The Ounce of Prevention Is Worth a Pound of Cure

Proper Borehole Completion and Artesian Well Containment

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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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3. Texas Commission on Environmental Quality. Disinfection Byproducts in Drinking Water. Source

4. Minnesota Department of Health. Iron Bacteria in Well Water. Source

5. Burte, L., et al. (2019). Kinetic study on clogging of a geothermal pumping well triggered by mixing-induced biogeochemical reactions. Environmental Science & Technology. DOI: 10.1021/acs.est.9b00453. Source

6. California Department of Water Resources. Combined Well Standards, Appendices: centralizers and tremie placement guidance. Source

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8. Publicly filed drilling contract (2005), SEC Exhibit 10.32, §6.2, Company's Representative. A documented turnkey example, not a survey of industry practice. Source

9. Ontario. Water Supply Wells: Requirements and Best Practices, Chapter 12, Flowing Wells. Source

10. Washington Administrative Code 173-160-251. Special sealing standards for artesian wells. Jurisdiction-specific example. Source

11. New South Wales Government. Great Artesian Basin, "Cap and pipe the bores." Updated 11 July 2025. Source

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

13. PACE Execution. PACE_Borehole_Completion_Review.png. Version 14. Conceptual completion illustration. Source

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15. Boart Longyear. How to reduce drill hole deviation. Source

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17. British Geological Survey. Africa Groundwater Atlas: Hydrogeology of Chad. Source

18. British Geological Survey. Africa Groundwater Atlas: Hydrogeology of Kenya. Source

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22. California DTSC (2014). Well Design and Construction for Monitoring Groundwater at Contaminated Sites. Structural casing considerations. Source