PAPER 5

BLUEPRINTS REIMAGINED: AN INTEGRATED WATER SECURITY STRATEGY FOR A WATER-STRESSED MUNICIPALITY – THE PRINCE ALBERT TOWN CASE STUDY

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ABSTRACT

Small to medium-sized municipalities in arid and semi-arid regions are becoming increasingly vulnerable to water shortages due to growing demands, climate variability, limited or restricted surface water allocations, ageing infrastructure and growing reliance on groundwater that is already under stress. The town of Prince Albert, located at the northern foothills of the Swartberg Mountains, reflects many of these challenges, having experienced repeated significant summer water shortages.

This paper presents a reimagined approach to the town's water security, developed through a comprehensive feasibility study, that brings together surface water management, short-term storage and managed aquifer recharge into one flexible and coordinated system. The proposed strategy combines several smaller, permanent, low-impact interventions, comprising an intake weir with reliable flow measurement and sediment control, off channel raw water storage and a series of check dams and a sand dam designed to support natural and assisted groundwater recharge.

Hydrological modelling based on below-average rainfall conditions and informed by climate change projections shows that a phased off-channel storage volume of 50,000 m^3, expandable to 100,000 m^3, can provide more than 72-months of water supply security when used together with moderate water demand management measures and existing groundwater sources. The inclusion of flood control and recharge structures promotes groundwater recharge and strengthens groundwater reserves, limits flood damage, while still meeting environmental flow requirements and protecting downstream water users.

The study demonstrates that carefully rethinking conventional water infrastructure, with an emphasis on flexibility, modular design and phased implementation, can significantly improve resilience without large once-off capital expenditure. Institutional coordination, environmental approvals and water demand and leakage management are integral to the proposed system, supporting long-term sustainability and regulatory compliance.

This case study provides a practical and transferable framework for other water-stressed municipalities, showing how integrated multidisciplinary planning, sound engineering and data driven decision-making can turn fragmented water sources into resilient and climate-responsive municipal water supply systems.

INTRODUCTION

Water security has become one of the most critical infrastructure challenges facing municipalities across South Africa. In South Africa, an analysis conducted by the Water Resources Group projects a water demand of 17.7 billion m^3/a against supply of approximately 15 billion m^3/a, resulting in a national shortfall of approximately 17% by 2030, if no major interventions are undertaken (Water Resources Group, 2012). Sixteen years later, in 2026, the situation has not changed as demonstrated in **Figure 1**.

The increasing frequency of prolonged droughts, declining reliability of surface water systems, ageing infrastructure, growing populations and climate uncertainty have shifted water resource planning from a supply-driven discipline to a resilience-driven discipline. Traditional municipal water supply systems have historically been developed around a dominant source, commonly a dam, river abstraction scheme or groundwater wellfield. While this approach was effective under relatively stable climatic

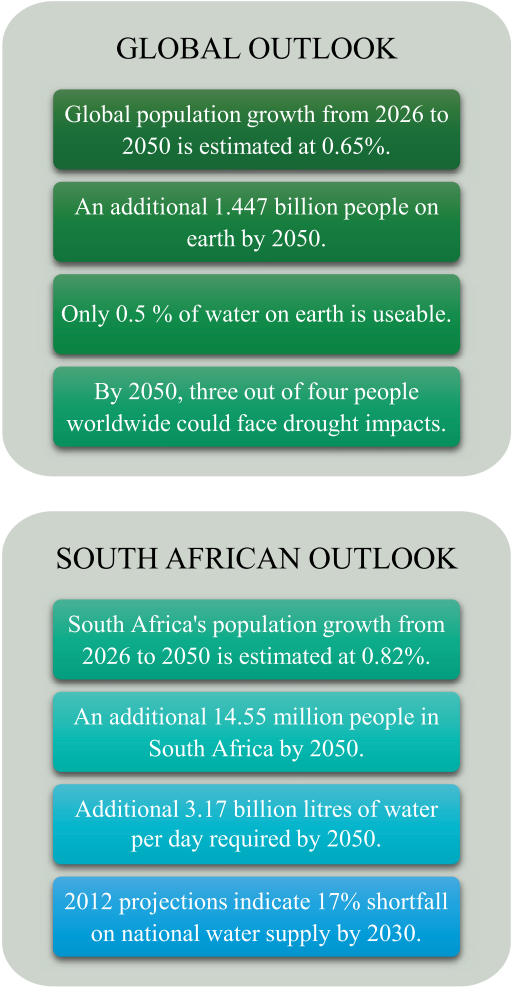


FIGURE 1: *Global and South Africa Water Outlook (United Nations, 2026); (Government of South Africa, 2024); (Water Resources Group, 2012)*

conditions, it has proven increasingly vulnerable in semi-arid and arid regions where hydrological variability is high.

Prince Albert Municipality is located within the Great Karoo region of the Western Cape and is one of the most water constrained regions in South Africa. The municipality relies on a combination of surface water abstraction from the Dorps River and groundwater abstraction from municipal boreholes. Although this conjunctive-use strategy has historically provided sufficient water, recurring droughts and increasing seasonal demand have reduced the reliability of the existing water supply system. During peak summer periods, the available supply reaches operational limits, increasing the risk of water shortages.

The feasibility study presented an opportunity to move beyond conventional augmentation planning and investigate a more comprehensive water security strategy. Rather than identifying a single infrastructure intervention, the study sought to develop an integrated raw water management system that improves resilience through source diversification, storage optimisation, groundwater recharge enhancement and operational flexibility. The resulting feasibility study therefore adopted a systems-based approach where multiple infrastructure components operate collectively to improve overall water security of the town.

This paper presents the engineering methodology, analysis, outcomes and lessons learnt from the feasibility study and proposes a framework for climate-resilient municipal water source management applicable to municipalities located in arid and semi-arid environments.

EXISTING WATER SOURCES AND FUTURE DEMAND

Current Water Supply

Prince Albert Town currently utilises a conjunctive water supply system comprising both surface water and groundwater sources. Surface water is abstracted from the Dorps River through the Kweekvallei Water Users Association (WUA) infrastructure, while groundwater is supplied from a municipal borehole field located south of the town. This approach has historically provided a degree of resilience against seasonal fluctuations in water availability and has enabled the municipality to maintain water supply during periods of reduced river flow.

The municipality holds a total authorised abstraction allocation of 500,000 m^3/a, consisting of 121,000 m^3/a from the Dorps River and 379,000 m^3/a from groundwater sources. In addition, the municipality receives a portion of the water conveyed through the WUA irrigation canal system, where a long-standing agreement provides access to a share of the available surface water resource.

Analysis of operational records indicates that current municipal water demand varies significantly throughout the year, ranging from a minimum measured daily demand of 0.42 ML/day during winter periods to peak demands exceeding 4.0 ML/day during the summer season. The calculated average annual demand based on the readings is rounded to 1.5 ML/day. Seasonal variations are largely driven by increased domestic consumption, tourism activity and irrigation-related water use during the summer months.

The average monthly consumption of Prince Albert Town has been presented in **Figure 2**.

Although the existing conjunctive-use system has generally been successful in maintaining supply, recent drought periods have demonstrated the vulnerability of the current arrangement. Extended periods of reduced river flows, increasing pressure on groundwater resources and limited operational storage have constrained the municipality's ability to respond to prolonged dry periods. Consequently, the town is becoming increasingly reliant on the effective management of water demand, as well as its surface water and groundwater resources, to maintain an acceptable level of water supply security.

Future Water Demand

Future water requirements were assessed using the Neighbourhood Planning and Design Guide "Old Red Book" planning methodology and a projected population growth rate of 3.32% per annum over a 20-year

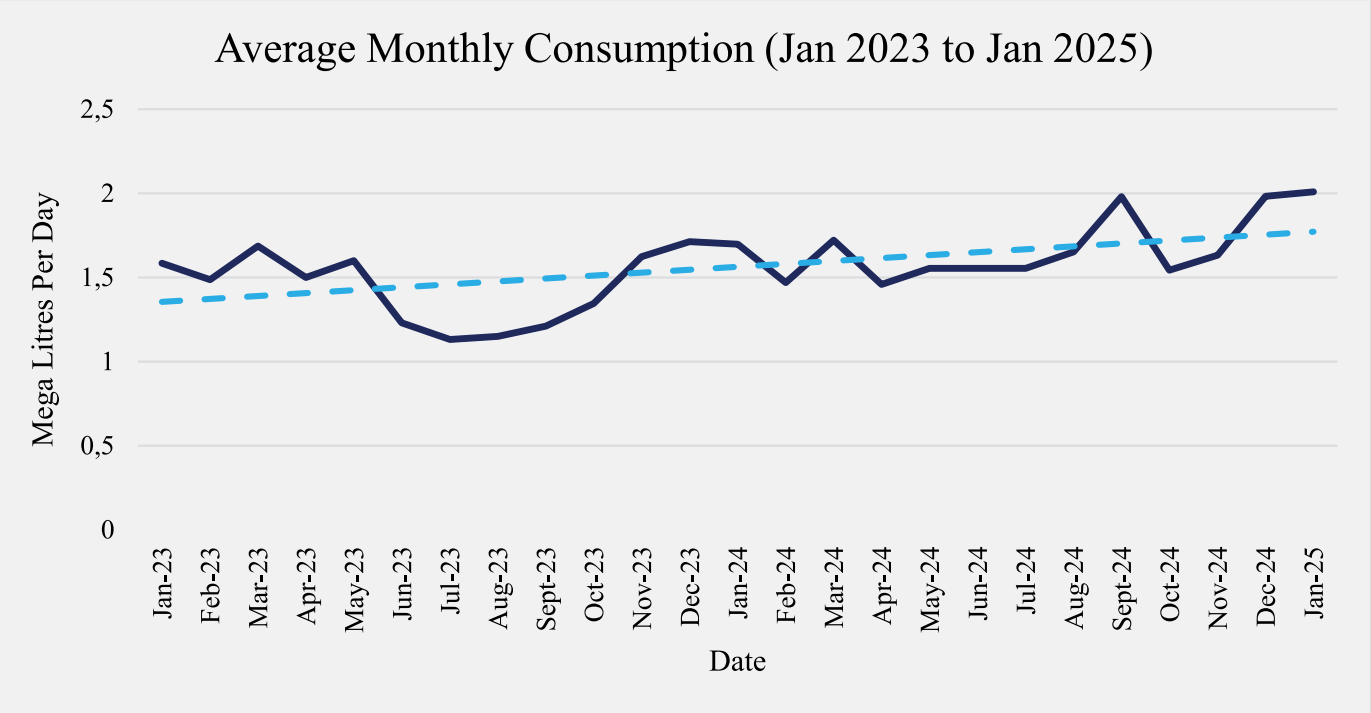


FIGURE 2: *Prince Albert Town average monthly consumption (Jan 2023 to Jan 2025)*

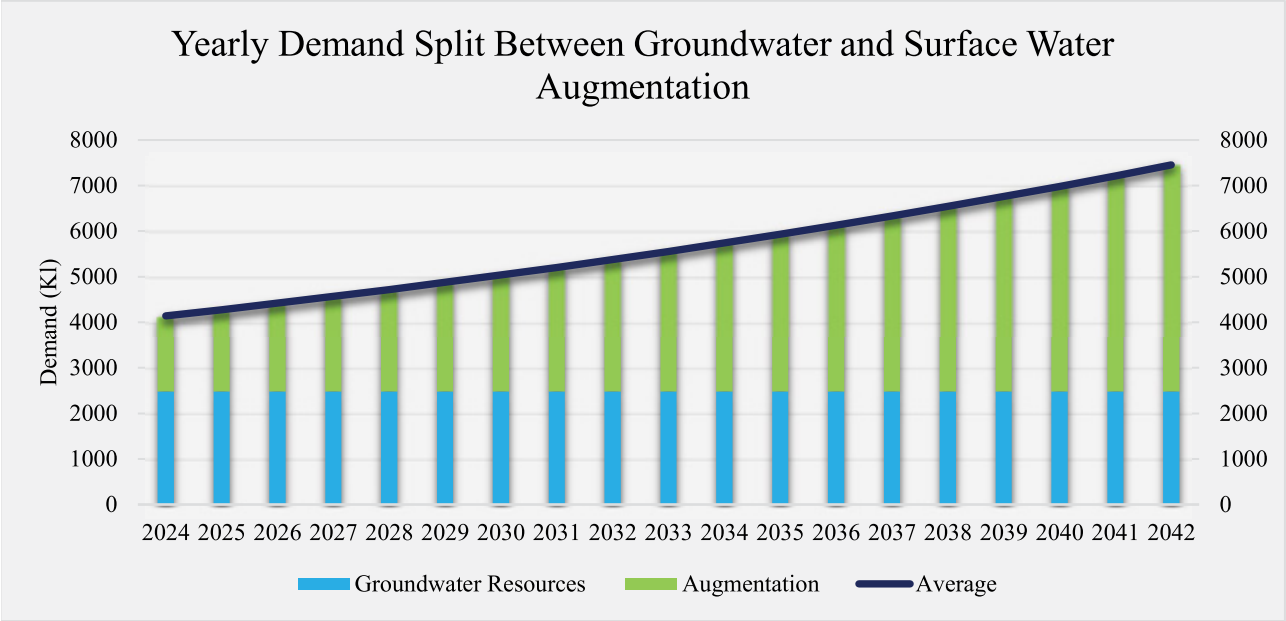


FIGURE 3: *Yearly demand split between groundwater and surface water augmentation*

planning horizon. The assessment indicates that the population of Prince Albert Town could increase from approximately 17,800 residents in 2024 to more than 32,000 residents by 2042. This growth will place significant pressure on the municipality's existing water resources and supporting infrastructure.

Based on the planning projections, average daily water demand is expected to increase from rounded 1.5 ML/day to 5 ML/day by 2042, while peak summer demands may increase from rounded 4.1 ML/day to 7.5 ML/day. These projected demands exceed the capacity that can be reliably supplied from the existing licensed resources during periods of drought and reduced river flow.

The projected annual average demand has been presented in **Figure 3,** indicating the required increase in the raw water augmentation from surface water sources.

An important observation from the feasibility study was that actual water consumption is currently lower than theoretical planning values. This is largely attributed to the existing demand management being implemented and the water-conscious behaviour of residents as a result of long-term exposure to water scarcity and drought conditions. While this behaviour has assisted the municipality in managing current demand, future planning cannot assume that these reduced consumption patterns will remain unchanged in the long term. Infrastructure planning therefore adopted a conservative approach by considering both observed consumption trends and projected development demands.

The demand assessment clearly illustrates that future water security cannot be achieved through continued reliance on existing system alone. Additional storage, improved operational control, enhanced groundwater recharge and optimisation of available surface-water resources will be required to ensure a reliable raw water supply capable of supporting future municipal growth and increasing climate variability.

DESIGN REFERENCE DATA AND VALIDATION

Importance of Data Confidence

A common challenge in Prince Albert Town's water resource planning is the absence of long-term, high-quality hydrological datasets. The Dorps River catchment has no permanent flow gauging stations currently, to provide sufficiently detailed information to accurately quantify low flows, flood frequencies and seasonal variability. Consequently, the study adopted a multiple-lines-of-evidence approach whereby independent datasets were analysed and cross-validated to improve confidence in the design assumptions.

The design process integrated:

- South African Weather Service rainfall records;
- Cape Nature weather station data;
- CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data) precipitation datasets;
- Catchment hydrological modelling;
- Existing water use information;
- Groundwater investigations;
- Historical operating practices of the Water Users Association.

The resulting mean annual precipitation (MAP) of 322 mm/a correlates well with previous regional studies and rainfall station analyses as indicated in **Table 1**.

TABLE 1: *Summary of rainfall datasets*

Rainfall Dataset	Mean Annual Precipitation (MAP)
[1]Old Toll Station	322 mm/a
[2]Oukloof Yield Study	329 mm/a
Catchment Average Estimate	335 mm/a

[1]Cape Nature; [2]Department of Water and Sanitation

Probabilistic analysis of precipitation data from 1995 to 2024 for the lower Dorps River catchment near Prince Albert Town indicates a greater likelihood of below-average annual rainfall than of annual rainfall equalling or exceeding the long-term mean. Despite this skew towards below-average conditions, the probability of annual precipitation declining to less than 50% of the mean annual rainfall is estimated at less than 0.002 (1:500). The probability of experiencing two successive years with rainfall below 50% of

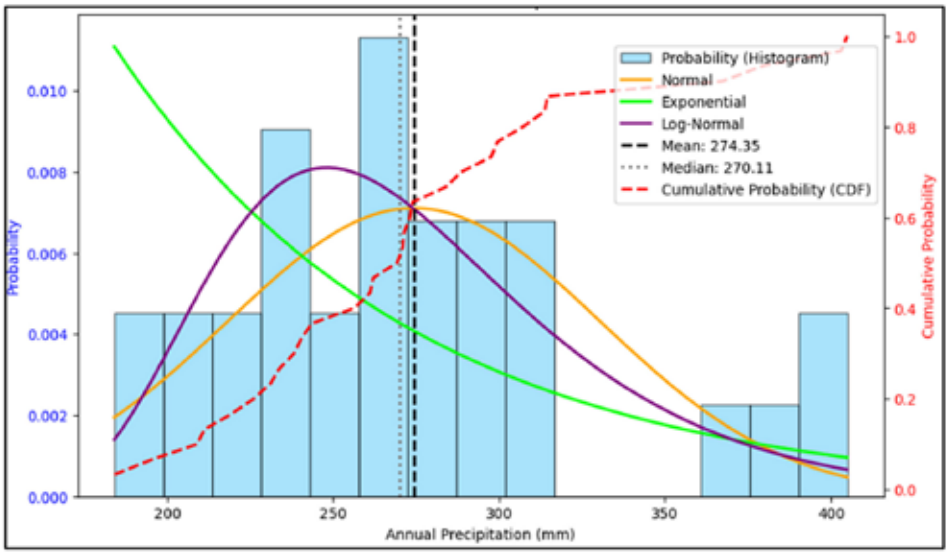


FIGURE 4: *Histogram showing annual precipitation distribution for catchment near Prince Albert Town derived from CHIRPS estimates (Myburgh, 2025)*

the mean is substantially lower, estimated at less than 0.000004 (1:250,000), as shown in **Figure 4**.

The close agreement between independently derived data sets increases confidence that the adopted hydrological inputs are representative of actual catchment conditions.

Based on this data, the interventions were evaluated against the scenario that the catchment will receive rainfall less than 50% Mean Annual Runoff (MAR) in three consecutive years.

Demand Validation

An important observation during the study was the significant difference between theoretical demand projections and actual demand measurements.

Design demand projections based on The Neighbourhood Planning and Design Guide, "Old CSIR Redbook", produced estimated future water demands considerably higher than current consumption trends. Further investigation revealed that Prince Albert Town residents have become exceptionally water conscious due to historical water resource constraints and recurrent drought conditions. The difference is presented in **Table 2**.

TABLE 2: *Standard design vs actual water use*

Water Use (2024)	Demand
Standard Design Norms (Department of Human Settlements, 2019)	2.76ML/d
Actual	1.5ML/d

Whilst actual consumption provides a useful indicator of present behaviour, infrastructure planning cannot rely solely on current consumption patterns. Future developments, economic growth, tourism expansion and changing consumer behaviour may result in demand approaching conventional design values. Consequently, the study adopted a conservative planning approach that incorporated both actual usage and theoretical future demand projections.

Climate Resilience Validation

The adopted climate assumptions were intentionally conservative. Evidence indicates that the region is likely to experience:

- Increased temperatures of between 1.7°C to 2.2°C;
- More intense storm events;
- Lower average rainfall;
- Longer drought periods.

This combination creates a paradox often observed in arid regions: larger floods occur less frequently. From a water resources perspective, this means municipalities must maximise capture, storage and recharge during short-duration high-flow events while maintaining security through extended dry periods. The proposed intervention strategy directly addresses this challenge by combining floodwater harvesting, temporary storage and aquifer recharge enhancement.

Stakeholder Engagement and Regulatory Alignment

The successful implementation of a project of this nature requires extensive coordination between technical, regulatory, environmental and institutional stakeholders. A key consideration during the feasibility study was to ensure that the proposed interventions adequately addressed statutory requirements, operational constraints, environmental sensitivities and the needs of affected water users. Early stakeholder engagement was therefore essential to identify potential fatal flaws, confirm project constraints and guide the development of technically feasible and implementable solutions.

The principal stakeholders consulted during the project included:

- Prince Albert Municipality
- Department of Water and Sanitation (DWS)
- Department of Environmental Affairs and Development Planning (DEA&DP)
- Breede-Olifants Catchment Management Agency (BOCMA)
- Cape Nature
- Kweekvallei Water User Association (Farmers utilising the water from the Dorps River through a canal system)
- Heritage Western Cape

Consultation workshops were held with the relevant stakeholders during the early stages of the project life cycle. These engagements provided an opportunity to test key assumptions, identify regulatory and environmental requirements, understand existing water-use arrangements and assess potential constraints associated with the proposed infrastructure. The outcomes of the consultation process informed the overall design approach, assisted in identifying critical approvals and authorisations, and contributed to the assessment of the feasibility of the proposed interventions.

This collaborative approach ensured that stakeholder requirements were incorporated into the planning process from the outset, thereby reducing implementation risk and improving the likelihood of successful project delivery.

OPTIONS ANALYSIS

Why a Single Intervention is Insufficient

One of the most important findings of the study was that no individual intervention could independently provide acceptable long-term water security.

Surface water systems alone remain vulnerable to drought. Groundwater systems alone remain vulnerable to declining recharge rates. Storage

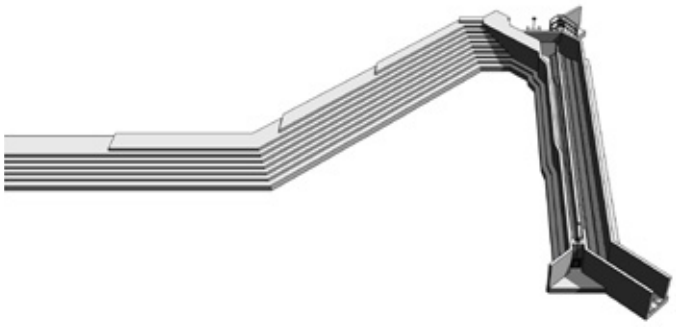


FIGURE 5: *Isometric view of weir and diversion structure*

facilities alone cannot generate water during prolonged dry periods. Consequently, each intervention was evaluated not only on its individual performance but also on how it contributes to the overall resilience of the integrated system.

An additional factor considered was the implementation plan, to allow for the implementation of functional components, that align with municipal budget allocation and improve the resilience and sustainability of the system.

Permanent Diversion Weir

The permanent weir forms the operational heart of the proposed system. Historically, abstraction from the Dorps River relied on temporary diversion structures that required regular maintenance and reconstruction after flood events. In addition to operational risks, the temporary infrastructure prevented accurate quantification of water availability and abstraction volumes.

The proposed permanent weir addresses these shortcomings by:

- Stabilising abstraction conditions;
- Providing reliable flow measurement within the Dorps River;
- Improving water allocation management by accurately quantifying diverted volumes;
- Facilitating future infrastructure integration;
- Creating conditions for improved aquifer recharge upstream though infiltration via the riverbed.

Perhaps the most significant benefit of the weir is not the abstraction itself, but the creation of an operational control point from which the entire water resource system can be managed and monitored. An isometric view of the proposed weir section and overflow diversion channel is provided in **Figure 5**.

Off-Channel Storage Dam

Traditional reservoirs typically function as primary water storage facilities. The proposed off-channel dam serves a fundamentally different purpose. Instead of serving as a facility for long-term storage of annual water requirements, the reservoir operates as a strategic water reserve. Water is captured during high-flow periods and retained for subsequent use within the municipal supply network. The availability of raw water from the storage dam decreases dependence on groundwater resources, thereby facilitating aquifer recovery and natural recharge while supporting the sustainable management of water supplies.

Storage modelling demonstrated that the evaporation in Prince Albert Town (which exceeds 1.5m/a), plays a critical role in the proposed systems performance. Various configurations were assessed, and within site parameters, the operational depth range of the dam was between 10m and 15m, and the minimise the evaporation losses, the 15m was proposed to minimise the surface area. The results in **Table 3** showed that a 50 000 m^3 dam with a 15 m operating depth provides significantly greater resilience than a shallower reservoir of similar volume. When combined with groundwater augmentation and demand reduction (on Redbook projected demand) of 25%, the system could provide security of supply for the town exceeding 72 months under severe drought conditions.

Managed Aquifer Recharge

Groundwater is frequently treated as a standalone source. The study instead viewed groundwater as a strategic storage reservoir and critical component of the proposed system.

TABLE 3: *Dam model sizing – summary (Green highlighted cells on WUA allocation indicate scenarios where water demand measures have been implemented)*

Summary									
Component	4	5	6	7	8	9	10	11	12
Rainfall (% below average)	45.0%	47.5%	47.5%	47.5%	50.0%	50.0%	50.0%	55.0%	55.0%
Dam Size (x 1000 m³)	50	50	50	75	50	75	75	75	100
Dam average Depth	10	10	10	10	10	10	10	10	10
Riparian Flow Allocation (L/s)	40	40	40	40	40	40	40	40	40
WUA Allocation (L/s)	75	75	70	70	65	65	60	50	50
2042 - No Augmentation	**>72**	**11**	**15**	**15**	**15**	**14**	**>72**	**28**	**15**
2042 - With Augmentation	**>72**	**14**	**>72**	**16**	**16**	**16**	**>72**	**>72**	**16**
Summary									
Component	B - 4	B - 5	B - 6	B - 7	B - 8	B - 9	B - 10	B - 11	B - 12
Rainfall (% below average)		47.5%	47.5%	47.5%	50.0%	50.0%	50.0%	55.0%	55.0%
Dam Size (x 1000 m³)		50	50	75	50	75	75	50	75
Dam average Depth		15	15	15	15	15	15	15	15
Riparian Flow Allocation (L/s)		40	40	40	40	40	40	40	40
WUA Allocation (L/s)		75	70	70	65	65	60	50	50
2042 - No Augmentation		**14**	**>72**	**>72**	**>72**	**>72**	**>72**	**>72**	**>72**
2042 - With Augmentation		**14**	**>72**	**>72**	**>72**	**>72**	**>72**	**>72**	**>72**

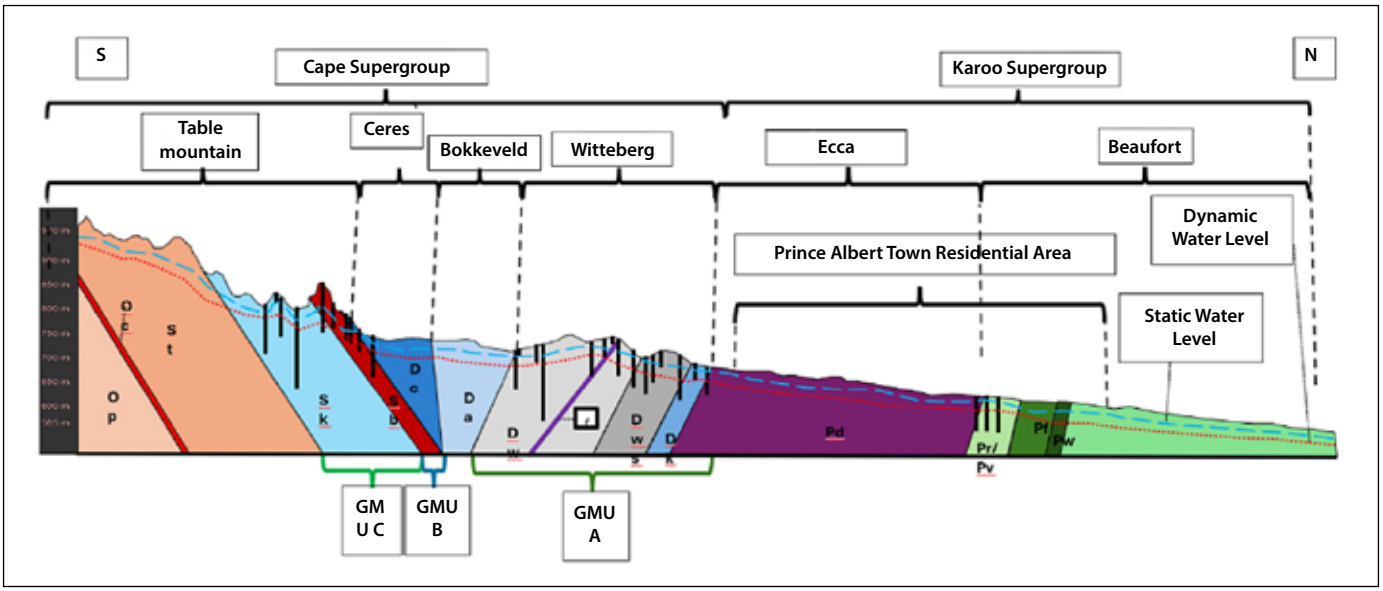


FIGURE 6: *Geological section along Dorps River (Myburgh, 2025)*

Managed aquifer recharge increases the volume of water stored underground during periods of surplus availability. Compared with surface storage, underground storage offers several advantages:

- Negligible evaporation losses;
- Reduced contamination risks;
- Improved drought resilience;
- Long-term storage capability.

The existing artificial recharge initiatives undertaken by the municipality provided confidence that additional recharge interventions could be successfully implemented in future. The feasibility study therefore sought to maximise opportunities for recharge throughout the river corridor using primary run-off water during flood events by siting injection boreholes along suitable geological substrates and passive infiltration measures to improve shallow aquifer recharge and utilise the sand bed above the phreatic surface as additional storage.

Sand Dams and Check Dams

Although relatively small compared to conventional dams, sand dams and recharge check dams are passive infiltration measures that improve recharge to shallow aquifers and form a crucial component of the overall system.

These structures achieve several objectives simultaneously:

- Reduce flood water flow velocity (reduces risk of damage during flood events);
- Increased infiltration time;
- Improve groundwater recharge;
- Create distributed storage in the substrate;
- Improve water availability near boreholes.

Rather than transporting floodwater rapidly through the catchment, the structures intentionally slow and spread flows, converting short-duration flood events into extended recharge opportunities. This transforms the flood into a recharge opportunity in this water scarce environment. This represents a shift from conventional flood management philosophy, where the objective is typically to remove water from the system as quickly as possible. During the study it was proposed to implement the first five check dams and a single sand dam as indicated by **Figure 7**. The sand dam will utilise a layer of highly porous sediment (12m-18m thick) to create additional storage within the system. Further check dams higher up in the catchment are recommended for future phases.

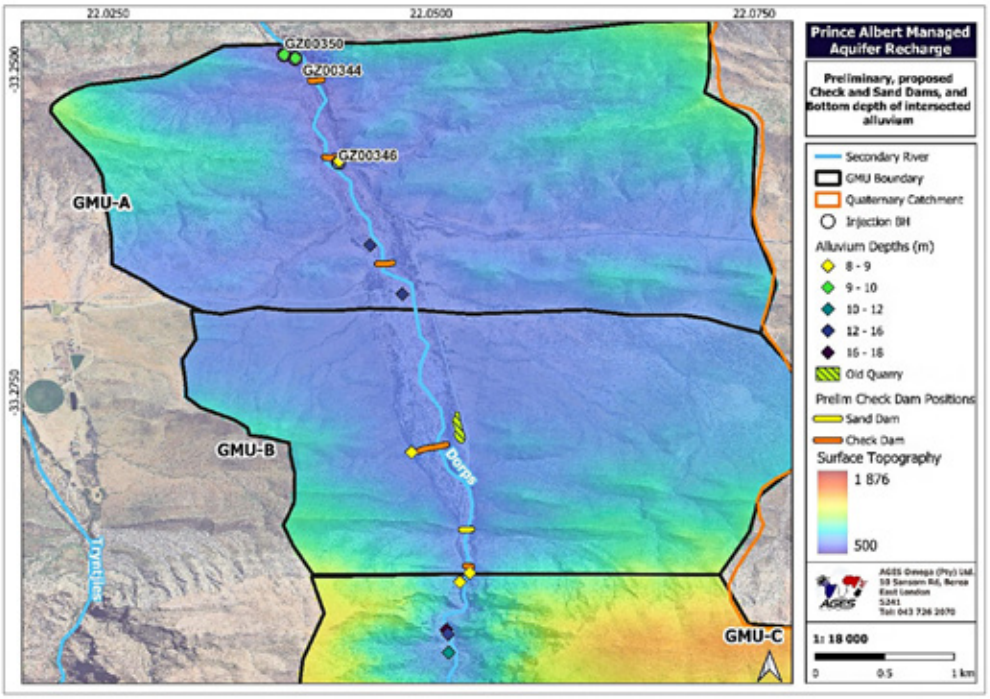


FIGURE 7: *Preliminary locations for check and sand dams with recorded alluvium depth measurements indicated by the heat map (Myburgh, 2025).*

Water Demand and Leakage Management

A fundamental component upon which the proposed system is anchored is the continuation and refinement of the municipal water conservation and demand management programme. This includes the continuation of the technical aspects such as the installation of improved infrastructure to define the system input volume (included in this project), maintenance of the billing meters and database, leak detection and repair programme, valve inspections and maintenance, and revenue collection. Further development of community education and awareness programmes is required to minimise the inefficient use of water. This will also help prepare and empower the community to partner with the municipality in protecting the resource. Communication with the community should also be strengthened to empower residents, disseminate critical information, and improve preparedness, enabling agile adjustments to water demand as and when required.

Water Reclamation

Prince Albert Town Town's wastewater will increase in line with its growth in water demand. This will require an increase in the treatment capacity of the wastewater treatment facility. The study further recommended that as part of the future plant upgrade, consideration should be given to the reclamation and re-use of the treated effluent to reduce the demand on raw water sources.

FRAMEWORK FOR CLIMATE-RESILIENT MUNICIPAL WATER SOURCE MANAGEMENT

The feasibility study demonstrated that sustainable water security cannot be achieved through infrastructure alone. Instead, municipalities require a structured holistic framework that integrates engineering, hydrology, operations, community and governance.

The proposed framework consists of six interrelated pillars as demonstrated in **Figure 8**.

Within the proposed system for Prince Albert Town, the following pillars were achieved:

- Pillar 1 – Diversified Water Sources
  Surface water, groundwater, reuse opportunities and artificial recharge should operate as a collective portfolio of resources.
- Pillar 2 – Capture High Flows
  Future rainfall patterns are expected to produce fewer but more intense runoff events. The municipal infrastructure was therefore designed to capitalise on these events through temporary storage, diversion and recharge systems.
- Pillar 3 – Store Water Where Evaporation is Lowest
  In this arid region, evaporation exceeds annual rainfall. Underground storage through aquifer recharge should therefore be prioritised wherever suitable hydrogeological conditions exist.
- Pillar 4 – Build Redundancy
  The failure of any single component will not result in system failure. Storage dams, boreholes, recharge infrastructure and abstraction systems complement one another.
- Pillar 5 – Measure Everything
  Reliable decision-making requires accurate information. The provision of accurate system input data and offtake control will result in the improved monitoring and effective management of the resource.
- Pillar 6 – Manage Demand as a Resource
  The study demonstrated that relatively small reductions in municipal demand substantially improve supply security. Demand management and the minimisation of losses should therefore be considered a water source in its own right.

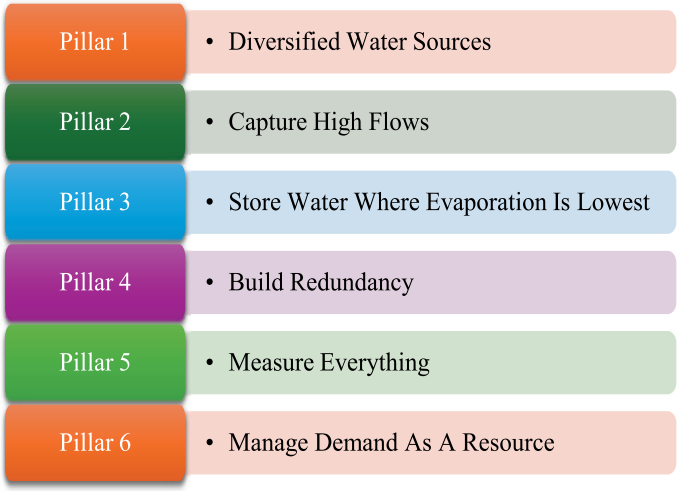


FIGURE 8: *Six Pillars of the Framework for Climate-Resilient Municipal Water Source Management*

CONCLUSION

The feasibility study illustrates the transition from conventional water augmentation planning towards integrated water resilience planning.

The key lesson emerging from the study is that sustainable water security is not solely dependent on the construction of larger infrastructure but can also be achieved through the development of smarter, integrated systems. The combination of a permanent diversion structure, strategic off-channel storage, managed aquifer recharge, sand dams, recharge check dams and demand management measures creates a resilient water supply portfolio capable of adapting to uncertain future climatic conditions.

Perhaps most importantly, the study demonstrates that groundwater and surface water should not be managed as separate resources. By actively linking river flows, recharge systems and groundwater abstraction infrastructure, municipalities can significantly increase the efficiency and resilience of existing water resources.

The proposed approach provides a practical model for municipalities across the Karoo and other arid regions facing similar challenges related to climate variability, increasing water demand and limited water resources.

RECOMMENDATION

Municipal water security planning in arid regions should transition from a "single-source augmentation" approach to a holistic water security framework incorporating storage, recharge, diversification, adaptive infrastructure, demand management and institutional control. The feasibility study provides a replicable model for climate-resilient municipal water source management across water-scarce regions of South Africa.

ACKNOWLEDGEMENT

The authors wish to acknowledge Mr Ashley America, Senior Manager: Technical Services at Prince Albert Municipality, for affording the opportunity to undertake this feasibility study and for providing the professional space to develop an integrated framework for climate-resilient municipal water source management. The authors further acknowledge Mr Jan Myburgh, Principal Hydrogeologist, for making himself available as part of the professional team and for his valuable technical contribution to the Managed Aquifer Recharge component of the study.

REFERENCES

Boccaletti, G., Stuchtey, M., & van Olst, M. (2010, June). Confronting South Africa's water challenge. McKinsey Quarterly, p. 6.

Department of Human Settlements. (2019). The Neighbourhood Planning and Design Guide. Pretoria: South African Government.

Government of South Africa. (2024). Official Guide to South Africa 21st Edition. Pretoria: Government Communications.

United Nations. (2026, July 01). Climate Change. Retrieved from Climate Action: https://www.un.org/en/climatechange/science/climate-issues/water

United Nations. (2026, July 01). Water Facts. Retrieved from UN Water: https://www.unwater.org/water-facts/water-scarcity

Water Resources Group. (2012). Background, Impact and the Way Forward. Davos-Klosters: World Economic Forum.