counting bags does not establish the installed interval: compare quantities with calculated annular volumes, sound the pack top, and reconcile discrepancies before covering the work.

Place pumpable grout from the bottom of the sealing interval upward using appropriate equipment. Pellet or chip products need their own approved procedures. Record quantities, mix properties, placement depths, returns where applicable, and hydration or setting time. Check bentonite suitability against water chemistry, confinement, and pressure. A surface apron, wellhead seal, annular sanitary seal, and interaquifer seal serve different functions. [7]

Seal locations must follow geology and hydraulic objectives. Repeated seals at casing-joint intervals may miss confining strata. An annular seal between two screens does not isolate aquifers if both screens open into the same continuous casing: water can still move internally. Where isolation is required, omit the unsuitable interval or use a specifically engineered isolated completion.

3. Make the owner's interests visible at the rig

The central governance risk arises when the contractor controls the design decisions, construction records, testing, and certification on which its own payment depends, while the owner has little independent capacity to verify them. This arrangement creates a conflict of interest even when the participants act honestly. A higher contract price alone does not remove it.

Design–build is a legitimate delivery method. Separating designer and builder is commonly called design–bid–build, and neither label by itself guarantees quality. The essential safeguard is competent verification accountable to the owner, supported by clear acceptance criteria and authority over concealed work. Contractor quality control remains necessary; it does not replace owner-side assurance.

This is already supported by water-sector practice. UNICEF's toolkit provides separate terms for siting and supervision consultancy and for drilling works. Its supervision provisions call for a resident supervisor throughout drilling, equipment checks, systematic records, and verification of completion. [2] In petroleum drilling, a publicly filed turnkey contract likewise provides for a company-appointed drilling supervisor with access to tests, the mud programme, work, and records. Turnkey delivery does not inherently eliminate independent owner representation. [8]

The transferable lesson is the function of supervision, not the oil industry's budget or a fixed staffing count. Staffing must cover the hours when critical operations occur. The representative needs relevant practical experience, technical judgment, and contractual authority; a qualification alone is insufficient, and the rig crew cannot be expected to substitute for an absent owner representative.

Proposed inspection hold points

Stage	Evidence required before release
Mobilization	Verify equipment, consumables, qualified personnel, clean water, and artesian contingency capability.
Final drilling depth	Verify depth, logs, water strikes, alignment and completion access; authorize changes.
Casing and screens	Approve intervals, ratings, joints, shoe, clearances, centralizers, tally and support before running.
Pack and seals	Witness placement; reconcile quantities and sounded levels; record deviations before concealment.
Development and testing	Witness agreed development, pumping/recovery tests, sampling, and artesian-control verification.
Handover	Accept as-built records, water-quality results, operating limits, and closure of nonconformances.

Pay for an accepted source, not discharge alone

Contracts should specify construction, documentation, water quality, sand production, development, test conditions, and containment requirements alongside yield. Use witnessed sampling and a competent laboratory, with sample traceability. Define how naturally unsuitable groundwater, dry holes, legitimate design changes, and defective workmanship will be treated. Unfairly transferring geological risk can create incentives to conceal unfavourable conditions. Link staged payments to verified work and completed records; provide a workable variation process and defined remedies.

4. Artesian containment protects more than one well

An artesian aquifer is confined under pressure; a flowing artesian well occurs when its hydraulic head is above the discharge elevation. If a borehole connects zones with different heads, water can flow from the higher-head zone into the lower-head zone, including when the pump is off. Under pumping, gradients and the direction of individual inflows can change. The higher-pressure aquifer is not necessarily the most productive aquifer.

Leakage can occur through a common screened casing, failed joints, an unsealed annulus, or connected fractures. Closing a valve at the wellhead addresses only the controlled discharge path. It does not demonstrate that subsurface leakage has stopped. Flow control must account for both the casing interior and the exterior pathway through the drilled confining sequence. Ontario's guidance emphasizes sealing casing into the confining layer and selecting grouting methods for the actual pressure and flow. [9]

Artesian risk should be assessed before drilling through the confining unit. The design should provide appropriate surface or conductor casing, seals, pressure-rated components, and suitable well-control equipment and personnel. Washington State provides a useful regulatory example: a written sealing plan is required where flowing conditions are known or suspected. These overseas examples illustrate engineering practice; they do not replace the requirements of the country where a project is built. [10]

Field examples and the scale of uncontrolled discharge

Cope identifies a Tanzanian well, a Ugandan well, and a Kenyan well as examples warranting assessment, reporting surface flows on the order of or above 100 m^3/h. These are field-reported examples, not independently established site measurements in this paper. Measurement methods and operating conditions should be verified before developing formal case studies.

At a constant illustrative discharge of 100 m^3/h, one well releases 2,400 m^3/day and 876,000 m^3 in a 365-day year: 876 million litres. That calculation describes surface discharge under the stated assumption. It does not quantify hidden interaquifer leakage. Pumped production and free flow must be measured over their respective operating periods; adding a full year of free flow to all pumped production can double-count water if pumping changes or replaces the free flow.

Uncontrolled discharge can lower confined-aquifer head and alter flow to other wells or springs. The affected area and long-term depletion depend on aquifer properties, recharge, boundaries, and cumulative withdrawals. Water entering another aquifer is a loss from the source aquifer, even though it is not necessarily lost from the wider groundwater system. Its destination and quality matter. A single well's discharge does not establish a continent-wide effect.

Australia's Great Artesian Basin provides an established management precedent. The New South Wales government reports pressure recovery in many areas following bore capping and piping. This supports treating containment as resource management, while leaving the benefits of any African intervention to be demonstrated locally. [11]

Prevention and remediation have shared beneficiaries

Proper completion can protect service users, reduce the operator's maintenance burden, and preserve groundwater head and quality for other users and ecosystems. Existing uncontrolled wells deserve investigation and remediation where feasible. New wells should be designed so that preventable leakage does not become the next generation's rehabilitation programme.

5. Evaluate the cost of an accepted water service

Centralizers, sound joints, adequate annular clearance, suitable screens, controlled placement, and competent supervision have real costs. Some projects also require larger rigs, additional casing, specialized equipment, or more time. It would therefore be premature to claim a universal percentage premium. The stronger proposition is that the incremental construction cost should be compared with the failures it can prevent over the service life.

The comparison should include pump retrieval, cleaning and replacement, transport to workshops, well rehabilitation, treatment, staff time, service interruptions, alternative water supplies, and premature replacement of the source. Where containment is involved, include the consequences of uncontrolled discharge and effects on other users. A low drilling invoice can transfer substantial costs to people and institutions with the least capacity to absorb them.

An illustrative break-even test makes the argument measurable. If verified completion and supervision cost an additional $3,000 and avoid a $1,500 intervention every two years, the undiscounted saving reaches $3,000 after two avoided interventions. These are hypothetical inputs, not Rhino Camp costs. A project appraisal should use actual failure probabilities, intervention costs, timing, discount rate, and the degree to which the proposed measure can prevent each failure.

PACE's practical recommendation is to record those costs prospectively. Compare completion records, water quality, specific capacity, sand production, pump maintenance, and downtime across wells with different verified construction practices. This can establish where additional effort produces the largest improvement in dependable water service.

The prevention commitment

Every new borehole should have an accountable owner representative, an approved and adaptable completion design, witnessed verification of work that will become concealed, and acceptance based on both construction integrity and intended water service. Where artesian conditions exist, that commitment must include control of surface discharge and unintended subsurface communication.

The owner should be able to explain where water enters, which intervals are excluded, how the pack and seals were placed, what was verified, and what operating limits apply. If these questions cannot be answered at handover, the project has accepted uncertainty that later inspections may never resolve.

Companion website illustrations

PACE_Borehole_Comparison.png illustrates adverse completion: deviation, limited surface sealing, shallow screens, gravel bridging, trapped components, and missed deeper targets. PACE_Borehole_Completion_Review.png illustrates completion components including wellhead sealing, centralizers, pack, and annular seals. They are conceptual illustrations, not site investigation records or universal specifications. [12,13]

Read the completion illustration with three technical qualifications: seal locations and lengths must follow site geology and pressure; its screens at multiple depths are not hydraulically isolated merely by the intervening annular seal; and dimensions, pump placement, and mechanical support details require project-specific design. The adverse illustration's iron and oxygen pathways represent mechanisms to investigate, not measured conditions at Amogu5 or another named site.

References and source notes

Numbered references support the associated technical or governance statements. Field examples are attributed to Christopher Cope's account of 4 November 2026. The proposed hold points and economic illustration are recommendations and calculations developed for this draft.

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12. PACE Execution. PACE_Borehole_Comparison.png. Version 15. Conceptual adverse-completion illustration. Source

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