



Design and Implementation of Water-Positive Construction Sites

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Abstract : Construction sites use water for concrete mixing and curing, masonry, plastering, cleaning, dust suppression, equipment washing and worker facilities. Yet site water is often managed as a supply requirement rather than as a resource that can be planned, recovered and monitored. This study examines construction professionals' reported water-management practices and implementation concerns, and combines the survey with published case studies to develop a practical Construction Management-oriented framework. The analysis uses 130 completed questionnaire records from a survey distributed through online and offline modes; descriptive statistics and the Relative Importance Index (RII) are used for the relevant five-point grid items. Eight published cases are reviewed, including dewatering-water reuse at a construction site, wastewater reuse at a Pune campus, rainwater harvesting in India, a Delhi rainwater-harvesting assessment, and an urban stormwater scheme in Australia. Groundwater or borewell was the most frequently reported main water source (33.1%), while concrete mixing and curing was the activity most often identified as a major water-use area (26.9%). The highest-ranked reported problems were failure to reuse suitable wastewater (RII 70.9%) and lack of water-consumption records (70.0%). Water-quality concerns (RII 76.2%) and unclear responsibility (76.0%) were the most frequently experienced implementation barriers by RII. At the same time, 65.4% considered an integrated water-management plan effective, and 70.0% considered training and awareness necessary or very necessary. Based on these findings, the paper proposes a staged management framework covering governance, demand assessment, demand reduction, source recovery, fit-for-purpose quality checks, reuse, role assignment, monitoring and verification. The findings reflect reported professional experience and published evidence; no direct site water measurements or field validation of the framework were undertaken.

IndexTerms - Construction water management; water-positive construction; construction management; rainwater harvesting; water reuse; implementation barriers; performance indicators

I. INTRODUCTION

Water is a basic requirement for construction, but the way it is planned and managed can vary considerably from one project to another. Concrete mixing and curing, masonry, plastering, cleaning, dust suppression, equipment washing and worker facilities all require water, while the demand at a given site changes with the work programme, local climate, construction method and available supply. In practice, the main management question is not simply whether water is available. It is also whether the project understands where water is used, where losses occur, which activities require particular water quality, and whether a suitable alternative source can be used safely.

Construction water management has received less attention than some other project resources, including materials, energy and solid waste. Research on building water footprints has shown that water impacts may arise both from direct site activities and from the materials incorporated into a building (Bardhan, 2011; Bardhan & Roy Choudhuri, 2016; Rauf et al., 2024). For the construction stage, activity-based assessment is important because site demand is linked to the sequence of work, including curing, masonry and finishing operations (Garg et al., 2023). These findings support treating water as a planned project resource, rather than only a utility arranged by the site team when required.

A water-positive approach seeks to move beyond isolated water-saving actions. At the level of a construction project, this may involve reducing avoidable demand, collecting rainwater, assessing dewatering water where it occurs, recovering and reusing suitable wastewater, monitoring sources and uses, and considering responsible water replenishment where appropriate. However, the term 'water positive' should not be used as a label for any project that installs a rainwater tank or reports lower freshwater consumption. The claim requires a defined system boundary, transparent measurement and evidence for any replenishment or beneficial-return outcome. Bona et al. (2025) similarly identify the need for clear parameters as water management moves from efficient buildings towards more integrated water communities.

The management challenge is therefore both technical and organisational. Water reuse may be technically possible but still fail if no one is responsible for testing, approvals, operation or maintenance. A treatment unit may be installed without sufficient storage or a dependable reuse demand. Rainwater potential may be estimated from an annual rainfall figure without considering seasonal timing, catchment losses or storage capacity. Wu et al. (2020) offer a strategic framework for adopting water-saving measures throughout construction project stages, while Waidyasekara et al. (2016) show that professional perceptions, cost and the priority given to water management influence implementation. Construction projects need an approach that connects these considerations in everyday planning and site control.

1.1 Research problem and gap

Existing literature provides separate evidence on construction water consumption, embodied water, rainwater harvesting, wastewater treatment and reuse, groundwater recovery, and water-sensitive planning. The practical gap addressed here is the need to bring these individual strands into a clear management sequence that can guide construction professionals through planning, implementation, monitoring and review. This is especially important because several published cases concern buildings, campuses or urban water schemes rather than measured performance at active construction sites. Their technical approaches cannot be transferred automatically; their management lessons must be adapted to project duration, site space, demand, water quality, cost and local requirements.

1.2 Aim and objectives

The aim of this study is to examine existing water-management practices and implementation barriers, and to develop a practical Construction Management-oriented framework for improving water management at construction sites.

The work follows six related objectives:

- To study the major sources and areas of water consumption associated with construction activities.
- To review existing water conservation, rainwater harvesting, water reuse, recycling, and replenishment practices applicable to construction sites.
- To assess the awareness and perceptions of construction professionals regarding water management and water-positive construction practices.
- To identify the major technical, economic, regulatory, and management challenges affecting the implementation of water-positive practices at construction sites.
- To analyse published case studies and the primary survey findings to identify suitable and practical water-management strategies for construction projects.
- To develop a practical Construction Management-oriented framework with implementation guidelines and performance indicators for improving water management at construction sites.

II. REVIEW OF RELATED LITERATURE

2.1 Construction water use and the case for measurement

Research on construction water use shows why the resource should be considered at more than one scale. Bardhan (2011) studied water consumption in Indian building construction and drew attention to the contribution of site activities and construction materials. Bardhan and Roy Choudhuri (2016) examined virtual water in urban buildings, reinforcing the value of life-cycle thinking. Garg et al. (2023) developed an activity-based approach for estimating construction-phase water footprints in Indian buildings. Together, these studies indicate that the demand profile is affected by material choices as well as on-site operations. The present paper focuses on the latter from a Construction Management perspective, while recognising that a complete water footprint would also need to account for embodied water in materials.

Measurement is a basic requirement for management. Without a baseline or source-wise record, project teams cannot distinguish a genuine increase in demand caused by a change in work activity from unnecessary use or leakage. Wu et al. (2020) grouped water-saving measures into source substitution, consumption reduction and monitoring. This broad structure is helpful because it links simple site actions—such as leak detection and monitoring major uses—with larger interventions such as harvested rainwater or recycled water.

2.2 Water conservation, reuse and implementation barriers

Conservation begins with avoiding unnecessary use. Leakage inspection, controlled outlets, better housekeeping, work instructions and worker awareness are often easier to implement than large treatment or recycling installations. Waidyasekara et al. (2016), using a survey of construction professionals, found that cost and water-source issues can motivate water-use efficiency, while low priority for water management can obstruct it. Their results also favoured practical behavioural and management measures alongside technical solutions. The implication for this study is that a framework should not prescribe technology first; it should begin with demand and loss assessment and then select measures suited to the project.

Reuse and recycling can reduce dependence on freshwater, but only when the source and intended use are matched. Mandal et al. (2011) examined greywater treatment and reuse in an Indian urban setting, while Masi et al. (2022) documented a nature-based wastewater treatment and reuse system at the College of Engineering Pune campus. These cases demonstrate the potential of decentralised reuse for non-potable demands. At the same time, Karunasena et al. (2024a, 2024b) discuss coordination and liquid-waste management gaps in the construction sector. The management task therefore includes identifying water streams, assigning responsibility for testing and approval, providing storage and distribution, and keeping operational records.

2.3 Integrated water management and water-positive approaches

Rainwater harvesting and catchment-based storage can provide an alternative source, but the benefit depends on rainfall, roof or ground catchment, runoff characteristics, storage and demand timing. The BARC Trombay case reported substantial reservoir capacity from rainwater harvesting (Srivastava et al., 2006), while the COEP hostel case demonstrates wastewater treatment and reuse at campus scale (Masi et al., 2022). The Orange stormwater scheme in New South Wales provides a different, urban-scale example in which stormwater is captured and treated as part of wider water-supply resilience (Department of Climate Change, Energy, the Environment and Water [DCCEEW], 2026). These examples illustrate a range of possible interventions, but their scale and setting differ from a temporary construction site.

Water-sensitive urban design and circular-water literature make a further point: outcomes should be judged using the whole system, not one device. Schulze et al. (2024) discuss the potential of water-sensitive design across urban scales, while Bona et al. (2025) call for clearer parameters for emerging near-zero-water and water-community concepts. Policy analysis in the Indian construction context also points to questions of enforceability and accountability (Sakhardande et al., 2025). For construction management, this means water-positive aspirations need explicit boundaries, assigned roles, feasible interventions and performance evidence.

2.4 Research gap

The reviewed work establishes several useful technical and conceptual directions, but three implementation needs remain relevant to the present study. First, individual options are often discussed separately, whereas construction managers must assess them as a package. Second, professional perceptions help indicate what may hinder adoption, but they do not prove that a practice is implemented or has reduced water use at a particular site. Third, water-efficient buildings, institutional campuses and urban catchments offer useful lessons but do not by themselves establish construction-stage water-positive performance. This study addresses these needs by combining a professional questionnaire, a comparative review of eight published cases and a staged management framework. Its contribution is a management approach, not a claim of measured water savings or a field-tested net-positive water balance.

III. METHODOLOGY

3.1 Research design and data sources

The study used a descriptive and exploratory design. The descriptive component summarised reported water sources, major water-use areas, familiarity with water-management concepts, reported practices, perceived barriers and views about implementation. The exploratory component combined these responses with literature and case-study lessons to identify a practical management sequence. The research did not include a physical site survey, flow-meter measurements, water-quality testing by the research team, a mathematical optimisation model or a software-based prediction system.

Primary data were collected through a structured questionnaire prepared around the research objectives. It covered four demographic questions and items on sources of water, major water-use areas, the frequency of water-related problems, familiarity with water-management concepts, reported practices, implementation barriers and views about water-positive management. The questionnaire was distributed through online and offline modes. The distribution record described 200 questionnaires; the supplied response workbook contained 130 completed records, which formed the dataset used in the analysis. Thus, 130 records were analysed (65% of 200 distributed questionnaires). The workbook contained no blank response cells in the 130 records analysed.

A non-probability approach combining convenience and purposive sampling was used to reach construction professionals. The dataset includes project managers, site engineers, planning engineers, consultants, contractors and other construction professionals. Since the sampling frame was not probability-based and no geographic stratification is documented in the response file, the results are interpreted as views within the survey sample rather than estimates representative of the entire construction industry.

3.2 Analysis procedure

Frequencies and percentages were calculated for each response category. The response distributions for the four grid questions were analysed item by item. Relative Importance Index (RII) was calculated for grid items using the five-point response weights, with higher scores indicating more frequent problems, greater familiarity, more frequent implementation or more frequently experienced barriers, according to the scale used in each question. The index was expressed as a percentage of the highest possible score:

$$RII (\%) = [\Sigma W / (A \times N)] \times 100$$

where ΣW is the sum of the assigned response weights, A is the maximum weight (5), and N is the number of responses for the item (130). RII ranks are interpreted within their respective question group; values from different scales are not treated as directly equivalent, and they are not tests of statistical significance. Descriptive analysis was carried out using the survey workbook and statistical tabulation approach described in the dissertation. No inferential tests or reliability coefficient are reported here because the paper's principal evidence is the observed descriptive pattern and the complete reliability output is not presented in the thesis results.

3.3 Case-study review and framework synthesis

Eight published cases were compared according to setting, main source, intervention, reported outcome and management lesson. They included a residential construction site in Fortaleza, the COEP hostel campus in Pune, BARC Trombay, Orange in New South Wales, Wadia College in Pune, the Centre for Science and Environment site in Delhi, a Delhi sports-complex rainwater assessment and an unnamed Indian higher-education campus. The selection includes one case directly focused on an active construction site and several institutional or catchment-scale examples. The latter were used as transferable management evidence, not as proof of construction-site performance.

Survey and case-study findings were then combined to formulate the framework. Particular attention was paid to the issues highlighted by the survey—wastewater reuse, water-consumption records, water quality, responsibility, initial cost and space—as well as lessons from the cases about demand matching, source quality, storage, operating cost, maintenance and the difference between estimated potential and measured results.

IV. RESULTS AND INTERPRETATION

4.1 Demographic Profile of respondents

The 130 respondents represented a mix of age groups and construction-related roles. The largest age group was 34–42 years (40 respondents; 30.8%), and 68.5% of respondents were male. Project managers formed the largest professional group (38.5%), followed by site engineers (21.5%) and planning engineers (19.2%). The two largest experience groups were 6–10 years (29.2%) and 11–15 years (27.7%). This profile includes professionals connected with project planning, site execution and coordination, while also reflecting the limitations of a non-probability sample.

Table 4.1. Selected characteristics of the survey sample (N = 130)

Dimension	Most represented category	Frequency	Percentage
Age	34–42 years	40	30.8%
Gender	Male	89	68.5%
Professional role	Project Manager	50	38.5%
Professional experience	6–10 years	38	29.2%
Professional experience	11–15 years	36	27.7%

4.2 Reported sources and major water-use areas

Groundwater or borewell water was the most frequently reported main source (33.1%). Municipal supply and tanker-supplied water each accounted for 23.1%. Harvested rainwater was selected by 12.3% and treated or recycled wastewater by 6.9%. These answers suggest that respondents more often encountered conventional supply sources than recovered water as the main source at the sites they knew. They do not establish the actual source mix or water volume of a particular project.

Concrete mixing and curing was the activity most often identified as a major water-use area (26.9%), followed by masonry and plastering (21.5%) and general site cleaning and maintenance (20.8%). Toilets and other domestic requirements accounted for 16.9%. The pattern suggests that water planning should include core construction activities and the less visible but recurring needs of cleaning and site maintenance. The results are a ranking of respondents' perceptions, not activity-level meter readings.

Table 4.2. Reported main water source and activity considered a major water-use area

Survey item	Category	Frequency	Percentage
Main source	Groundwater or borewell	43	33.1%
	Municipal water supply	30	23.1%
	Water supplied through tankers	30	23.1%
	Harvested rainwater	16	12.3%
	Treated or recycled wastewater	9	6.9%
Major use area	Concrete mixing and curing	35	26.9%
	Masonry and plastering	28	21.5%
	General site cleaning and maintenance	27	20.8%
	Toilets and other domestic requirements	22	16.9%

4.3 Water-related problems, familiarity and reported practices

The highest RII among the reported water-related problems was recorded for suitable wastewater not being reused (70.9%). Lack of proper water-consumption records followed at 70.0%, while use of freshwater where suitable non-potable water could be used scored 69.4%. These priorities point to a combined challenge: water may be lost as a resource because the site does not recover it, and management may lack the records needed to recognise the opportunity. Leakage and runoff collection remained relevant, although their RII values were lower within this problem group.

Familiarity was strongest for reuse and recycling of suitable wastewater (RII 69.8%) and water monitoring and consumption recording (68.3%). Rainwater harvesting and groundwater recharge received the lowest familiarity index within that set (64.8%). This is not evidence that respondents lack the ability to implement harvesting; it suggests that the subject may need clearer practical guidance on catchment assessment, feasibility, water quality, storage and maintenance.

Among the six reported practices, worker awareness had the highest implementation RII (77.7%), followed by collection of rainwater for suitable site requirements (76.9%) and reuse of treated water for suitable non-potable activities (76.5%). Monitoring and recording water consumption had an RII of 75.8%. The result is encouraging, but these are self-reported practice frequencies and were not confirmed through site audits. The grouping around 'often' and 'sometimes' across items suggests there may be scope to make existing practices more consistent and routine.

Table 4.3. Highest-ranked items within the four five-point grid sections

Question group	Highest-ranked item	Mean score	RII	Interpretation within group
Water-related problems	Suitable wastewater not being reused	3.55	70.9%	Most frequently reported problem
Water-management concepts	Reuse and recycling of suitable wastewater	3.49	69.8%	Highest familiarity
Reported practices	Water conservation awareness among workers	3.88	77.7%	Most frequently reported practice
Implementation barriers	Concerns about the quality of reused water	3.81	76.2%	Most frequently experienced barrier

4.4 Perceptions of feasibility and adoption

Most respondents viewed early water planning positively: 61.5% agreed or strongly agreed that water management should be included in construction planning and budgeting from the beginning. Similarly, 66.2% considered freshwater reduction important or very important where suitable non-potable water could be used, and 61.5% rated rainwater harvesting and groundwater recharge as feasible or very feasible. These figures suggest that the core ideas are not unfamiliar to the sample, although the feasibility judgment remains dependent on local conditions.

Support for appropriately treated water reuse was selected by 64.6% of respondents. Agreement that meters and consumption records can reduce wastage reached 66.2%. The two results complement one another: reuse planning can identify alternative supply, while metering can help establish how much is actually delivered and used. A quality approval process remains essential because water suitable for one activity may not be suitable for another.

Seventy per cent of respondents selected ‘clearly’ or ‘very clearly’ when asked about the assignment of water-management responsibilities. However, the separate barrier grid ranked lack of clear responsibility as a frequently experienced challenge (RII 76.0%). The questions framed the issue differently: one asked about clarity at sites known to the respondent, while the other asked how frequently unclear responsibility affects implementation more generally. Rather than collapsing these answers into one measure, the pattern suggests that responsibilities may be clear on some projects while remaining a sector-wide implementation concern.

The likelihood of adopting a formal water-management plan was more mixed. A total of 52.3% were very likely or likely to adopt a plan if practical guidelines were available; 29.2% were neutral and 18.5% were unlikely or very unlikely. By contrast, 70.0% considered training and awareness necessary or very necessary, 63.8% considered performance indicators important or very important, 65.4% considered an integrated water-management plan effective or very effective, and 68.5% described the industry as ready or very ready. The gap between general support and formal-plan adoption underlines the need for simple, cost-conscious implementation guidance.

Table 4.4 Selected positive responses relating to implementation

Question focus	Combined positive categories	Frequency	Percentage
Water management included in early planning	Agree / Strongly Agree	80	61.5%
Reduce freshwater where suitable non-potable water is available	Important / Very Important	86	66.2%
Support treated-water reuse for suitable non-potable activities	Support / Strongly Support	84	64.6%
Monitoring and records can reduce wastage	Agree / Strongly Agree	86	66.2%
Training and awareness are needed	Necessary / Very Necessary	91	70.0%
Integrated management plan would be effective	Effective / Very Effective	85	65.4%
Ready to adopt water-positive practices	Ready / Very Ready	89	68.5%
Likely to adopt a formal water plan	Likely / Very Likely	68	52.3%

4.5 Barriers to implementation

The barrier results need to be read in two ways. The frequency grid ranked water-quality concerns first (RII 76.2%), followed closely by lack of clear responsibility (76.0%), low management priority (73.7%) and lack of space or infrastructure (72.6%). When asked to select only one single most significant barrier, respondents selected high initial implementation cost most often (22.3%), followed by quality concerns about reused water (21.5%) and lack of infrastructure or available space (19.2%). The questions are different and do not have to produce the same order: one rates the frequency of several barriers; the other requires a single choice.

The findings suggest that cost is a decision barrier, while water quality and responsibility are ongoing operational concerns. A feasible framework must address all three. It should require a preliminary cost and demand assessment before installing a system, a fit-for-purpose water-quality review before use, and a responsibility matrix that names who approves, operates, records and maintains the system. Space constraints also mean that not every construction site will support storage tanks, treatment units or extensive reuse infrastructure. The framework should allow a project to select a suitable combination rather than demand the same facilities everywhere.

5. COMPARATIVE LESSONS FROM PUBLISHED CASE STUDIES

The case studies show that useful water-management interventions differ in scale, source and maturity. Their common value is not that they prove all sites can become water positive; instead, they show what needs to be checked before a measure is adopted. Table 5 summarises the cases discussed in the dissertation and distinguishes calculated potential from reported operational outcomes.

Table 4.5 Comparative summary of selected published cases

Case and setting	Water-management approach	Reported point in source	Transferable management lesson
Fortaleza, Brazil (Sousa et al., 2021)	Recovery of dewatering groundwater for selected site uses and later landscape irrigation	Reported construction-stage saving of R\$225,869.04; estimated 294 m ³ /month for later irrigation	Test water quality and match each source to a specified use before budgeting for reuse.
COEP hostel campus, Pune (Masi et al., 2022)	Anaerobic treatment and constructed wetlands for domestic wastewater reuse	Around 180 m ³ /day processed; reused water intended for flushing and landscaping	Plan treatment, storage, demand and maintenance as one operating system.
BARC, Trombay, Mumbai (Srivastava et al., 2006)	Rainwater harvesting and reservoir storage	Nearly 400 million litres of storage capacity reported; a further 150 million litres identified	Assess catchment, storage, intended use, capital cost and maintenance.
Orange, New South Wales (DCCEW, 2026)	Catchment-based stormwater capture, treatment and storage	Scheme reported to supply up to 25% of annual unrestricted urban water demand	Coordinate water quality, storage, risk control, monitoring and responsibilities.
Wadia College, Pune (Shah & Madurwar, 2014)	Roof and playground runoff collection, filtering and groundwater recharge	Authors reported harvesting potential near 46 million litres/year and a 40% reduction in municipal water bill	Use site and drainage surveys and maintain filters, pipes, pits and wells.

CSE, New Delhi (CSE, 2017)	Rainwater harvesting plus decentralised wastewater treatment and reuse	About 8 KLD design capacity; case record notes around 1,200 litres used for a lawn-watering event	Reserve space and maintenance access; match capacity to actual demand.
Delhi sports-complex assessment (Hamid & Mehmood, 2024)	Calculated rainwater yield compared with pool and replenishment demand	Estimated potential of 29,693.8 m ³ /year; calculated potential, not measured annual capture	Separate estimated yield from measured capture and consider seasonal balance.
Indian higher-education campus (Zang et al., 2021)	Combined wastewater reclamation and roof rainwater harvesting	32% of annual demand from reclaimed wastewater and 7% from roof-collected rainwater	Compare water yield, cost, energy, chemicals and demand before selecting measures.
			
Case Study 1: Illustrative view of water collection and temporary reuse at a construction site	Case Study 2: Illustrative view of a constructed wetland and treated-water storage system.	Case Study 3: Illustrative view of reservoir storage and controlled runoff.	Case Study 4: Illustrative view of urban stormwater treatment wetlands and storage.
			
Case Study 5: Illustrative campus rainwater-harvesting and recharge arrangement.	Case Study 6: Illustrative decentralised wastewater treatment and reuse landscape.	Case Study 7: Illustrative sports complex with rainwater collection and retention features.	Case Study 8: Illustrative integrated campus water-reuse system.

5.1 Cross-case interpretation

The Fortaleza case is the closest match to construction-stage reuse because it assessed groundwater collected through dewatering at a residential construction project (Sousa et al., 2021). It points to an opportunity that depends on an existing site operation, but the water-quality check remains central. The same principle applies to runoff, wash water or other recovered streams: the presence of water does not establish suitability for every purpose. The construction manager must identify the source, intended use, volume, quality requirement, storage route and responsible operator.

The COEP, BARC, Wadia College and CSE examples show the value of planning systems as a whole. Treatment or collection facilities are only one part of the arrangement; the project must also identify demand, provide space and access, maintain equipment and establish where the recovered water will go. The Delhi sports-complex case reinforces a separate distinction between potential and measured performance: the estimated annual yield depends on assumptions about catchment and rainfall and cannot be treated as actual captured water. Similarly, the Orange scheme shows integrated catchment-scale treatment and monitoring, but it is an urban supply project rather than a construction-site trial (DCCEEW, 2026).

Zang et al. (2021) also show why cost must be considered along with water performance. In their higher-education campus case, reclaimed wastewater supplied a substantial share of demand, whereas the rainwater-harvesting component was less attractive under the conditions assessed because of its capital cost. This is a useful lesson for construction management: a technically possible option is not automatically the best option for a temporary project with limited duration. Whole-life cost, operational skill, the quantity and timing of demand, and system handover all affect the decision.

VI. PROPOSED WATER POSITIVE CONSTRUCTION SITE MANAGEMENT FRAMEWORK

6.1 Framework logic

The combined findings support a framework that provides a consistent decision sequence without prescribing one technical installation for every construction project. The framework is intended as a management tool for planning, resourcing, coordinating, monitoring and reviewing water. It is not a detailed hydraulic or treatment-plant design. Its main value is to ensure that the choices about water-saving and recovery are connected to project scope, quality requirements, cost, responsibility and evidence.

6.1 Framework stages

Table 6.1 Framework stages and management records

Stage	Key management action	Record or output
1. Governance and baseline	Define the scope, name the accountable lead, and record sources and uses.	Approved plan and source register.
2. Assess demand	Estimate activity demand, seasonality, project duration and losses.	Demand estimate and source-use map.
3. Reduce	Repair leaks, control overflow, and issue practical work instructions.	Inspection and corrective-action log.
4. Identify recovery sources	Assess rainwater, dewatering water and suitable wastewater.	Source assessment and feasibility note.
5. Check quality and approval	Match source quality to the intended use; record testing and approval.	Source-use matrix and test records.
6. Collect and reuse	Plan treatment if needed, fit-for-purpose storage, labelled distribution and back-up.	Operation and maintenance plan; reuse log.
7. Monitor and improve	Compare actual use, reuse, losses and costs; address exceptions.	Performance review and corrective-action log.
8. Verify claims	Document measured performance and evidence for any replenishment claim.	Close-out report and performance statement.

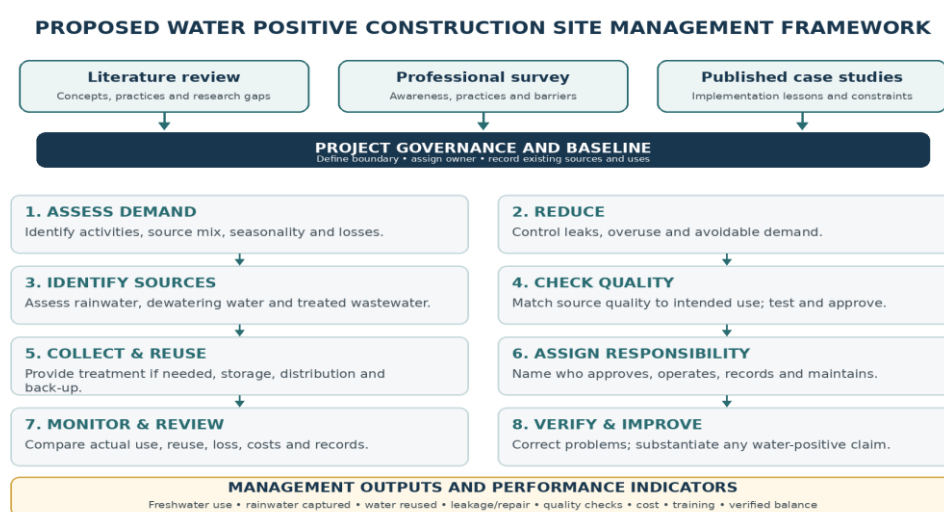


Figure 6.1. Proposed management sequence for water-positive construction sites.

6.2 Planning and demand reduction

The first stage is to define what the project intends to manage. A simple boundary can include water entering the site, important uses, water captured or recovered, water reused and water discharged. If the scope excludes embodied water in materials, this should be stated. The baseline should list major construction activities and water sources, with better measurement applied to high-demand or high-risk activities where feasible. The survey points to concrete mixing and curing, masonry and plastering, and general site cleaning as practical areas for attention, although the relative importance at any specific project should be confirmed through site records.

Demand reduction should precede investment in complex systems. Leak inspection, hose and outlet control, tank-overflow prevention, planned cleaning and worker instructions can be incorporated into routine site supervision. This ordering is consistent with the survey's high ranking for worker awareness as a reported practice and with the construction management literature on behavioural and organisational measures (Waidyasekara et al., 2016). Demand reduction should never undermine essential construction quality, appropriate curing, health or safety requirements; the aim is controlled use, not arbitrary restriction.

6.3 Source recovery, quality and reuse

After avoidable demand has been addressed, the project can assess sources that may be recovered. Rainwater is more attractive where the catchment and seasonal supply are adequate, storage is possible and a compatible use exists. Dewatering water may be available during excavation, but quantity and quality can vary. Wastewater from equipment washing or other site activity may be recoverable only after considering contamination, treatment need and the approved use. The source assessment should include expected quantity, timing, collection location, water-quality risks, legal requirements, capital and operating cost, and the duration for which the project will need the system.

A 'fit-for-purpose' approval gate is central to the framework. It should record what water is proposed for what use and what checks are required. It should not assume that non-potable water is acceptable for every activity. Testing, treatment, storage and distribution requirements depend on the water source and use; they should be agreed with competent personnel and applicable regulations. Separate and clearly labelled distribution lines, safe access, and maintenance responsibility reduce the risk of misuse or cross-connection. These measures turn reuse from an informal idea into a controlled site operation.

6.4 Roles, records and performance indicators

The framework assigns responsibility as a management control. The client or project director sets expectations and approves appropriate resources. The project manager coordinates the plan and reviews performance. Site engineers and supervisors maintain

records, inspect for losses and apply approved-use rules. Contractors and subcontractors follow site instructions and report leakage or failures. System vendors maintain treatment or collection assets within the agreed scope, while a competent laboratory or specialist supports water-quality checks where required. Workers need short, practical instructions on conserving water, reporting losses and using recovered water only for authorised purposes.

A small number of reliable indicators is preferable to a long list of measures that cannot be collected consistently. Depending on the project, the site may monitor source-wise incoming water, freshwater use, rainwater actually captured and delivered, recovered water treated, water reused for approved purposes, leakage incidents, response time, water-quality compliance, operating cost and training coverage.

For any intensity indicator, the denominator—such as a defined quantity of work—must be clear. Estimated harvesting potential should be kept separate from measured capture. The same volume should not be counted more than once as a newly recovered resource.

6.5 Implementation over the project life cycle

During pre-construction, the project should identify likely demand, available sources, site space, regulatory conditions, expected system life and budget. During mobilisation, responsibilities should be assigned, records started, water points and separate lines labelled where needed, and staff briefed. During active construction, the plan should be operated alongside the work programme, with source-wise recording and inspections. Periodic review should compare planned and actual results and revise the plan when the scope, sequence, water source or season changes. At close-out, the team should retain a summary of use, reuse, quality checks, cost and maintenance issues so that lessons can be transferred to later projects.

The framework is deliberately flexible. A short-duration project with limited space may achieve most of its immediate improvement through demand control, leak repair, records and a limited reuse opportunity. A longer project with a dependable wastewater stream may be able to justify a more developed treatment and reuse arrangement. The decision is based on site conditions and evidence, not on the expectation that every possible measure must be installed.

6.6 Water accounting and the meaning of a water-positive claim

A water-management plan should make a distinction between input reduction, water recovery and replenishment. Input reduction can be shown by comparing source-wise supply with a documented baseline, provided that the work scope and measurement period are comparable. Reuse should be recorded as the volume of water actually treated and delivered to an approved end use, not simply the theoretical capacity of a treatment unit. Rainwater should be recorded as captured volume where a meter or reasonable measurement method exists; a calculation based on rainfall and catchment area should remain labelled as estimated potential.

The accounting boundary should also define whether the assessment covers the temporary construction stage only or includes the completed building and its operational water system. This matters because a project can save freshwater during execution without demonstrating that it has replenished or returned water to the relevant catchment. Where water-positive language is used, the report should describe the calculation method, data limitations and the basis of any replenishment action. Reused water should not be double-counted as both new supply and replenishment, and a water-quality result should be linked to the specific intended use. These rules are intended to improve the transparency of project reporting; the present survey did not measure a net water balance at any site.

VII. DISCUSSION AND CONSTRUCTION MANAGEMENT IMPLICATIONS

The survey points to three connected concerns: suitable wastewater is often not reused, water-use records are limited, and freshwater may be used where an approved alternative is available. These issues show that recovery depends on information: managers need a basic record of sources, demand, reuse and losses before selecting investments.

Respondents were generally positive about integrated water management, but adoption remains uncertain: 52.3% were likely or very likely to adopt a formal plan, while 29.2% were neutral. Initial cost was the most commonly selected single barrier; water-quality concerns and unclear responsibility were the most frequent barriers. The framework should therefore clarify decisions, approvals, records and life-cycle costs early.

The case studies add practical detail to these findings. Water recovered at a construction site or campus becomes useful only when there is a defined demand and the required quality, storage, treatment and maintenance arrangements. Rainwater potential must be assessed against catchment and seasonality. The Orange case indicates what coordinated stormwater management can achieve at urban scale, but its reported contribution to city water demand cannot be transferred directly to a temporary site. Likewise, campus wastewater systems offer lessons on reuse and operation, rather than proof of water-positive performance during construction. These distinctions matter when a research paper translates diverse case studies into one management framework.

For construction managers, the proposed contribution is an integrated sequence that can be embedded in project planning, procurement, site supervision, worker briefings, cost control and project close-out. It does not require a sophisticated digital platform to begin. A source register, demand estimate, leak inspection log, water-quality approval, reuse log and periodic performance review may provide the basic control structure. Digital metering can improve the process where it is feasible, but a measurement system creates value only when the records are reviewed and trigger action.

Finally, the term ‘water positive’ deserves discipline. Lower freshwater demand is an important achievement, as are rainwater capture and appropriate reuse. However, a claim that a project is net water positive requires a specified boundary and evidence for the relevant balance and replenishment or return outcome. The present study proposes a framework that can help organise such evidence, but the survey does not measure water volume and the case studies do not collectively demonstrate a water-positive balance for construction sites. The next step is a live-site pilot with source-wise metering and independent review.

7.1 Implications for procurement, cost and project control

The survey finding that initial implementation cost was the most commonly selected single barrier has a direct implication for procurement and budgeting. Water-management options should be considered early enough to compare capital cost with the cost

of operation, water supply, energy, testing, maintenance and the remaining project duration. A reusable asset that takes years to recover its cost may not be appropriate for a short construction programme unless it has a value after project completion or can be redeployed. Conversely, leak repair, controlled washing points, clear work instructions and simple logs may be justified even on short-duration projects because they require limited infrastructure.

Procurement documents can also specify the practical requirements for water systems: the source to be accepted, the intended uses, quality testing and approval responsibilities, storage and distribution needs, maintenance expectations, data to be returned, and the method for reporting failures. These details help avoid the common situation in which equipment is installed but operational responsibilities remain unclear. From a project-control perspective, water indicators can be reviewed alongside programme and cost information at routine site meetings. The aim is not to create extra paperwork; it is to connect water records with decisions about repair, source selection, activity planning and expenditure.

7.2 Priorities for different construction settings

The same management sequence can lead to different priorities in different settings. In a compact urban site, limited space may make storage and treatment difficult, so the first actions may be demand reduction, leak detection, water-use scheduling and selective reuse from a predictable source. On a larger site, separate collection areas, temporary storage or a more formal source-wise monitoring plan may be practical. Where excavation creates a steady flow of dewatering water, a source assessment can be useful, but quality, discharge permission and effects on local groundwater need to be checked before reuse.

In areas with seasonal rainfall, rainwater harvesting should be assessed against storage capacity and the timing of demand instead of relying on an annual potential figure alone. A long-duration project may have more time to benefit from a fixed treatment or storage system than a small project that will close soon. These are management decisions rather than universal technical prescriptions. The proposed framework is intended to help a project document why a measure was selected, what assumptions were used, who will operate it and how its performance will be checked.

VIII. LIMITATIONS AND FUTURE RESEARCH

The study has several limitations. First, the survey used convenience and purposive sampling and should not be treated as representative of the whole construction industry. The supplied dataset does not establish a probability sampling frame or provide a basis for national estimates. Second, the results capture professional reports and perceptions, not direct measurements of water consumption, quality, reuse or savings at construction sites. Third, the eight cases vary in scale and type: the set includes an active construction site, institutional campuses, an urban stormwater system and a calculated rainwater-harvesting assessment. Reported quantities cannot be compared as if they came from identical trials. Fourth, the framework has not been evaluated through a monitored live-site implementation in this study; its practical effectiveness remains to be tested.

Future work should apply the framework at a live project and define a baseline before introducing measures. Source-wise meters and activity records could be used to measure freshwater use, captured rainwater, reuse volume, losses and costs over defined construction stages. A pilot could also evaluate water quality, seasonal variability, treatment energy, maintenance needs and the effect of project duration on whole-life cost. A broader professional sample and structured expert review could refine the responsibility matrix and indicators. These steps would test whether the proposed management sequence produces repeatable improvements and what evidence is needed for a defensible water-positive claim.

IX. CONCLUSION

This study examined water management at construction sites through a professional questionnaire and eight published case studies, then used the combined findings to develop a Construction Management-oriented framework. Groundwater or borewell water was the most frequently reported main source, while concrete mixing and curing was the activity most often identified as a major water-use area. The leading reported problems were failure to reuse suitable wastewater and lack of consumption records. Water-quality concerns and unclear responsibilities were the most frequently experienced barriers by RII, while initial cost was the most common single barrier selected by respondents.

Overall, the findings support a flexible management sequence linking conservation, source recovery, quality checks, reuse, monitoring and clear responsibilities. The cases offer transferable lessons, not proof of net water-positive performance. A live-site pilot should test the framework using measured water data and transparent accounting.

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