

The Atlantis Water Resource Management Scheme: 30 years of Artificial Groundwater Recharge



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I INTRODUCTION

Atlantis provides an example of wise water use. Treated wastewater and storm water is diverted to large basins where it infiltrates into a sandy aquifer from where it is abstracted and reused for municipal supplies. Polokwane in the Northern Province and Windhoek in Namibia practice similar forms of water conservation and storage, and a number of other towns throughout South Africa are in the process of investigating or implementing such schemes. The story of Atlantis is one of far-sighted water engineers and hydrogeologists that led to about 30% of the town's groundwater supplies being augmented through artificial recharge.

The town of Atlantis is located 50 km north of the centre of the City of Cape Town on the dry west coast. It has a population of 57,000 people (2001 census) and presently forms part of the metropolitan area of Cape Town.

Artificial groundwater recharge is the process whereby water is transferred for safe storage in aquifers. More information on this can be found at www.artificialrecharge.co.za.



Infiltration basins with Cape Town's Table Mountain in the background.



Coastal infiltration basin.

Initially prompted by the need to find an alternative to marine wastewater discharge, Atlantis began recharging its storm water and treated wastewater into its sandy soils in 1979. With the recognition that the natural groundwater yield of the aquifer was not sufficient to meet the long-term needs of the town, the focus shifted to *recharging* the aquifer and *recycling* water. The addition of storm water to the recharge system was a major development, as was the eventual separation of domestic and industrial effluent that was done in order to allow recharge of the highest quality water in the areas of the greatest importance. Currently, treated domestic effluent, all of the domestic storm water, and most of the industrial storm water is used for recharging the aquifer up-gradient of the wellfields in two infiltration basins. Industrial effluent and industrial storm water from the noxious trade area is diverted to the coast down-gradient of the main aquifer to coastal recharge basins in order to raise the water table and prevent seawater intrusion into the main aquifer. The overall scheme is referred to as the Atlantis Water Resource Management Scheme (AWRMS).

The AWRMS provides a local South African example of a cost-effective artificial recharge solution that has been proven over time, successfully supplying water to both the residential and industrial areas of Atlantis for nearly 30 years. A renewal of careful management of the water sources and aquifer is now required to ensure its future long-term sustainability.

The Atlantis Water Resource Management Scheme (AWRMS) has successfully recharged and recycled water for almost three decades. It is estimated that on average, approximately 7500 m³/d of storm water and wastewater is currently recharged up-gradient of the wellfield, thereby augmenting the water supply by more than 2.7x10⁶ m³/a (i.e. approximately 25 - 30% of Atlantis' groundwater supply is augmented through artificial recharge). Some 4000 m³/d higher salinity industrial wastewater is treated and discharged into the coastal basins downgradient of the wellfield close to the ocean.



Gideon Tredoux at Basin 7, Atlantis.

"We are standing here at Basin 7, the main recharge basin at Atlantis. It receives all the storm water as well as the treated domestic wastewater from the town. It is upgradient from the main wellfield and takes about 18 months to 2 years to seep through the underground to reach the wellfield.

The contribution to the water supply of Atlantis is of the order of 25 - 30% and makes an important contribution to the sustainability of this water supply".

Gideon Tredoux, video interview, 2009.

Dr Tredoux, a hydrogeochemist formerly from the CSIR, played a leading role in monitoring, managing and modifying the scheme.

The overview in Figure 1.1 shows which Department in the City is responsible for the specific part of the AWRMS. Groundwater is also obtained from the Silwerstroom wellfield but the diagram only covers the Witzand part of the system where the water recycling takes place. In view of the fact that various Departments are involved a coordinating structure is required to ensure a seamless operation providing high quality water after recycling. Whereas storm water detention basins 1 to 4, 8 and 11 were designed to be mostly dry and only serve for peak flow reduction, basins 5, 6, 9 and 10 were designed or redesigned to act as wet basins in which reed beds developed. The Donkergat River serves as an alternative discharge point for wastewater mainly during maintenance work on the system.

The diagram also shows future planned diversions intended to improve the water quality management, e.g. diverting the oily industrial storm water from Basin 9 via Basin 10, which collects runoff from the noxious trade area, to the Coastal Recharge Basins.

Figure 1.1/...

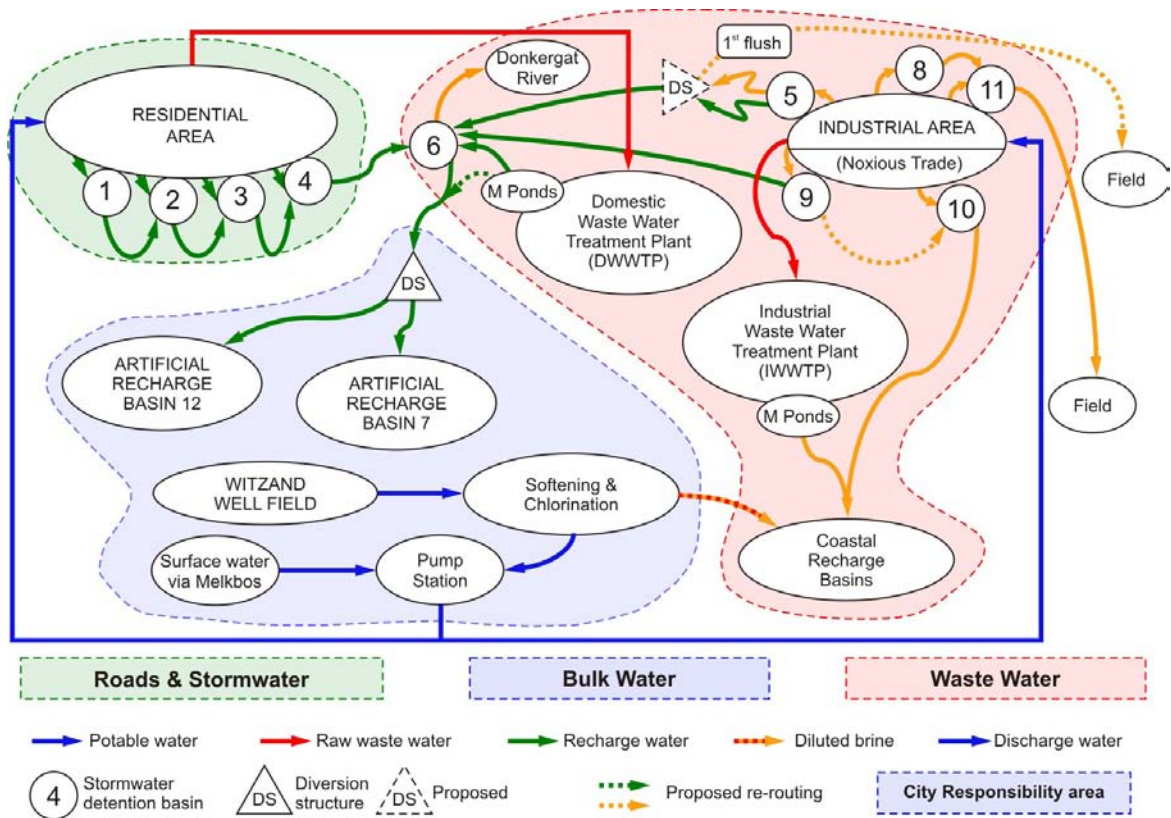


Figure 1.1: Overview of Witzand part of the AWRMS.

2 EARLY HISTORY OF THE TOWN

Atlantis was a planned town from its planning inception in the late 1960s. Although originally conceived as an apartheid concept, the town planners of the time were heavily influenced by the 'New Town' ideas that had developed in post-war England. The New Town concept embraced the idea of building carefully planned new towns, in areas far enough away from other centres to be self-contained towns, typically in previously underdeveloped areas. Part of this vision was that all those living in a New Town would have work within their town as well. By the late 1960s, England had developed its third (and last) wave of New Towns, best illustrated by the new town of Milton Keynes. New Town ideas were quite influential amongst town planners and influenced the development of many towns in different parts of the world. In the South African context of the early 1970s, Atlantis was planned within the apartheid context as a 'coloureds only' new town, making it a uniquely South African version of the New Town approach. This historical association with apartheid became detrimental to Atlantis' post-apartheid future development, and to a certain degree negated the good planning that went into the town's early development.

The original planning concept that local government was tasked with implementing was for a city housing approximately 500,000 people in six interlinked towns. The local government of the time for the area was the Divisional Council of the Cape of Good Hope, commonly referred to as the DCC. Ultimately, however, only one town, known as Wesfleur, came to fruition. Over time, this has simply become known as Atlantis. (Planning for the 2nd town went as far as the design for a wastewater treatment works for that area – which was planned for location between Silwerstroom and Witzand wellfields).

The idea driving the development of Wesfleur was to build a 'coloured' town that would in part help to ease the over-population of Elsie's River. Elsie's River was by that time a Grade 1 slum with a population of 110,000 living in an area built for 60,000 people. Some of the engineers and planners that were active in government at that time saw the development of Atlantis as an opportunity to start with a clean slate and build a high quality town free from the problems seen in other areas such as Elsie's River. Thus in 1976, the Atlantis area was declared a National Growth Point under the government's "decentralisation initiative."

Development began in Atlantis with a combined residential and industrial component. Effort had to be made to attract both industry and residents to this new town that was located relatively far away from Cape Town. (Note that the planning of Atlantis was also part of the early planning of the Koeberg nuclear power station, and so the exclusion zone around Koeberg was part of the reason that Atlantis was built so far away). Various incentives were introduced for attracting industries. Water supply and quality were a key issue for industry in terms of re-location considerations. In particular, one of the reasons the textile industry had traditionally developed in Cape Town was because of the city's exceptionally high quality 'soft' water, and so the textile industries needed water quality assurance of a similar standard of supply in Atlantis. As well, the early development in Cape Town of the clothing industry had been based on the "C&T" ("cut and trim") skills found in plentiful supply amongst the population of 'coloured' women living there, with the soft water being a bonus. These skilled labourers also had to be attracted to Atlantis.

The first residential construction in Atlantis began in the Avondale area where 635 houses were built in the first phase. These houses were sold for a reasonable amount over a 20-year period with a subsidised interest rate. These were small but well-built 50-square metre houses with two bedrooms. (Note that these original houses are still sewered to the current industrial wastewater treatment works, which was originally the only wastewater treatment works for both the residential and industrial areas). The facilitation of home ownership ultimately contributed to significant wealth creation for the skilled and employed members of this new community. Skilled 'coloured' people who moved to Atlantis got top jobs within the factories and industries based there. ('Whites' employed by industry in Atlantis had to commute from Melkbos or Cape Town). However, while the planners had envisioned that the only people that would move to Atlantis would be those employed in the new Atlantis industrial area and town along with their immediate families, a great deal of unemployed extended family members also came to Atlantis. Thus Atlantis never escaped the problems of unemployment, poverty, and over-crowding as had been hoped by those involved in its early planning. Another issue for people living in Atlantis was the difficulty of changing jobs – unless a person could find alternative employment within Atlantis, changing jobs generally meant moving from Atlantis because it was so far away from Cape Town. Early hopes for developing a light rail system for Atlantis never came to fruition.

"Two things hindered the further development of Atlantis:

- 1. The tax exemptions offered by government to industry were stopped; and*
- 2. The transport link between Atlantis and Cape Town was inadequate."*

Rodney Bishop, interview, 2009.

Rodney Bishop, the Principal Engineer at the Bulkwater Branch at the City of Cape Town, has played a key role in the management of the AWRMS since the scheme was transferred to the Cape Metro Council in July 1997.



Atlantis' CBD (in the far right one can see Table Mountain).

A key question throughout the early development of Atlantis was always around who came first – people or industry? The planners of the time tried to balance and match these two needs together, although the growth of Atlantis was essentially driven by industrial demand. By 1987, there were approximately 50 industrialists employing people drawn from some 8000 housing units (i.e. 40,000 inhabitants, some of whom were employed in Atlantis and some of whom commuted to Cape Town for work). These industries included some very big companies such as Tedelex and Atlantis Diesel Engines. However, by the end of the 1980s, the industrial incentives had stopped and Atlantis had come to be equated with apartheid. Furthermore, government of the time had only ever tried to attract industry and not business to Atlantis. This failure to attract business to the town undermined its potential growth and development, and the grand plan for a self-sustaining city of 6 towns was abandoned.

Despite the fact that Atlantis never continued to develop as had originally been envisioned, it is still one of the largest towns in the Western Cape. There may also still be a future for Atlantis in terms of eventual rejuvenated growth and development. Once the out-lying area of Table View fills up, further development on that side of Cape Town will have to jump the exclusion zone around Koeberg and may come to Atlantis.



Industrial area of Atlantis.

3 WATER SUPPLY: EARLY OPTIONS AND DEVELOPMENTS

At the time of the construction of the first houses in Atlantis, the water supply was provided from a single borehole which pumped water up to the bottom fed 10 Ml Pella Reservoir. Later, the perennial springs at Silwerstroom, which produced an average flow of about $1 \times 10^6 \text{ m}^3$ per year, were used. A weir was constructed to capture the spring flow in a small dam, from which it was pumped to the same Pella Reservoir and then gravity-fed on to Atlantis.

While sand filters were installed at Silwerstroom, they were never used as the water quality did not require this – only pH correction was done for stability as well as chlorination.

However, there was a general recognition that more water would soon be needed than could be abstracted from this small weir. A plan was put forward to use the surface water of the Berg River some 70 km distant as it was the closest feasible source of reliable surface water to the semiarid west coast location of Atlantis. Despite the prohibitively high cost of the proposed full Berg River supply project, the Withoogte water treatment plant near Moorreesburg, which obtains its supply from the Misverstand Weir, was designed with sufficient capacity for supplying water to Atlantis.

However, the next step in augmenting water supply to Atlantis that actually took place was the development of the Silwerstroom well field around the spring. John Clark -- considered a creative and far-sighted thinker in his field by many -- was the The Engineer of the Divisional Council of the Cape (DCC) during the 1980s. Clark was interested in groundwater, and from the early 1970s, the then Department of Water Affairs and Forestry (DWAf) was doing a lot of groundwater exploration by drilling investigatory boreholes. As part of this, groundwater was found in the Atlantis area. Initially, there were some that thought this groundwater was a diversion of the Berg River and that an “endless” source had been discovered. This was soon disproved, however, and it was confirmed that this groundwater was recharged by rainfall. By 1978, the first production boreholes had been drilled at Silwerstroom. With the realisation that there was a lot of water in the aquifer, the Silwerstroom wellfield was developed. Scotty van der Merwe, a geohydrologist from DWAf, then identified the possibility of a wellfield in the Witzand area. This proved to be a good groundwater area and later became the main wellfield for Atlantis.

Interestingly, the Berg River plan never materialised. The cost of bringing water 70 km to Atlantis based on this plan would have placed a huge financial burden on the growth point. Thus the DCC was interested in developing interim measures in order to postpone this undertaking. Largely thanks to the innovative thinking of those involved, the ‘interim’ groundwater supply was developed into a long-term solution for Atlantis. Tony Murray, having been in charge of the Elsie River redevelopment scheme, became the Project Engineer for Atlantis in 1980.

Other key individuals that became involved at this time were Alastair Bishop, a civil engineer and a specialist in storm water management, from Liebenberg & Stander Engineers (later known as Bergstan); Peter King, the Chief Chemist of the DCC (later the Chief Engineer – Services), specialising in wastewater treatment; and Gideon Tredoux of the CSIR, a hydrogeochemist specialising in groundwater quality, also having carried out pilot recharge tests with treated wastewater in the Cape Flats. It was from this group of engineers and scientists that the ideas for artificial recharge emerged and developed for Atlantis. The two wellfields, Silwerstroom and Witzand, have thus been providing a sustainable groundwater resource for close to thirty years. Only since 2000 was limited augmentation of the water supply by surface water introduced via an alternative route.



*Silwerstroom weir and pump station
(The foreground on the left shows the natural discharge from the Silwerstroom springs).*

4 TOWN PLANNING, STORM WATER & WASTEWATER LAYOUT

The initial planning concept, which was for the proposed mega-city of six interlinked towns, was the brainchild of Dave du Plooy of the firm Plan Associates, later The Planning Partnership. When du Plooy retired, the bulk of the detail design for Wesfleur was undertaken by Johan Prinsloo, Chris Kannenberg and Geoff Underwood.

As a town planned from its start in the 1970s, Atlantis benefited from the planned separation of residential and industrial areas. All residential areas were developed in the northern half of Atlantis, while the industrial areas were developed in the southern half. Furthermore, within the industrial area, the borders of the noxious trade area were delimited to its southwestern corner. This location took advantage of the prevailing winds and protected the residential area from any odours emanating from this area.

The interaction between the town planners and the designers of the storm water management scheme was significant during the development of Wesfleur. It was the first case in South Africa of integrating detention basins into the urban design of a town. The planning at the time incorporated the latest ideas regarding the construction of the storm water collection and wastewater treatment systems. The different systems – water supply, wastewater, and storm water – were all initially separate, but then became integrated through the development of the AWRMS.

"The town planners wanted a good-looking efficient town built on modern lines with people walking to work through open spaces."

Tony Murray, interview, 2009.

Tony Murray was the Project Engineer on the AWRMS from the Divisional Council of the Cape from 1980. He eventually became Head of Engineering at the Cape Metropolitan Council (a successor to the DCC) and retired in 1998.



Artist's impression of a recreational street.



The development of the storm water system began in the late 1970s and modifications had to be made to accommodate this system (e.g. slopes of roads; pipelines). This was to some extent influenced by workshops held in South Africa by the American Environmental Protection Agency (EPA) at that time, which seriously promoted the ideas of storm water detention and artificial recharge. Initially in Atlantis, detention basins were developed simply to control peak flow. The peak storm water flow reduction features mirrored the latest international technology at the time, and its continued operation over the last 30 years has proven the system's effectiveness to deal with urban runoff. The system later evolved into one of recycling storm water by recharging it into the aquifer.

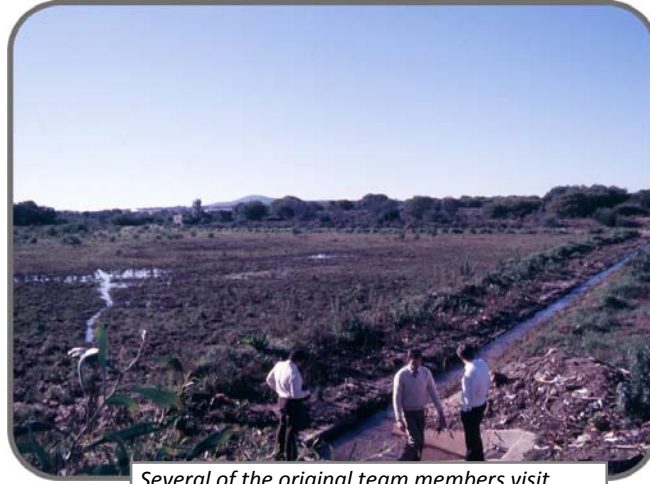
From the wastewater side, the sewage of Atlantis' original 2000 unit development was initially dealt with through one Wastewater Treatment Works. The first WWTW was a plastic lined oxidation pond built near the van Leer factory. The activated sludge works with maturation ponds was started in October 1978. Basin 7 was both the final disposal pond as well as the main recharge basin. It continues to be directly fed from Basin 6, which is a collector and final polishing wet pond serving as an artificial reed bed. There were occasional oil spills in the industrial area and the reeds that were encouraged to develop in the retention ponds in these areas (primarily basin 9, but also basins 5, 6 and 10), worked very well in dealing with these situations.

"Several of the industries were not too concerned with storm water pollution until we started hitting them with the costs for clearing up.

... The flow into Pond 9 still has the highest potential to be oily due to the nature of the surrounding industries and should be diverted away from pond 6."

Peter King, interview, 2009.

Peter King was the Chief Chemist of the DCC, and later became the Chief Engineer - Services. He is currently the Head of Operation Support of the Wastewater Branch for the City of Cape Town.



Several of the original team members visit Basin 3 after a storm. Dry weather flow bypasses the pond in the dry-flow channel. The last of the retained storm flow trickles into the system.

The separation designed by town planners between residential and industrial areas facilitated the later separation of the industrial wastewater and domestic sewage effluents. Peter King from the DCC headed up the wastewater treatment for Atlantis. He came up with the concept of one WWTW for the industrial area (plus the original 635 houses), and another WWTW for the rest of the area. This was a major step in the fine-tuning of the overall AWRMS system as it enabled the relatively higher quality treated domestic effluent, the domestic storm water, and most of the industrial storm water to be conveyed to Basin 7 for recharge into the aquifer, while the poorer quality treated industrial effluent could then be separately channelled to the coastal basins for recharge. *(Note that storm water runoff emanating from the noxious trade area goes via Basin 10 into the pipeline conveying treated industrial wastewater to the coastal recharge basins.)*



Storm water retention pond within residential area today (Basin 3).

When visiting the town today, the broad open streets with storm water inlets in the established residential suburbs reflect the rigorous planning that went into these areas. The many open green spaces within these established residential areas also reveal the planners' expectations for the town's growth – rows of houses that were never built, and expectations that were never met. On the other hand, the original planning for low-cost housing consisted of the construction of centrally located high-density 'council flat' type buildings intended for the labouring classes.

There was a belief at the time that the upper and middle-class areas had to be built separately from the working class areas – a division that was over-emphasized. In terms of predicting and balancing the different types of housing needs at that time, one needs only look now at the informal settlement shacks on the periphery of Atlantis, filled with people who cannot afford or access formal housing. The extent of the current housing challenges have led to the development of new areas of "RDP housing" bordering the informal settlement area. These areas reflect the ubiquitous realities of South African towns today that must be taken into consideration in terms of planning.

"The big disaster was that the town planning was based on having full employment. But employed people brought their extended families and thus lots of unemployed people. Then those that didn't have jobs in Atlantis needed to get to Cape Town and the transport between Atlantis and Cape Town was a problem - there was bus transport only and people wanted a train."

Tony Murray, interview, 2009.



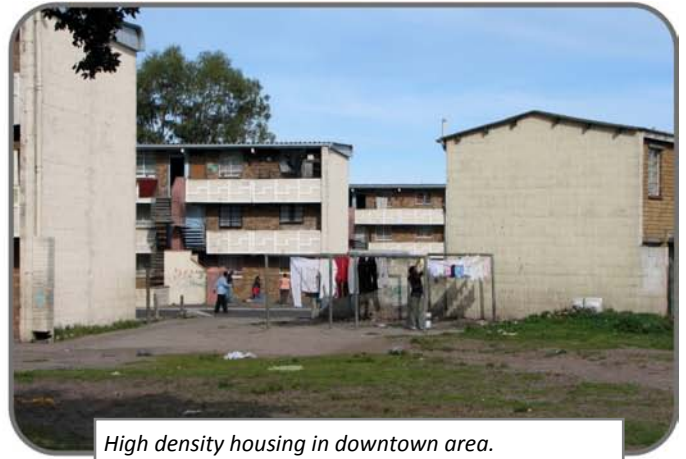
Atlantis wastewater treatment works.



Industrial wastewater treatment works.



Large tract of undeveloped residential area.



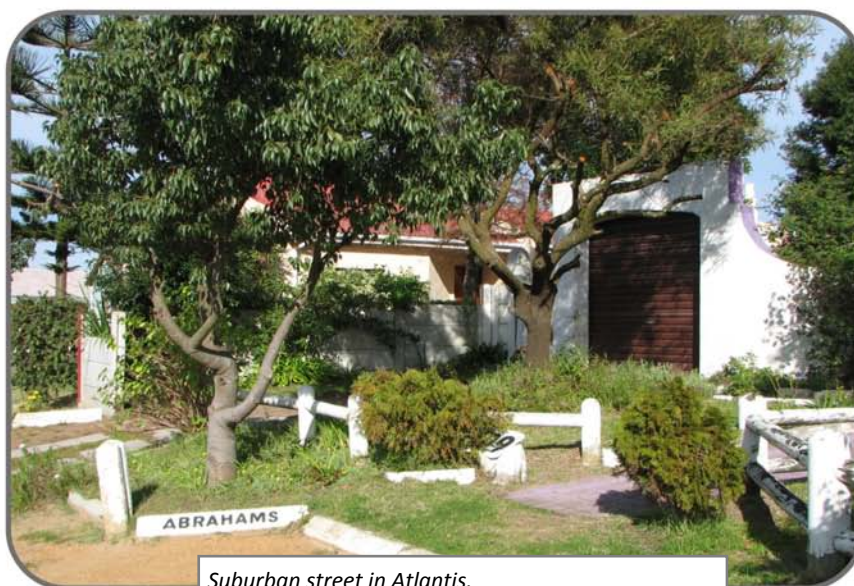
High density housing in downtown area.



High density housing.



Storm water inlets on residential streets.



Suburban street in Atlantis.



Left: Shack in Atlantis informal settlement. Right: New RDP housing development.



Tapstand level of service in informal settlement.

The layout of the Atlantis Water Resource Management Scheme (AWRMS) is shown in Figure 5.1.

5 THE ARTIFICIAL RECHARGE SCHEME

5.1 LAYOUT OF THE SCHEME

The layout of the AWRMS including the location of the recharge basins and wellfields is shown in Figure 5.1. The following aspects of the scheme are reflected in this map: Residential and industrial areas; the storm water system, including the storm water retention basins; the artificial recharge basins that recharge the aquifer centrally (no. 7 and 12); the coastal recharge basins by the sea; both the industrial and the domestic wastewater treatment works; the water Softening Plant; the Silwerstroom and Witsand wellfields; as well as the alternative discharge route to the Donkergat River.

*"The main disadvantage for sea outfalls is the loss of water."
Peter King, interview, 2009.*

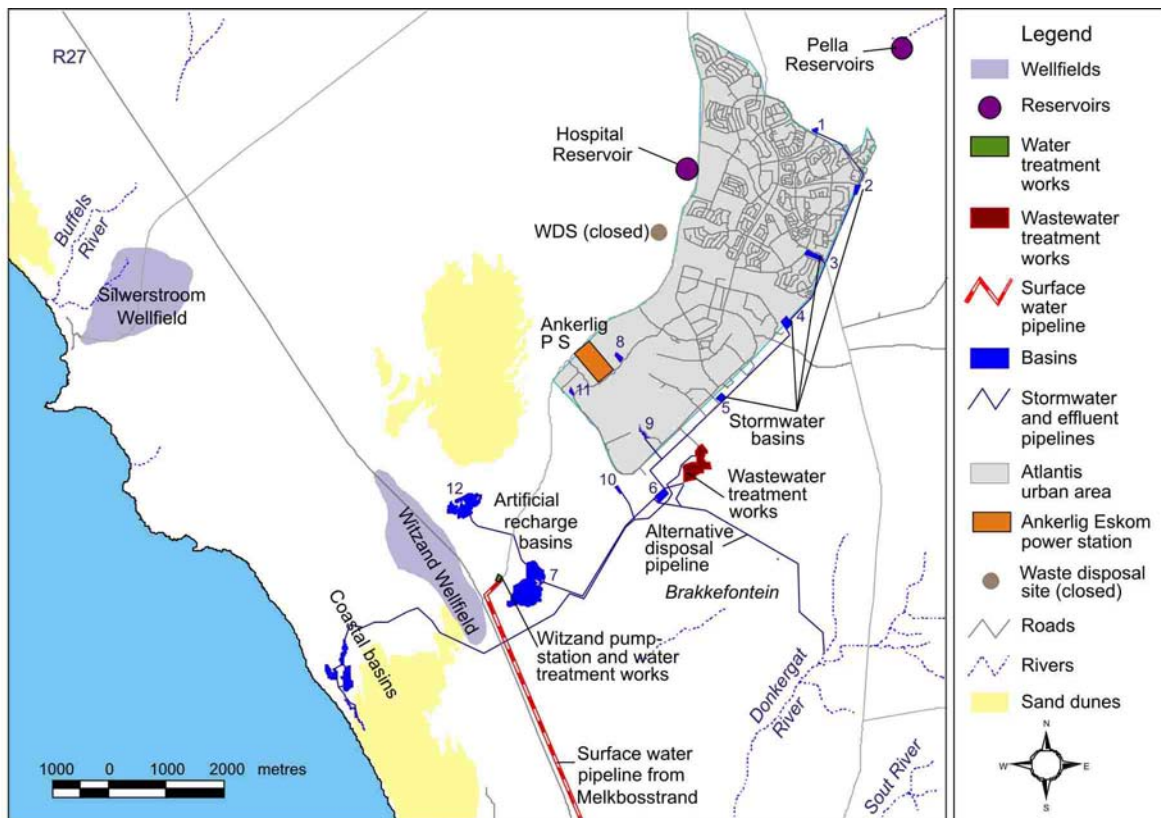


Figure 5.1: Layout of AWRMS.

5.2 CONCEPTUALISATION

The ideas for artificial recharge emerged over time within the circle of experts brought together under the leadership of John Clark. As mentioned previously, recharge in Atlantis initially began as an alternative way of dealing with wastewater. Marine discharge had been a common method of disposal in South African coastal areas up until that time because of convenience. However, this situation was changing due to public resistance in the 1970s, and because DWAF was not in favour of sea outfalls because it resulted in a loss of water. By

the 1980s DWAF had promulgated strict marine water quality criteria for such outfalls. This was enforced by means of a permitting process, requiring detailed monitoring programmes for marine water quality and filter feeders near marine outfalls. Outfall designs had to be refined to ensure maceration of solids, thorough dispersion and dilution with seawater to achieve the microbiological criteria within a set distance from the outfall. The costs associated with outfalls and the monitoring programmes that these systems required gradually became prohibitive and largely discouraged the development of new marine outfalls for wastewater discharge. (Note, however, the successful marine discharge for Hout Bay implemented in 1990 that was a big savings over treatment works).

John Clark was aware of the pilot scale artificial recharge studies using treated wastewater that the CSIR had been carrying out in the Cape Flats from 1973 to 1979 (Tredoux *et al.*, 1980). This example provided an attractive alternative for dealing with wastewater, and Clark gathered his team to implement a similar system for Atlantis. Hence the residential and industrial effluent (jointly treated at the time in the combined Wastewater Treatment Works) was directed from maturation ponds onwards to detention ponds for infiltration into the sandy soils of the area. By 1979, the case had also been made to add the urban storm water runoff into the wastewater recharge system. This meant that the storm water was not lost. Alastair Bishop designed the storm water management system.

Once the aquifer was studied more intensively, it emerged that the natural yield of the aquifer was insufficient to sustain the water supply to Atlantis in the longer term. The need for water recycling introduced a new perspective to the water management system at Atlantis and the management of water quality throughout the system became a key issue from that time. The industrial wastewater was significantly affected by various industries, particularly the textile industries, which had set up their own water softening works. These industries used ion exchange resin with salt as a regenerant to soften the water. The molar ratio was 3 salt to 1 hardness, which meant a large quantity of sodium chloride was being added to the industrial effluent, which in turn significantly downgraded it. Out of this need to ensure water quality, various role-players began to push for the separation of domestic and industrial wastewater treatment, and the recycling via the aquifer of only the treated domestic wastewater. During construction of the new domestic sewage treatment works, all water was diverted to the Donkergat River for discharge for a period of 18 months. During this time there was a noticeable decrease in the level of the aquifer. Once the recharge water was back online and going to Basin 7, however, the problem of borehole clogging had emerged. After completion of the new domestic treatment works, the old wastewater treatment works was refurbished for treating the industrial wastewater. The idea later emerged for the industrial effluent to be directed into coastal detention beds to develop a barrier to seawater intrusion into the aquifer. Peter King of the DCC, Alastair Bishop from Liebenberg & Stander Engineers, and Gideon Tredoux from the CSIR led the development and implementation of these systems. Similarly, the storm water system was later adjusted to channel peak flow and base flow to different recharge basins to maintain good quality water in selected areas of the aquifer. Note that the recharge water can still be diverted to the Donkergat River if necessary (e.g. if industrial effluent gets in, or if the water quality goes down for any other reason). The industrial effluent can also be diverted to the Donkergat if the coastal basins are full.

Note that at the time the Atlantis Water Resource Management Scheme was initiated more than three decades ago, the Water Act No 54 of 1956 was in force in South Africa. That Act did not have any sections dealing with the authorisation and regulation of artificial groundwater recharge nor with the recycling of water. As the CSIR concluded pilot scale studies on the artificial recharge of treated wastewater in the Cape Flats, the Western Cape Regional Office of DWAF realised the need for monitoring. Hence in 1982, DWAF requested

the DCC to set up a monitoring programme for the Atlantis water supply scheme in collaboration with the CSIR.

The National Water Act (Act No 36 of 1998) replaced the Water Act of 1956 and the new Act specifically controls artificial groundwater recharge through a permitting system. However, the permitting system is only gradually implemented, and whereas new systems will only be permitted once pilot studies have been carried out and strict requirements are met, the permitting of existing operations has not been completed. In 2002 an audit was recommended covering all legal compliances, licences, and authorisations required to legalise the Atlantis water system (Tredoux and Cavé, 2002). This process has yet to be completed. However, Peter King from the City of Cape Town has applied for a permit for both of the wastewater treatment works to discharge treated effluent in the area.

In summary, artificial recharge has played a key role in the augmentation of the groundwater supplies at Atlantis. Whereas initially indirect recycling of wastewater and urban storm water runoff was considered an economic means of wastewater disposal, water conservation became a key feature of the scheme. Various combinations of urban storm water and treated wastewater from sources in the town have been infiltrated into the aquifer over the years to maximise the available groundwater. At the same time, several refinements have been made to the artificial recharge system to ensure that any potential deterioration of water quality would not jeopardise the scheme. In this way the Atlantis Water Supply Scheme has pioneered the application of artificial groundwater recharge as a water management tool for bulk water supply in southern Africa.

5.3 THE ATLANTIS AQUIFER

Atlantis is located along the semi-arid to arid West coast of South Africa. The area is practically devoid of surface drainage features, with the exception of the Buffels River at Silwerstroom. In winter, the Donkergat and Sout Rivers flow to the south of the Atlantis area. All these rivers are non perennial and dry up in summer. Perennial springs feeding the Buffels River near the coast at Silwerstroom have been used for water supply since 1976. There is also a spring in the north at Mamre and a minor spring at Groot Springfontein near the coast.

The primary coastal aquifer system in the Atlantis area is formed of unconsolidated Cainozoic sediments of Tertiary to Recent age, overlying Malmesbury Group bedrock consisting of greywacke and phyllitic shale (Van der Merwe, 1983). Granite plutons have intruded the bedrock (Figure 5.2). The Cainozoic successions in the area consist of quartz sands belonging to the Sandveld Group.

"The engineers and scientists involved at the time didn't think about it as "Artificial Recharge" - we simply knew the hydraulic gradient, had checked out the water quantity and quality, and thought our plan would work.

We saw ourselves as a group that applied the principles of our respective expertise and came up with a viable plan. We were conscious of the importance of managing the system and we got our monitoring systems in place early".

Alastair Bishop, a civil engineer and a specialist in storm water management from Bergstan Engineers, was key to designing the storm water system.

These comprise a lower unit of shallow marine origin, the Varswater Formation, and an upper, primarily aeolian unit, the Bredasdorp Formation (Rogers, 1980). The Bredasdorp Formation is subdivided into the Springfontein, Mamre and Witzand Members. The base of the Springfontein Member is a peaty sand bed, while the rest of the member consists of relatively well-sorted quartz sand, free of shelly material, ranging from fine- to coarse-grained. The Witzand Member overlies the central part of the area and consists of calcareous quartz sand, shell fragments and discontinuous calcrete layers. The total sand cover reaches a thickness of 60 m in the central area, with an average thickness of 25 m (Van der Merwe, 1983).



Dune field with the Atlantic Ocean in the distance.

The Atlantis aquifer covers an area of about 130 km², stretching inland from the Atlantic Ocean to the town itself in the east. It pinches out against the Malmesbury Group shale and Cape granite outcrops to the north and east. The thin aquifer slopes steeply in a south-westerly direction from a maximum elevation of about 160 m in the north-east down to sea level in the west. A small part of the aquifer extends below sea level in the Witzand and Silwerstroom areas. The granite outcrops of Dassenberg, Kanonkop, and at Mamre form the highest points in the area, at heights of 210m to 410m above sea level (van der Merwe, 1983).



Dune fields.

The area enjoys a Mediterranean climate, with most of the 450 mm mean annual rainfall received from April to September. Due to the sandy surface over most of the area, recharge percentages of 15 to 30% of the annual rainfall are generally experienced, with the higher recharge occurring in the unvegetated dune area.

Groundwater flows westwards to south-westwards and discharges along the coast in areas where the aquifer dips below sea level. The groundwater table has a relatively steep gradient (approximately 1:58) towards the coast. The saturated thickness varies considerably, but seldom exceeds 35 m. Groundwater is abstracted in two wellfields, Silwerstroom in the north and Witzand in the south (Figure 5.1). The runoff and recharge system flow is operated by gravity only. Due to topographic constraints, artificial recharge is only practised near the Witzand wellfield in the south. The overlying Witzand Member is a calcareous quartz sand succession containing shell fragments and cemented calcrete horizons.

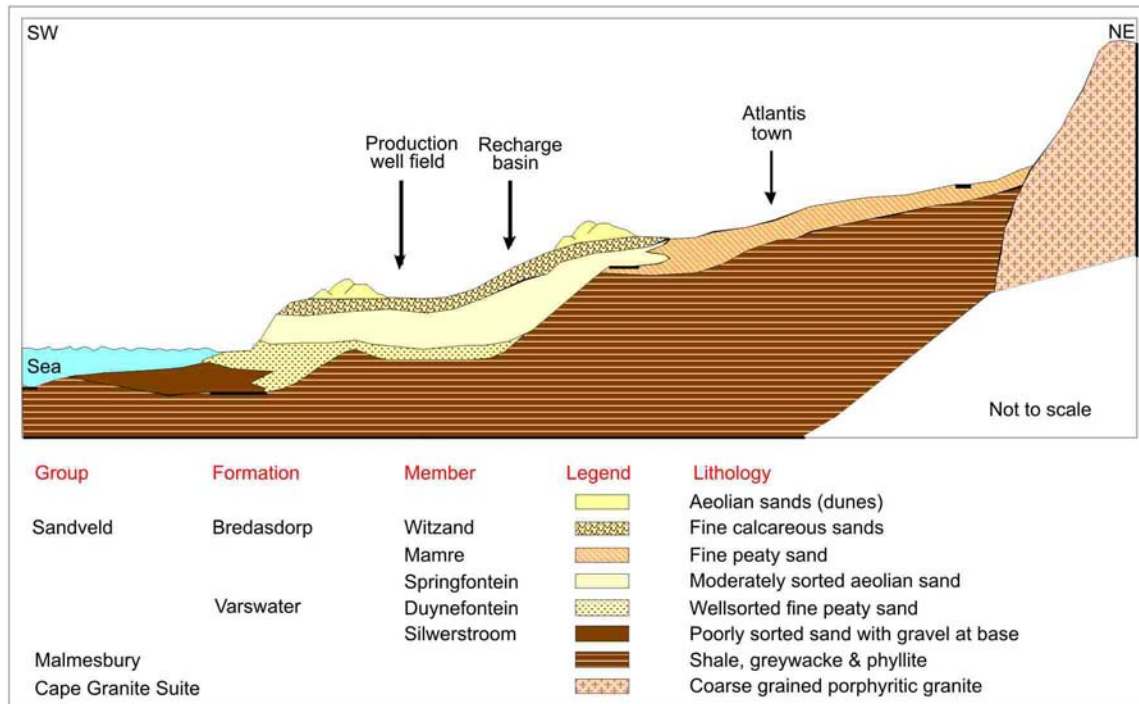


Figure 5.2: Geological cross section through the Atlantis aquifer.

The bedrock also contains groundwater, but the weathered upper zone of the shale forms an impervious clay layer preventing any exchange of groundwater. Sandy-peat layers of varying thickness and calcrete lenses are often interbedded in the aquifer or interfinger laterally with clean sands, producing local heterogeneities in aquifer properties.

5.4 DESIGN OF THE ATLANTIS WATER RESOURCES MANAGEMENT SYSTEM

The various components of the Atlantis Water Resources Management System as it currently exists are shown schematically in Figure 5.3 below.

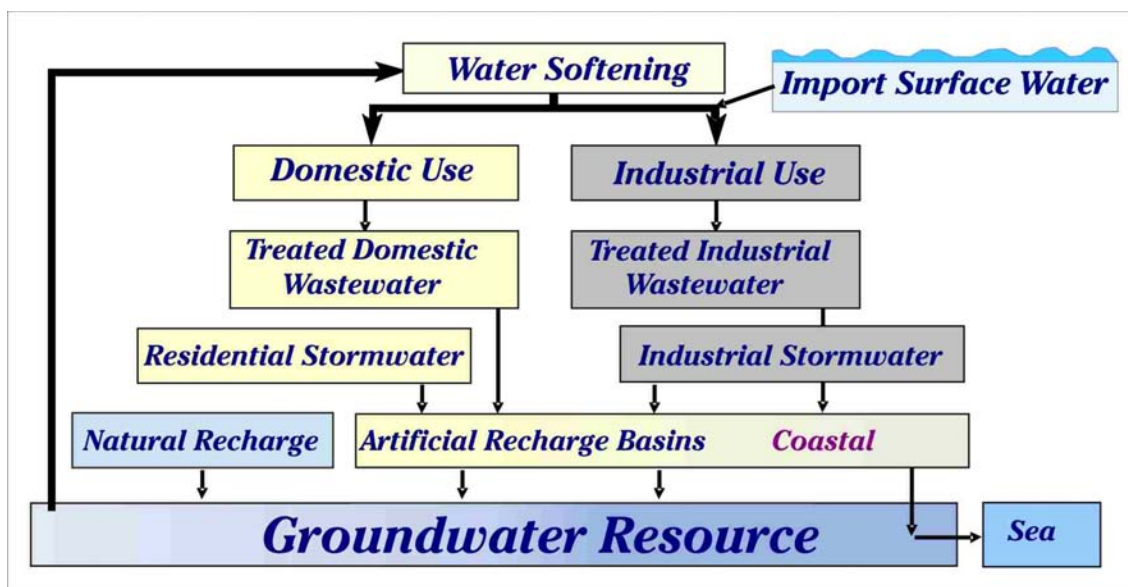
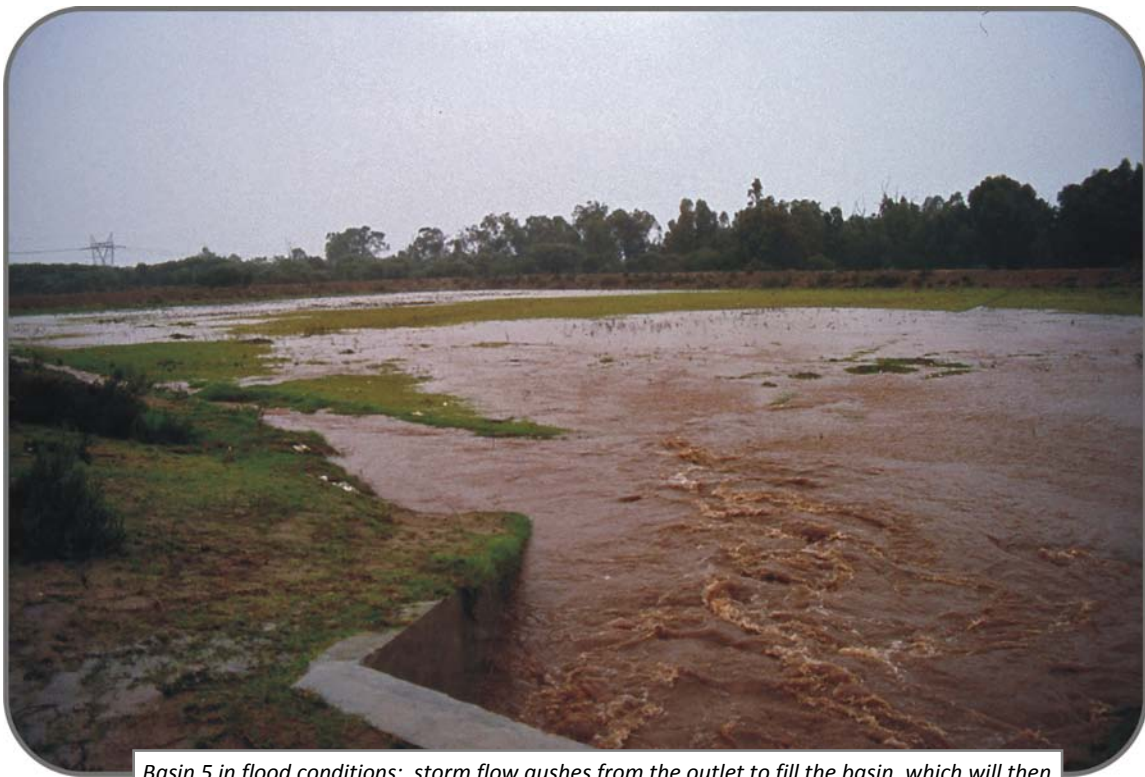


Figure 5.3: Components of the Atlantis Water Resource Management System.

The large volumes of storm water runoff that were anticipated after urbanisation and the associated hardening of surfaces was seen as a valuable water source for augmenting water supplies and this prompted the construction of a storm water collection system. The storm water system now consists of twelve detention and retention basins and the necessary interconnecting pipelines with peak flow reduction features (Liebenberg and Stander, 1976). The storm water system at Atlantis was designed with the flexibility to control water flows of differing salinity and to collect the best quality water for infiltration into the aquifer. Low salinity flows are channelled into two large spreading basins, Basin 7 and Basin 12, for artificial recharge up-gradient of the Witzand wellfield. Discharges during storm events can reach up to 72 000 m³/d at Atlantis, while summer base flow, averages 2160 m³/d (Wright, 1994). In summer, the base flow is primarily groundwater entering the storm water pipelines in areas where these are below the water table.



Basin 5 in flood conditions: storm flow gushes from the outlet to fill the basin, which will then drain away in dry weather.

The vegetation and natural characteristics of the aquifer material affect the groundwater quality, e.g. it imparts high hardness to the water, significant dissolved organic carbon and, in certain parts, measurable dissolved iron, or high salinity to the water. This level of 'hardness' was not acceptable to industry, and as part of their incentive package, a Water Softening Plant was constructed in 1986 to improve the quality for industrial uses, particularly the textile industry. The hardness of the water is thus reduced by ion exchange softening of part of the flow. In the process, most of the iron is also removed but the organic carbon remains in solution.



Ion exchange softening plant in the wellfield.



Interior of the pumping station.

Initially all wastewater was treated in a single wastewater treatment plant and all the treated effluent was used for artificial recharge. In November 1986 this practice was discontinued due to water quality considerations and separate treatment plants were constructed for domestic and industrial wastewater treatment. These came online in 1992. The domestic wastewater undergoes full secondary treatment with nitrification-denitrification steps (anaerobic-anoxic-aerobic). The effluent from the secondary settling tanks is then polished in a series of maturation ponds (Figure 5.4). At Basin 6, the maturation pond effluent is blended with the urban storm water runoff before discharge into the main recharge Basins 7 and 12. The more saline treated industrial wastewater is discharged into the coastal recharge basins and seeps into the ocean through the subsurface.

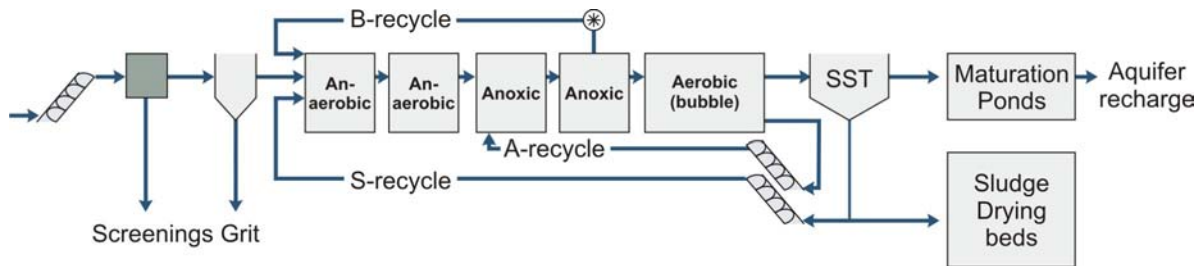


Figure 5.4: Schematic diagram of domestic wastewater treatment plant at Atlantis.

5.5 CONSUMER RELATIONS

Consumer relations for the AWRMS have a relatively untroubled history. Communication with industry was managed through quarterly meetings. While the industrialists were much more active in engaging with the scheme management than the community was, there were never any big problems. Industries' interests were around their own requirements for water quality and assurance of supply and they helped drive the continued development of the scheme. Textile industries also wanted 'soft' water and so an ion-exchange water Softening Plant was built even though the water being supplied met SANS 241 standards (note that the

water from the Witzand wellfield did not meet the standards). So this was part of developing incentives for textile industry. (The water quality in Cape Town is one of the best in the world and the basis on which the textile and clothing industry traditionally developed there, and so incentives were needed for these industries to move to Atlantis).

Communication between the community and the scheme management was done through meetings with the Atlantis Management Committee, which acted as an advisory body to the Divisional Council of the Cape. From the community side, there were not many demands. People living in the residential areas were generally satisfied with their local water supply and wastewater systems because they were in working order. However, as many people who lived in Atlantis worked in Cape Town, they had hard water at home (175 mg/l) and soft water at work (~45mg/l). This led to some complaints. The 'hard' quality of the water supply caused geysers and kettles to build up deposits of calcium. Also, the first hot water cylinders in Atlantis residences were fitted with soft water elements, which caked up and then failed. Once hard water elements were installed, this problem went away. Although the SANS 241 had a limit of 200 hardness, a hardness of 175mg/l was aimed for as it was the original quality of the Silwerstroom water. As Witzands water was over 200mg/l, a Softening Plant was required. As well, the industrialists' key requirement of water quality was *consistency*. For this purpose as well, a Softening Plant was required.

The fact that treated wastewater was being recharged into the groundwater was never raised as a concern by the community. Initiatives were taken to involve the community, and at least once, educational awareness programmes were carried out with matric students to make them aware of their unique water supply system.

"I remember being interviewed on a local radio show back then. People in Atlantis weren't really aware of where their water was really coming from . . . but there were lots of complaints about the costs of washing powder!"

Rodney Bishop, interview, 2009.



Local signage.

5.6 SCHEME CONSTRUCTION

As has been indicated, the Atlantis Water Resource Management System, which is based on the integration of its water supply, wastewater, and storm water systems was developed over time. In fact, it took approximately 40 different projects over time to develop the entire integrated scheme as it now exists. Throughout these developments, a key consideration was that the quality of the water to be recharged should match or be better than the quality of the groundwater at that point. The chronology of developments is listed in Appendix 1.

*"A key guiding principle for those involved in the project from its inception was that there should be as little change as possible made to the aquifer."
Alastair Bishop, interview, 2009.*



Basin 3 under construction.



Construction of water softening plant.

5.7 OPERATION

5.7.1 Overview

The water reclamation scheme at Atlantis is presently operated by the City of Cape Town, with the CSIR having been involved in an advisory capacity for more than 25 years. In principle, urban storm water runoff and treated domestic wastewater are recycled via the aquifer and augment the limited natural yield of the Atlantis aquifer. An important feature incorporated into the Atlantis recharge system is the separation of the storm water runoff and wastewater into components of different qualities, mainly with respect to salinity (Tredoux and Cavé, 2002). This allows the recharge of lower salinity water in parts of the aquifer where the natural groundwater salinity is lower. Hence two recharge basins were constructed with Basin 7 intended for higher salinity water and Basin 12 for lower salinity water. This is achieved by means of a diversion structure ('splitter box') for diverting peak flows to Basin 12 while the low flows and particularly the more saline base flow in the system are directed to Basin 7. The more saline industrial wastewater and high salinity storm water from Basin 10 are

*"Mathematical modelling was a very big part of the management of the scheme . . . The mathematical models were always being revised . . . Not over-exploiting the water resource was the key to the whole show."
Tony Murray, interview, 2009.*

diverted to the coastal recharge basins and are not used for recycling water in the main part of the aquifer.

It was decided to use the weak base ion exchange for removal of temporary hardness using sulphuric acid as a regenerant for the Softening Plant ion exchange resin. The team worked out that the industrial WWTW effluent going to the coastal ponds could be used to dispose of the regenerant effluent so no additional spent acid neutralisation was required at the Softening Plant. Additionally, Borehole G30966, which provides water containing calcium bicarbonate, was added as a diluent into the effluent basin at the Softening Plant to reduce scale formation in the effluent pipeline.



Splitter box during high flow with water diverted to both Basin 12 (left) and Basin 7 (right).



John Charles in the control room of the Softening Plant.

On my left hand side you can see there is the computer system we call the SCADA control system. From the SCADA control system, we can stop and start the boreholes - which are a few kilometers away -- as the need arises. Also the pump station and other control aspects can be controlled from here. This is a very unique and significant set-up that we have here because in the old days we used to have to go out to the different sectors - the borehole pumps, the big pump stations. This is all now brought to the control of the control center and from here we can control everything.

John Charles, video interview, 2009.

John Charles is the current Manager of the Atlantis Water Scheme Utility Service - Bulk Water.

The operation and maintenance on the AWRMS is currently carried out by 48 staff members that operate on a rolling shift.



Night repair of burst pipe by AWRMS staff.

5.7.2 Changes in operation over time

The limitations of the groundwater supply and the fact that there was surplus water available in the Melkbosstrand area led to the linking of the Atlantis water supply to the main Cape Town water scheme via a link to the pipeline from Voëlvlei Dam in 1998, allowing the importation of low salinity surface water. A difficulty presently (2009) experienced in the operation of the scheme is the borehole clogging ascribed to biofouling and the natural occurrence of iron in the groundwater. This seriously affects the wellfield production capacity and borehole rehabilitation has become part of overall operation and maintenance (O&M). One result is that larger volumes of surface water from the City of Cape Town are currently being imported. Hence the groundwater (and recycled water) content of the final water supply may be as low as 50% at this stage (2009). This means that the aquifer is not currently being optimally utilised. However, an important spin-off is the decrease in overall salinity in the system. This is brought about by the low salinity imported surface water which is recharged into the aquifer after use and which blends with or displaces more saline groundwater. This improves the quality of the water and is also useful as it helps reduce the problem of bio-fouling, which affects all production boreholes. As mentioned, the bio-fouling problem has O&M ramifications. In Atlantis it presents a real challenge to staff and equipment capacity.

5.7.3 Basin clogging

‘Basin clogging’ refers to the build up of fine sediments and organic material on the bottom of a basin over time. This build-up of material slows down the infiltration rate (i.e. the rate at which the water goes into the ground) of the recharge basin. In the case of Atlantis, the infiltration rate decreased noticeably over the years in Basin 7 (the original recharge basin). The clogging rate of the infiltration surface depends on the rate at which the fine particles transported in the recharge water are deposited in the basins. Initially, a heavy load of fine particles and sand reached Basin 7 where a large part thereof was deposited in the stilling basin at the inlet (which acted as a silt trap), but also in the basin itself.

To address this situation, action was taken in two ways. Firstly, Basin 6 was modified in 1988 by blocking off the bypass channel and subdividing the basin in order to force all water to flow over the new weir that was constructed in the centre of the basin changing it from a dry to a wet basin. Soon thereafter reeds established themselves in Basin 6, and since then the sand and silt transported by the storm water system is now deposited at the storm water outlet into Basin 6 so that Basin 6 acts as a silt reduction point, greatly reducing the amount of silt carried on to recharge Basin 7. In the past, this material has been removed several times from Basin 6, but it needs to take place on an annual basis.





Inflow to Basin 6: treated domestic effluent (centre); storm water (right); with sediment deposits showing on left.

Secondly, following the modifications to Basin 6, all flow was diverted temporarily from that point to the Donkergat River, allowing Basin 7 to dry out completely in 1989. A front-end loader was brought in to scrape away the layer of sediment at the bottom of the basin. This improved the infiltration rate dramatically, also because the water level in the subsurface had dropped in the meantime. However, in the 20 years since then, it has never been cleaned again. Thus, Basin 7 currently (2009) needs scraping as there is a significant layer of fine material that is evident whenever the water level drops sufficiently. Basin 7 should be cleaned every 15 years based on the present flow regime. Furthermore, subdividing Basin 7 would allow for alternative wetting and drying. This will assist in maintaining a high infiltration rate and will aid in improving water quality by reducing the dissolved organic carbon load. Such a modification would also enhance the regular cleaning operation, as it will facilitate scraping when needed (it is also possible that fines may blow away after drying out).



Basin 7 – original recharge basin.

Basin 12 has never been cleaned. It dries out regularly and the fine material deposited on the surface dries out, cracks, and is largely blown away. Only the top few centimetres are discoloured by darker fine material but this does not influence the recharge rate significantly. It has been in use for 15 years and according to the present regime, it may need cleaning only in another 20 or 30 years.



Basin 12 sand sampling - thin silt layer.

5.7.4 Infiltration rates

The infiltration rates of the basins are given in Table 5.1 below. Approximately 7500 m³/d or more than 2.7x10⁶ m³/a is recharged in the two main infiltration basins - Basins 7 and 12.

Table 5.1: Recharge facility characteristics (average values)

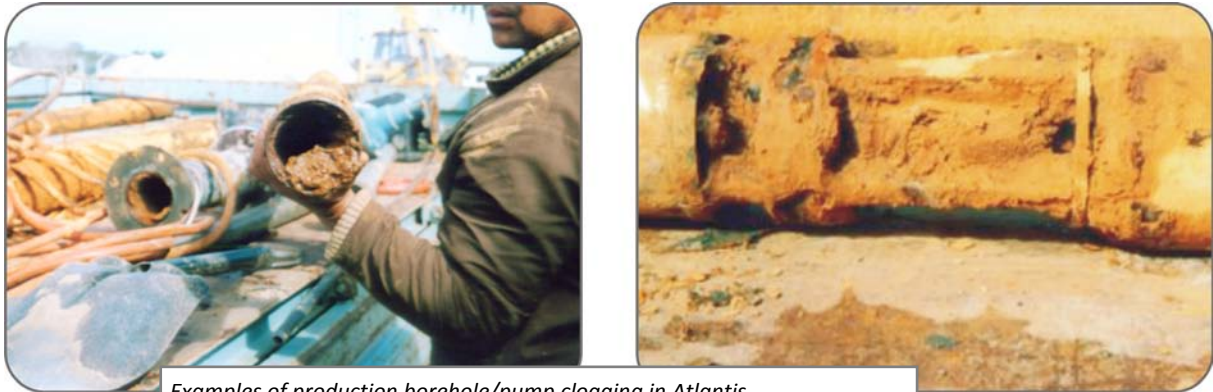
Facility	Area (ha)*	Unsaturated zone (m)	Infiltration rate (m/day)**
Basin 7	28.3	1.5	0.01
Basin 12	16.8	4.5	0.16
Coastal Basins	12.5	10.5	0.11

* Total basin area when full; Basin 12 mostly dry

** Rate based on total basin area

Note that the infiltration rate at Basin 7 is ten times lower than the infiltration rates at Basin 12 and the Coastal Basins for two reasons:

- a) At Basin 12 and the coastal basins, the sand is comparatively coarser than the fine material found at Basin 7;
- b) The unsaturated zone at Basin 7 is extremely small. With the large extent of the basin (28 ha), the unsaturated zone becomes saturated and the water has to leave the area via horizontal flow. This is difficult at the low gradients.
- c) The silt load in Basin 7 is higher than the other basins.



Examples of production borehole/pump clogging in Atlantis.

5.7.5 Borehole clogging / Iron bacteria

The first well clogging occurred in the early 1990s when due to drought conditions the boreholes were over-pumped and air entered the screened section of the borehole. The situation was aggravated because the construction of the wastewater treatment plant was still in progress and only storm water runoff could be recharged. The first regenerant used to address the borehole clogging was citric acid. This was a fairly successful treatment initially but was only effective for the short-term. In the latter half of the 1990s, borehole clogging emerged as a serious problem, both at Silwerstroom and at Witzand production wellfields. Pumping at too high a rate in order to meet the high water demand caused by housing construction at the time triggered the worsening of the clogging problem. The widespread nature of the problem and elevated iron and sulphate in the groundwater pointed to biological iron-related clogging rather than physical clogging of individual boreholes (the biological nature of the clogging had not been recognised at first). This was confirmed by analysis of red-brown slimes coating the borehole pumps and pipes, which were found to host high concentrations of microorganisms. Over-pumping that results in air entering the system upsets the balance of the natural ecology at a borehole site, this in turn can stimulate the over-growth of micro organisms in the soil. This time the clogging problem was addressed by blended chemical heat treatment and rehabilitation of the boreholes during the period 1999 - 2002, as well as redesigning the wellfield management programme to treat the cause of the clogging. The borehole treatment included cleaning the pipe, the screen, and the immediate underground area of each borehole using both heat and chemical dispersion into the soil to destroy the bacteria, followed by pumping out the slimes. The treatment was fine-tuned during the pilot phase. By the end of 2002, 35 (of 37) boreholes had been brought back to a very good state of cleanliness, but at a cost of R50,000 per borehole. This treatment, combined with the redesigned management programme kept the borehole clogging problem under control for the following five years. Recommended yields for each borehole were reassessed after



A. Hön sampling the clogging material on the borehole pump.

rehabilitation and boreholes were set to pump at lower rates by means of orifice plates where necessary. Pump cut-out probes have been checked to ensure that these are all at least 1.5 m above the pump intake to prevent air being drawn into the pump. Boreholes with screens placed within the drawdown zone have been identified and these need to be observed closely to ensure that they are not over pumped. New electrical control panels for the boreholes were installed in 2002 to facilitate management of the pumping.



Atlantis borehole in Witzand wellfield.

Borehole rehabilitation restored yields for many of the 37 production boreholes treated, but the treatment methods seem to have certain limitations. It now appears that clogging may be recurring more rapidly in some rehabilitated boreholes. The rehabilitation process needs further research and development, integrated with a detailed water quality and performance monitoring programme for the production boreholes. An investigation into the causes of clogging included a survey of the abstraction conditions, which revealed that the boreholes were often stressed by pumping above the recommended rate, and that some of the pumping infrastructure, such as flow metering equipment, needed mending or replacement. Subsurface *in situ* treatment for iron and Dissolved Organic Carbon (DOC) removal poses a challenge and could play a key role in reducing biofouling.

5.7.6 Other problems

Groundwater pollution and uncontrolled abstraction from the Atlantis aquifer provide the two main threats to the sustainability of the water supply. Financial and staffing constraints are also limiting factors. Note that the construction of the Melkbosstrand surface water pipeline in 1998 has provided an important emergency back-up to the groundwater supply.

5.7.6.1 Uncontrolled abstraction threats

Uncontrolled groundwater abstraction in the Atlantis area reduces the volumes of groundwater available for public supply and affects the predictions of sustainable yield from the aquifer. Two forms of uncontrolled abstraction are:

Small and medium scale users

Many of the agricultural smallholdings and industries in Atlantis have private boreholes that they use for a variety of purposes, but mainly for irrigation. Although the National Water Act (1998) requires that users register their groundwater abstraction with the Department of Water Affairs (DWA), it is doubtful whether many of them have done so. The individual abstraction volumes are also likely to be low and are generally expected to fall within the 10 m³ per day that is generally authorised (Government Notice 1191) and does not require registration. Nevertheless, the cumulative impact of these users may have a significant effect on the aquifer.

Alien vegetation

Infestation by alien invasive species, which use considerable volumes of water, has been rife in the Atlantis area. The dominant invader is *Acacia cyclops* (rooikrans) with occasional *Acacia saligna* (Port Jackson) (Colvin *et al.*, 2001). The dense *Acacia* stands result in an increase in biomass, which is generally associated with an increase in evapotranspiration, so it is likely that the invaded stands may intercept or transpire more water than the natural vegetation, thereby reducing groundwater recharge. Eskom, the City of Cape Town and DWA's Working for Water Programme have been involved in alien vegetation eradication programmes in the catchment, particularly in the areas of Koeberg Nature Reserve, at recharge Basin 7, and Witzand Farm.



Borehole with stand of alien Rooikrans (Acacia cyclops) in background.

5.7.6.2 Threat of saline water encroachment and increased groundwater salinity

Managing water quality and, in particular, salinity has been one of the greatest challenges for the Atlantis Water Resource Management Scheme. High quality, low salinity water (electrical conductivity <70 mS/m) occurs in and around the high recharge area of the Witzand dunes. Lower salinity groundwater is also encountered at the wellfields, which are located in the thicker portions of the aquifer, but the fresher regions of the aquifer are generally bordered by waters of marginal quality where the aquifer thins out against the bedrock. The main threat is posed by the saline water from the Brakkefontein area in the south where the sand deposits are thin and pinch out against the shale bedrock (see Figure 5.1). Abstraction from the southernmost boreholes in the Witzand wellfield was discontinued to obviate the attraction of more saline water to the wellfield when the high pumping rate and less water to Basin 7 meant that southern boreholes pulled in high Fe and SO₄ water. The high SO₄ water occurred near Basin 10 and moved southwest towards the Koeberg Nuclear Power Station. The recharge into Basin 7 helps to keep the brackish water from the Brakkefontein “compartment” at bay.

"We got results weekly at that time and were able to see the changes when they started happening. It was a good system then - we could take action within hours - we were all in the same building. That is no longer the situation."
Peter King, interview, 2009.

5.7.6.3 Groundwater pollution threats

The following potential sources of groundwater pollution pose a risk to the Atlantis Aquifer:

Caltex oil pipeline

A pipeline for the transport of crude oil runs alongside the R27 (West Coast) road from Saldanha Bay harbour to the Caltex Refinery in Milnerton. This pipeline passes through the eastern part of the Witzand wellfield and a major leak from the pipeline could be potentially disastrous for the groundwater supply. Caltex is responsible for the pipeline and have developed an emergency oil spill contingency plan to deal with any leaks, but do not have a specific monitoring programme for the Atlantis area at this stage. A cathodic protection study of the pipeline has also been undertaken. Pressure tests carried out on the pipeline are not sensitive enough for detecting “smaller” leaks that could be disastrous to the water supply.

If a leak is detected, the Witzand wellfield should be shut down immediately and Caltex Refinery notified. Silwerstroom wellfield or the Melkbosstrand pipeline should be used for temporary water supply while the extent and impact of the leak is assessed.

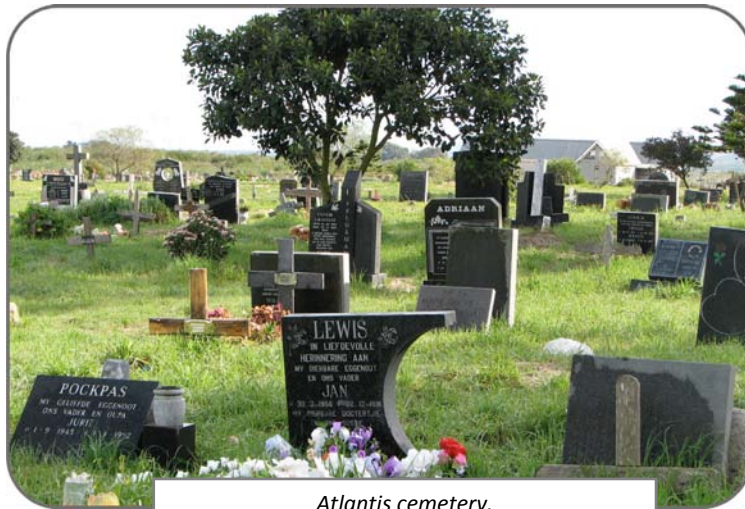
Hazardous chemical spills

Emergency incidents such as spills may occur in the industrial area or if there is an accident involving hazardous chemical transport by road or rail. These may affect the aquifer directly by infiltration at the site of the spill or by entering the storm water system and arriving at the recharge basins by that route. Particularly, spills along the R27 pose a direct threat to the wellfields. Discharge of industrial waste to the storm water system has occurred in the

past and the Water Pollution Control Office of the City of Cape Town imposes heavy fines for this offence.

Point sources of pollution

Most of the known point sources of pollution in the Atlantis area have been sited away from the productive areas of the aquifer that deliver high quality water. Examples of pollution point sources include the wastewater treatment works (e.g. the sludge drying beds); the Atlantis Foundries waste disposal site (situated on the Brakkefontein compartment of the aquifer – see Figure 5.1); the cemetery to the north of the town; and the old, unlined municipal waste disposal site along Dassenberg Drive (see Figure 5.1). This site was closed in 1988 because of the threat to groundwater quality. The Ankerlig Eskom Power Station (see Figure 5.1) constructed in 2008 and extended in 2009 presently uses diesel fuel and although extensive precautionary measures were implemented a limited pollution risk may still exist.



Atlantis cemetery.

Non-point sources of pollution

Rural development in the area is accompanied by several activities that provide potential non-point sources of groundwater pollution. Examples include the agricultural practices of small scale farmers and the development of unserviced informal settlements. These have not been investigated in any detail to date. The industrial activities in Atlantis Industria are also a potential non-point pollution source.



Toilets of informal settlement.

6 RESULTS FROM NEARLY 30 YEARS OF OPERATION

As indicated previously, monitoring systems were incorporated into the Atlantis Water Resource Management Scheme from an early stage. Based on an extensive system of monitoring wells and sampling activities, mathematical modelling was used to enhance the understanding of the aquifer and to assist with its management. Out of this work (some of which began as early as 1982), the following results have been gained about the AWRMS, including aquifer yield, water quality, and a greater understanding of the impact of artificial recharge on the aquifer.

6.1 WATER QUANTITY (VOLUMES RECHARGED AND ABSTRACTED)

It is estimated that on average approximately 7500 m³/d of storm water and wastewater is recharged up-gradient of the wellfield (Basins 7 and 12, Figure 4.1) augmenting the water supply by more than 2.7x10⁶ m³/a. Some 4000 m³/d higher salinity industrial wastewater is treated and discharged into the coastal basins down gradient of the wellfield close to the ocean.

Note that the recharge volume measurement instrumentation functioned relatively well until the mid-1990s but was then subjected to vandalism. Of concern is that while alternative instrumentation that would be vandal-proof was eventually installed, it is not functional yet, possibly because it is not entirely suitable for the task. As a general note, vandalism and security measures have significant cost implications for the scheme.



A proud moment: Receiving ISO 9001_2000 accreditation for water quality.



The rising cost of security measures.

The changes effected from time to time to the recharge regime had a significant influence on the water levels in the Witzand well field (Figure 6.1). WP9 and WP51 are located in the southern part of the well field while borehole G33108 is located opposite the northern part of the well field. The southern part of the well field is directly affected by recharge from Basin 7 and shows a marked seasonal effect. Initially when all wastewater and storm water was recharged the water levels in the southern well field area was around 50 m above mean sea level. When wastewater recharge was discontinued at the end of 1986 water levels started declining strongly in the southern well field area. At that time the well field to the east of the R27 had not been installed but once abstraction also started in that area in the mid 1990s the water levels in the northern part also declined more rapidly.

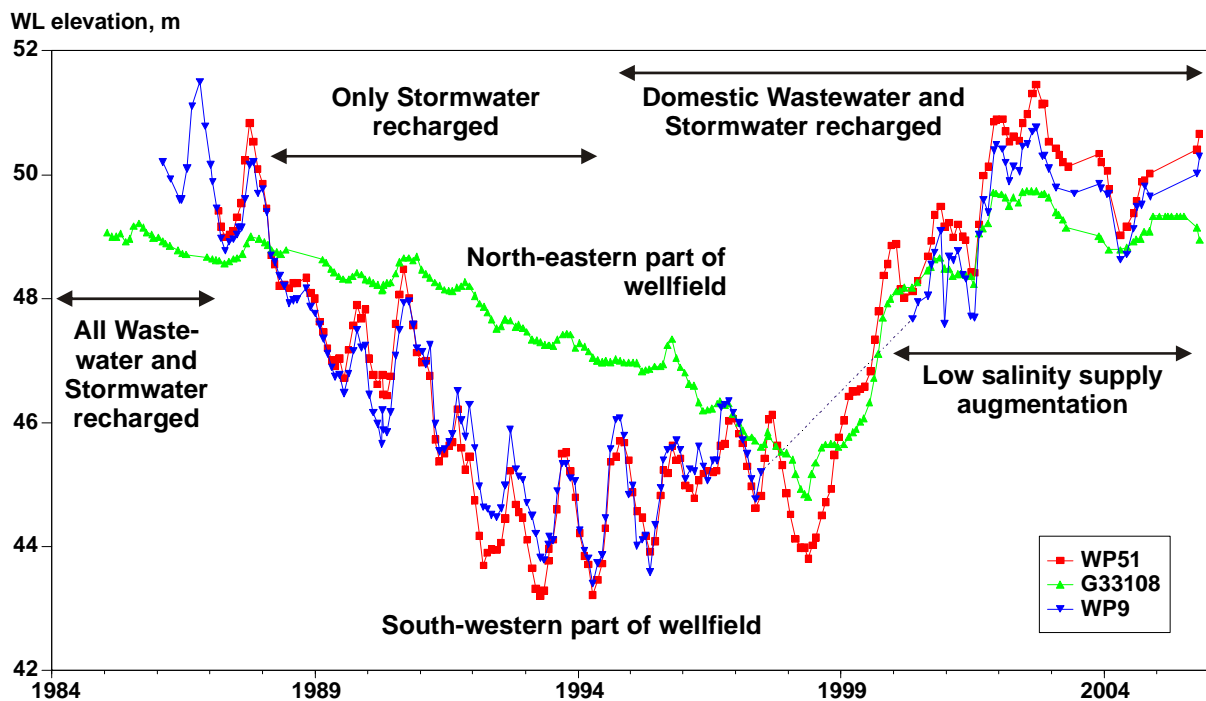


Figure 6.1: Water level response in the Witzand wellfield to different recharge regimes.

When treated domestic wastewater recharge resumed in 1994 the water levels in the south began to stabilize. Once the surface water augmentation started in 1999 abstraction was reduced while the recharge continued at the same rate. As a result water levels recovered rapidly both in the south and the north where Basin 12 was also in operation.

6.2 WATER QUALITY (RECHARGED AND ABSTRACTED)

The water quality in the Atlantis Water Resource Management Scheme is assessed taking the following groups of water samples at the indicated points: the input points; in the aquifer; product (i.e. water treated for consumption); and non-recycled waste discharge. The sampling points are shown schematically in Figure 6.2.

i) Sampling points A1 to A5 (input): The feed water sources sampled consist of the following: secondary treated domestic wastewater -- before and after -- the maturation ponds; the

final storm water; as well as the blend (after passing through the reed bed) that is used for recharging the aquifer (including the blend to recharge Basin 7 and the blend to recharge Basin 12).

ii) Sampling points A6 to A10 (aquifer): The groundwater blend was sampled down gradient of each of the recharge Basins (7 and 12) approximately halfway to the production wellfield. Groundwater was also sampled at two production boreholes influenced by the respective recharge operations at the two basins. Finally, the groundwater blend from all production boreholes was sampled immediately before the softening process.

iii) Sampling points A11 to A12 (product): The product water after softening was sampled in order to determine the effect of softening on the general water quality. The second product sample represented the final chlorinated water before pumping to the town for determining the effect of the chlorination on the overall water quality.

iv) Sampling point A13 (non-recycled wastewater discharge): The last sampling point is of the treated industrial wastewater, which has a higher salinity and is discharged into the coastal recharge basins (i.e. this water does not form part of the recycling system). This sampling recorded the composition of the industrial wastewater in order to provide an indication of the possibility to make better use of this source instead of it being discharged into the coastal dunes and seeping into the ocean.

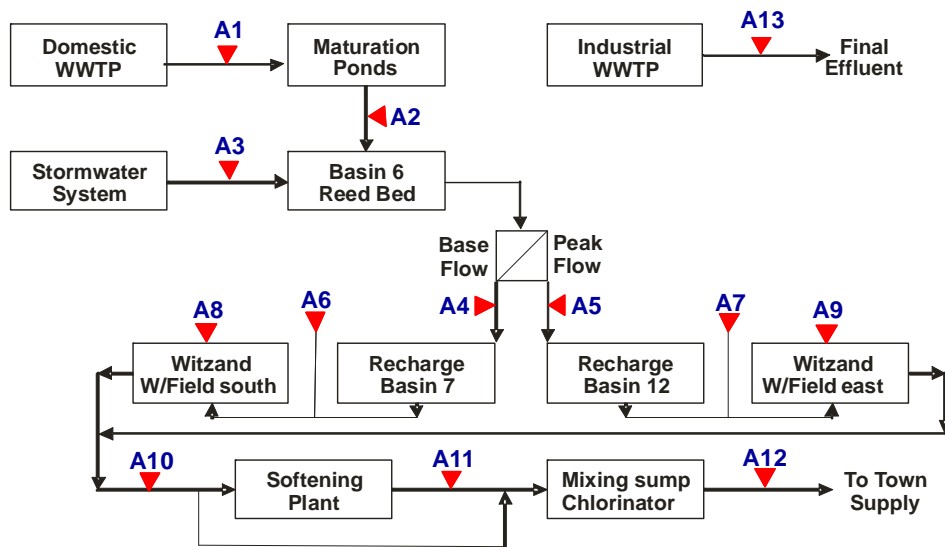


Figure 6.2: Schematic layout of the Atlantis system showing the monitoring points.

Water salinity data for most of the operational period has been procured and is presented below. The recharge water quality at Basin 7 is shown in Figure 6.3. Little data is available for the recharge water quality at Basin 12. The better quality water from the Basin 12 area is only reflected in Figure 6.6, which shows the lower salinity from those production boreholes.

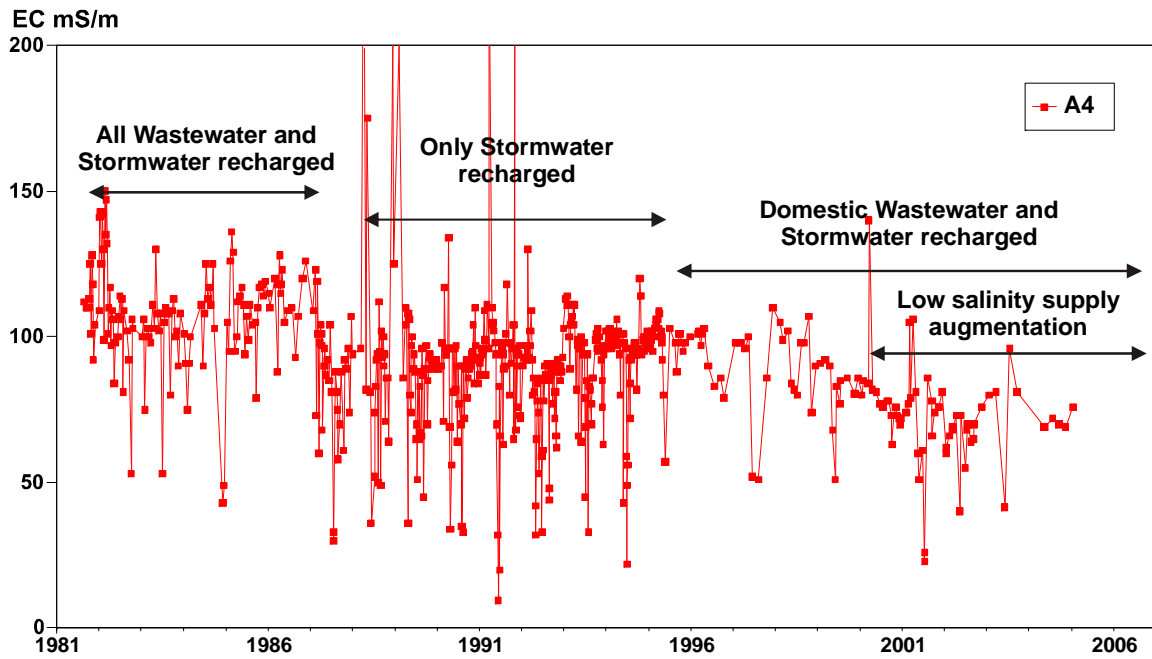


Figure 6.3: Electrical conductivity of recharge water at Basin 7 (sampling point A4).

From scheme inception in 1980 until November 1986, all treated wastewater (both domestic and industrial) and all urban storm water runoff were recharged in Basin 7 (the only recharge basin in operation from the start). Clogging of Basin 7 was evident in 1988 and the basin was dried out and cleaned by scraping the surface at the beginning of 1989. Up to this point, the load of organic compounds and heavy metals was high (Figure 6.4). In addition, the sediment load was considerable. The modification of Basin 6 for serving as a silt trap made a distinct difference to the sediment load and silting problem at Basin 7. Basin 6 then also developed into an artificial reed bed which trapped even more of the fine material in the storm water runoff.

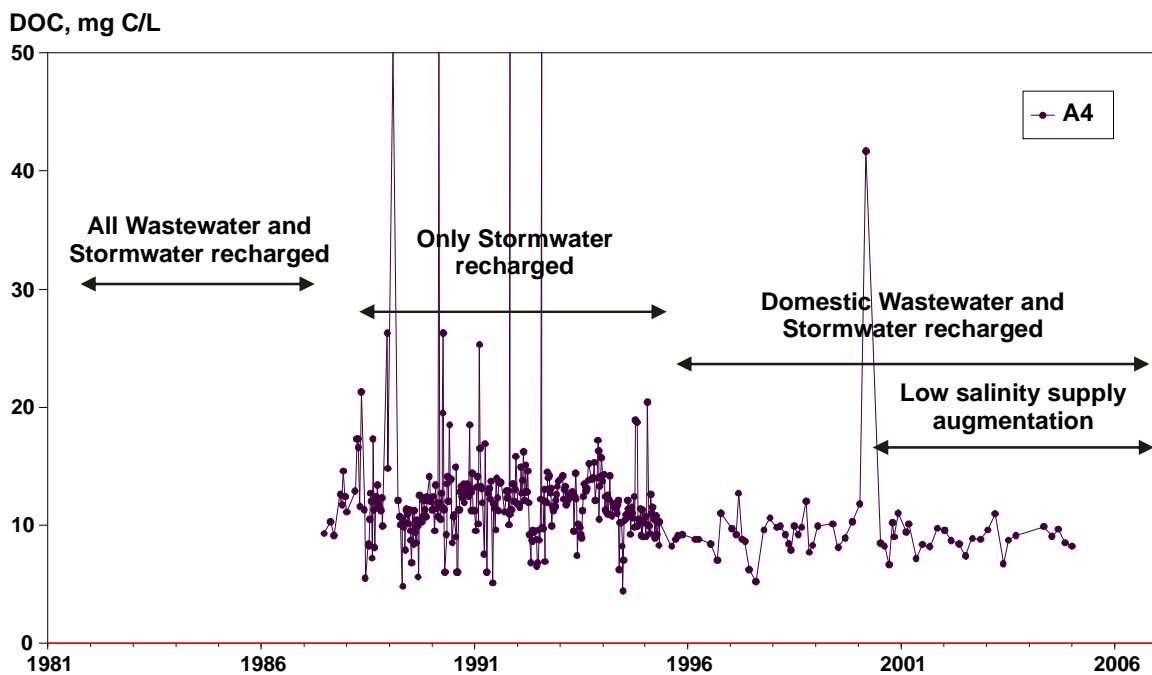


Figure 6.4: Dissolved organic carbon concentration of recharge water, Basin 7 (sampling point A4).

Due to the layout of the town, with the industrial area totally separate from the residential areas, separation of the higher salinity industrial wastewater was readily achieved. A new wastewater treatment works was built for the treatment of domestic wastewater to a high standard for recharge. Subsequently, after refurbishment, industrial wastewater was treated in the older works and the treated wastewater routed to newly constructed recharge basins at the coast for infiltration and subsurface discharge into the ocean. At the same time, a Softening Plant was constructed for reducing the hardness from 275 mg/L to approximately 175 mg/L (Witzand hardness ranges from 200 to about 275mg/L). By using a weak base ion exchange resin, temporary hardness is removed and the Total Dissolved Solids (TDS) of the treated water decreases from 570 mg/L to approximately 460 mg/L. The brine from the regeneration stage is diverted to the coastal recharge basins together with the treated industrial wastewater (Tredoux *et al.*, 1999). Note that Basin 10, a storm water retention basin and operated as a wet basin with a reed bed, in the industrial area that is high in SO₄ originally went to Basin 7, but was diverted to the coastal basins line in the 1980s.

Modification of the infrastructure took several years and during that time only the urban storm water runoff was recharged in Basin 7 (November 1986 – mid-1990s). Only from the mid-1990s was the treated domestic wastewater recharged together with the storm water runoff. Basin 12 was also constructed at that time and linked to the system.

Historical water quality trends at the recharge basins are illustrated by means of the electrical conductivity (EC) as shown in Figure 6.3. The sampling point corresponds with A4 as set out in Figure 6.2 (i.e. the blended water after going through the reed bed of Basin 6 (and before entering recharge Basin 7)). The initial period (1980 – 1986), shows the higher salinity water that was recharged. In the subsequent period (1986 – mid-1990s), the salinity varied significantly as the storm water input volume varied, but nevertheless the salinity was somewhat lower. It should be recognised that the flow regime was such that the lower salinities represented peak flow storm water and thus higher flow rates. Higher salinities are generally associated with base flow and lower input volumes. The lower salinity water that was recharged from 1996, after the domestic wastewater was added back into the system, eventually reached the Witzand wellfield and the overall salinity started decreasing (Figure 6.3). This trend was enhanced in 2000 when the surface water pipeline came into operation for importing low salinity surface water from the Cape Town water supply system.

The dissolved organic carbon (DOC) measurements only started in the late 1980s and the exact reduction in the organic load when the treated industrial wastewater was diverted is unknown (Figure 6.4). The DOC is of concern due to the potential mobilization of iron from the geological material, which causes clogging of the production boreholes. A high DOC also causes difficulties in disinfection of the water as trihalomethane compounds are formed during chlorination. It is evident that the load in the storm water is higher than in the treated domestic wastewater hence the decrease in DOC from 1996 onwards. The low salinity surface water importation did not affect the DOC of the recharge water.

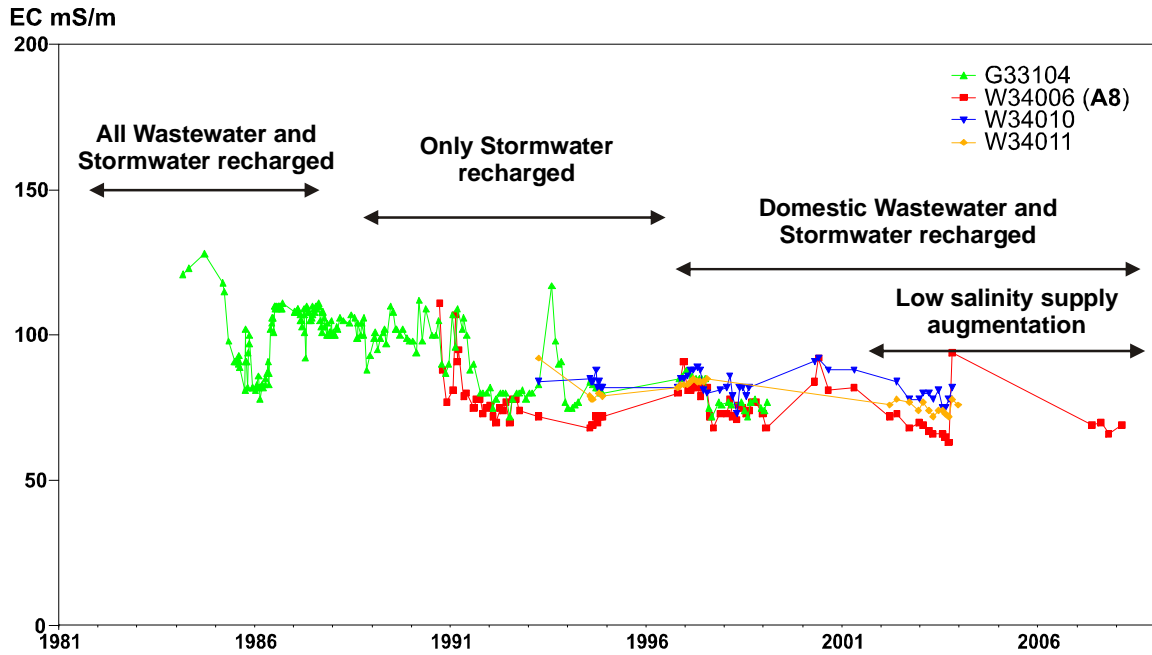


Figure 6.5: Electrical conductivity at production boreholes in the southern part of the Witzand wellfield.

(Note: Borehole W34006 represents sampling point A8 in Figure 6.2)

It is therefore evident that the salinity and contaminant load of the recharged water varied considerably with time. In the early days when Basin 7 was the only recharge facility, the water quality was also poorer. Basin 12 benefited from the modifications to the system for enhancing the quality of the recharged water and mainly received high quality recharge water. This is reflected by the low salinity water in the eastern part of the Witzand wellfield (Figure 6.6).

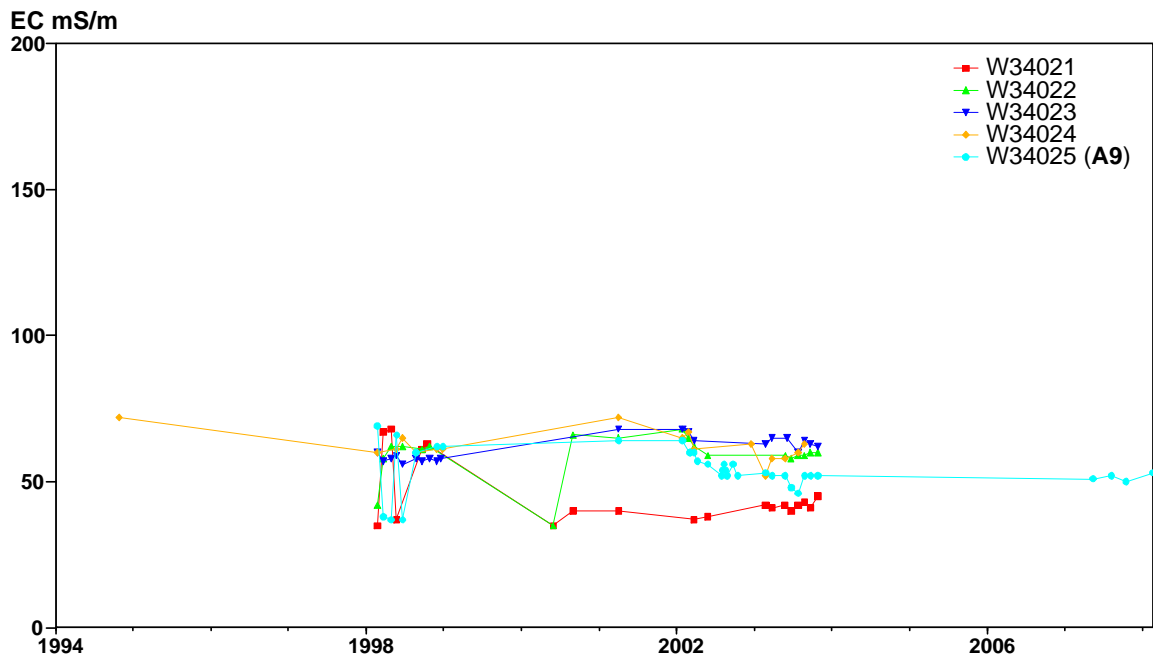


Figure 6.6: Electrical conductivity at production boreholes in the eastern part of the Witzand wellfield receiving recharge water from Basin 12.

(Note: Borehole W34025 represents sampling point A9, refer Figure 6.2)

6.3 YEAR 2007/8 SAMPLING PROGRAMME

Recently, over 2007 through 2008, data were collected regarding the accumulation of chemical compounds and contaminants in the subsurface. This took place within the EU Project “Reclaim Water” (FP6 Contract No 018309) in which CSIR was a partner. This afforded the opportunity to evaluate the system after an operational period of nearly three decades.

The purpose of this sampling programme was to determine the efficiency of the removal of contaminants. Four sets of samples were taken at the sampling points shown in Figure 6.2 for a qualitative evaluation of the overall performance of the water recycling scheme with regard to chemistry and microbiology. These results are discussed below.

From a water supply point of view, the general inorganic chemistry of the water supply at Atlantis is of key importance due to the salinity and hardness of the groundwater. The average values of the macro chemical results at the different sampling points are illustrated by means of Stiff diagrams in Figure 6.7. In each diagram the cations are shown on the left and the anions on the right. For direct comparison, the concentrations of the parameters are presented in milliequivalents per litre (meq/L). In the case of the first four sets of diagrams (a) to (d), the full scales for the cations and anions are both 6 meq/L, while for the last set of two diagrams (e), the full scale is 16 meq/L. At the top of each diagram, sodium and potassium are shown opposite chloride and nitrate; in the middle, calcium is shown opposite total alkalinity; and on the bottom axis, magnesium is opposite sulphate.

The series (a) to (d) in Figure 6.7 show the sampling points A1 to A12 that represent the various stages in the recycling. Series (a) represents the recharge components and it is evident that the maturation pond effluent (A2) is a sodium chloride water which is chemically very similar to the secondary effluent (A1). Inspection of the data shows that only the nitrate decreases slightly during the residence in the maturation ponds. The urban storm water (A3) has a slightly different composition with a little less sodium and chloride but slightly higher calcium, magnesium, and bicarbonate (total alkalinity).

In series (b) the blend of maturation pond effluent and storm water used for recharge in Basin 7 is shown at A4. As the water progresses through the subsurface, past sampling point A6 to the nearest production borehole (W34006, sampling point A8), both calcium and bicarbonate increase to some extent. These changes, together with the slight increase in sodium and chloride, are ascribed to the dissolution of calcium carbonate from the aquifer and blending with slightly more saline groundwater.

Series (c) represents the lower salinity parallel flow path from Basin 12, past observation point A7, to the closest production borehole (W34025, sampling point A9) in the wellfield. In this case, calcium and bicarbonate also increase but both sodium and chloride decrease due to blending with low salinity natural groundwater. The impact of the lower salinity groundwater is clearly visible by comparison of the two production boreholes at A8 and A9.

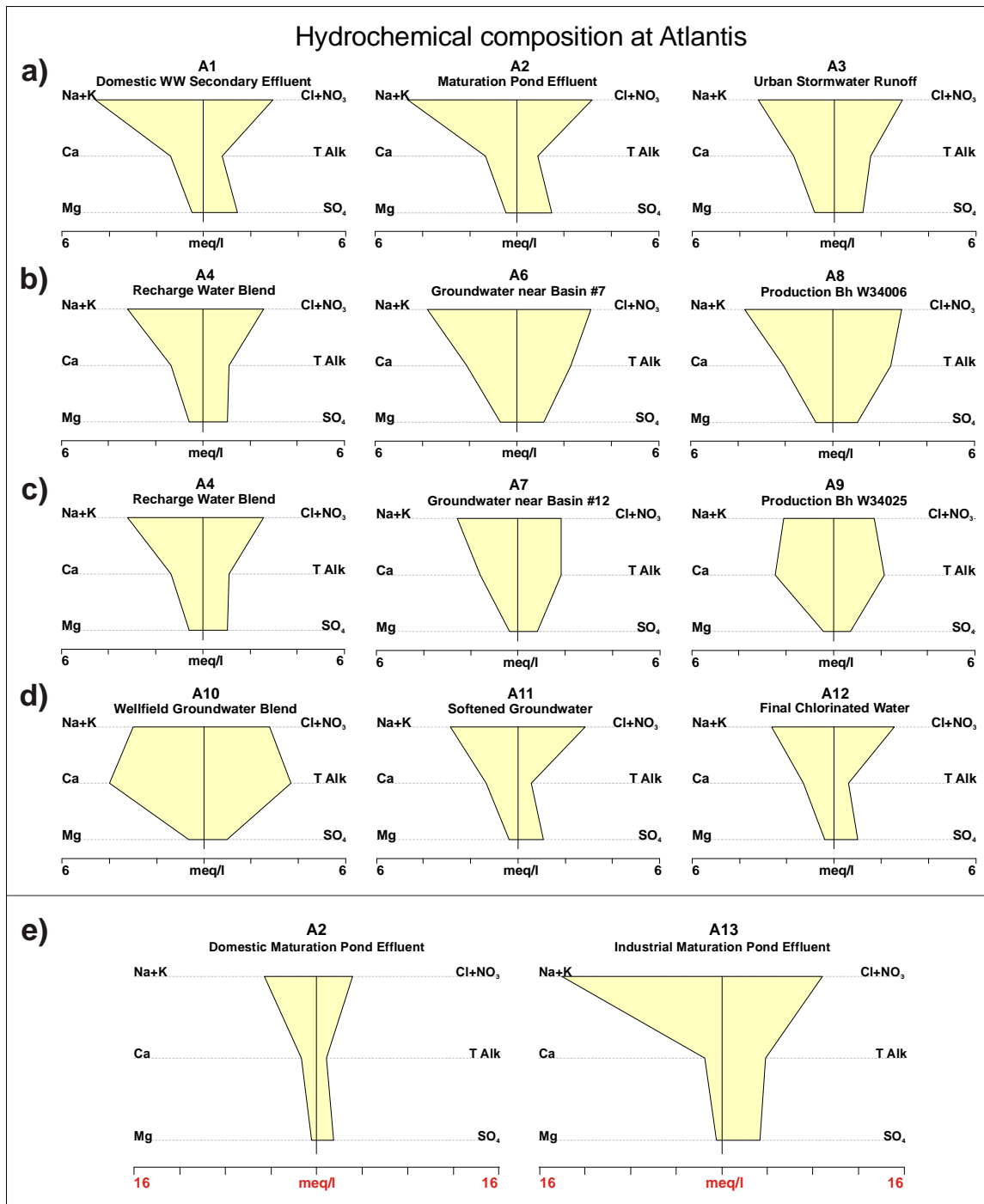


Figure 6.7: Hydrochemistry and salinity at various points in the Atlantis recycling system.

Series (d) shows the groundwater blend from the whole wellfield (A10), the softened water (A11) and the final chlorinated water (A12). It is evident that sodium and chloride levels in the blend (A10) are similar to those at the production borehole A8 but higher than at A9. The blend also has a significantly higher calcium and bicarbonate content and this represents the impact of the natural groundwater in the aquifer which is relatively hard. After softening, calcium, magnesium, and bicarbonate are significantly lower (A11) and the composition remains the same after chlorination (A12). During use in the town, the sodium, chloride and sulphate increase notably when considering the treated domestic effluent (A1) and comparing it with the final chlorinated water (A12).

In series (e) the domestic and industrial wastewater are compared after the maturation ponds (A2 and A13). The diagrams in series (e) were redrawn on a different scale to accommodate the higher salinity of the industrial wastewater; hence the diagram for A2 in series (e) looks different to that in series (a). The large increase in most parameters (compare A13 with A12) during use in the industries is noteworthy, and from the salinity viewpoint underlines the necessity to divert the industrial wastewater from the recycling system.

The salinity of the domestic wastewater is generally slightly above 70 mS/m compared to the average of the water supply which is just below 50 mS/m. On average the salinity of the storm water runoff is lower than that of the wastewater and this helps to offset the increase in salinity in the subsurface. The salinity difference between Basin 7 (sampling points A6 and A8) and the low salinity Basin 12 (sampling points A7 and A9) is evident from the graph (Figure 6.8). The effect of the low salinity peak flow water recharged in Basin 12 during winter is clearly visible up to six months later at the monitoring point (A7) down gradient of the basin. The wellfield includes boreholes outside the influence of the recharge basins and hence the overall EC of the abstracted groundwater blend (A10) is higher than that of the two production boreholes (A8 and A9) shown in the graph. This is mainly due to the increase in calcium bicarbonate (Figure 6.7), but by ion exchange softening the calcium bicarbonate is removed again. Sampling point A13 shows that the treated industrial wastewater has EC levels of the order of 170 to 180 mS/m which would make treatment for recycling for potable purposes very costly.

Dissolved organic carbon (DOC) levels were relatively high both in the treated wastewater and in the storm water (Figure 6.9). As mentioned, the DOC is of concern due to the potential mobilization of iron from the geological material, which causes clogging of the production boreholes, and because a high DOC causes difficulties in disinfection of the water as trihalomethane compounds are formed during chlorination. In winter (August 2007) the storm water had its highest DOC level at A3 (i.e. the outlet from the storm water system and before the reed bed), possibly due to intensive wash-off from roads and other surfaces in town. Via both recharge basins (A6 and A8 representing the Basin 7 route, and A7 and A9 representing the Basin 12 route) there is a significant reduction in DOC but the levels in the abstracted groundwater is still approximately 4 mg/L. In the case of Basin 12, receiving mainly peak flow storm water and underlain by a thicker unsaturated zone, the resultant groundwater has a lower DOC when comparing production borehole A9 with A8. The presence of natural organic matter in the groundwater elevates the DOC level in the final water. The much higher DOC level in the industrial wastewater (A13) is noteworthy and supports the decision to exclude the industrial wastewater from recycling.

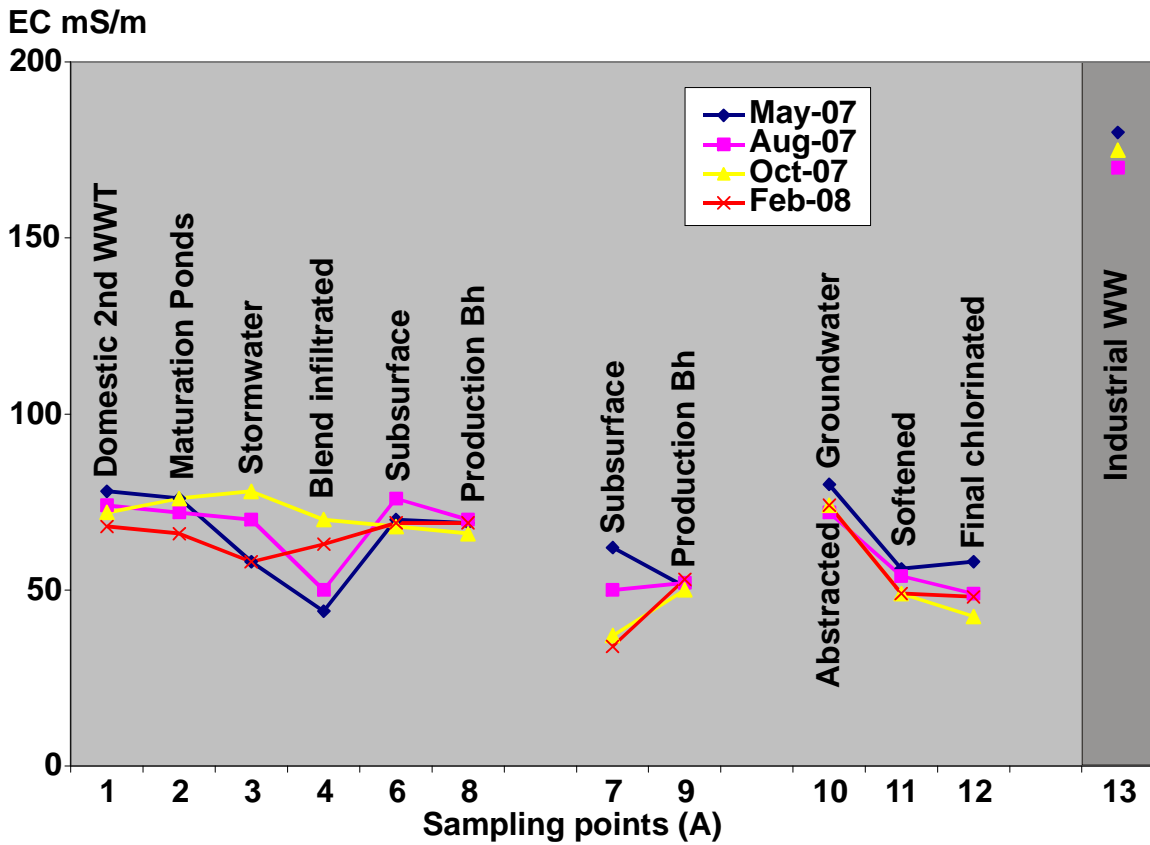


Figure 6.8: Electrical conductivity at various points in the Atlantis water recycling system.

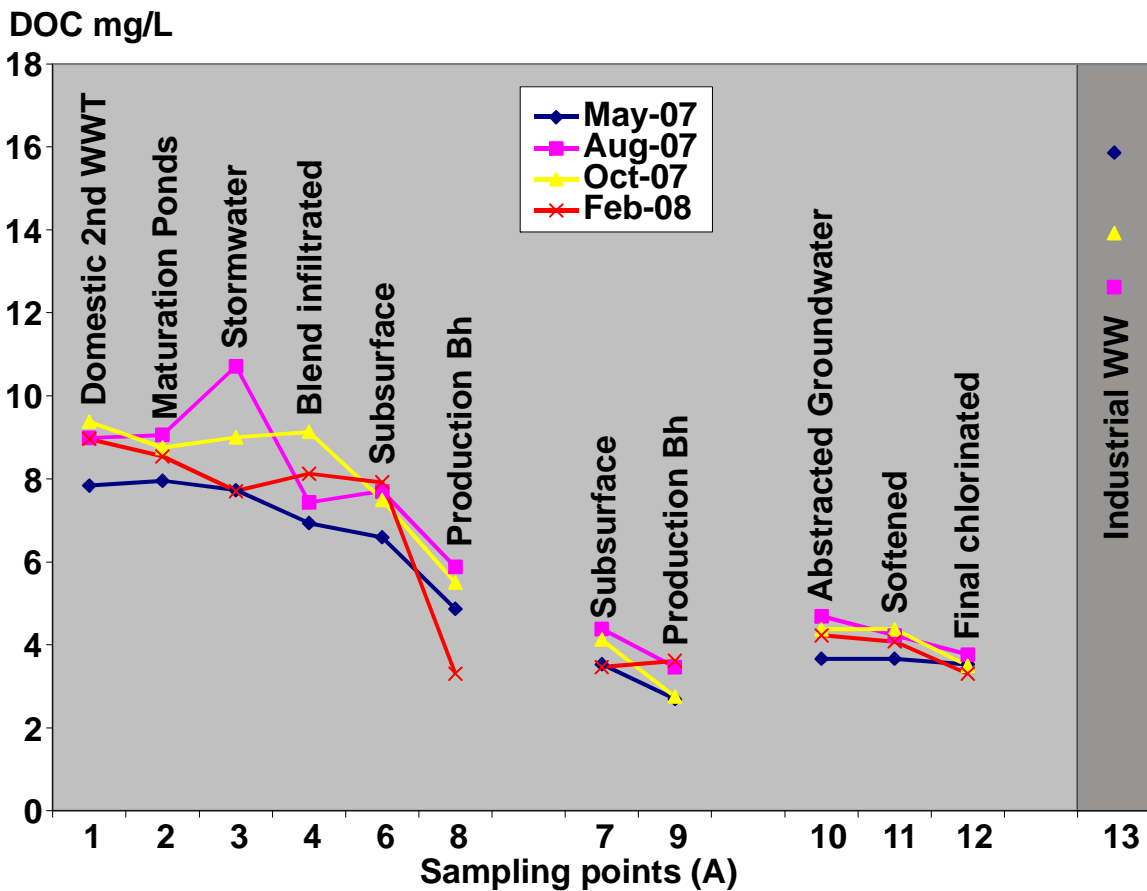


Figure 6.9: Dissolved organic carbon levels at various points in the system at Atlantis.

7 LESSONS LEARNED

Ultimately, the Atlantis Water Resource Management Scheme has proven itself as an innovative and highly successful scheme that has won various awards and worked extremely well. The AWRMS has proven that these types of recharge schemes are feasible: that they can be managed; that it is possible to integrate storm water; and that it is possible to separate different types of wastewater and storm water and manage them all. The performance of the water recycling system at Atlantis was shown itself to be relatively robust with respect to the elimination of contaminants, and based on present knowledge, the recycling of the water does not present a threat to the potable water supply.

The successful integration of the storm water at Atlantis was a successful innovation that has provided a big learning opportunity, which in turn has fed into the thinking around storm water systems in the Western Cape (and is also starting to make an impact in Gauteng and Durban). Encouraging “natural groundwater recharge” has become part of the new draft by-laws of the City of Cape Town with regards its storm water plans.

On a more cautionary note, longer-term sustainability of the AWRMS depends on proper maintenance of all components for eliminating risks. The subsurface passage of the water plays a key role in the microbiological safeguarding of the system. The Atlantis Water Resource Management Scheme is a complex operation and its successful operation requires a multidisciplinary approach. Initially this was relatively straightforward as Atlantis was managed as a town on its own by the Divisional Council of the Cape. The integrated management controlled the water supply system (i.e. wellfields, water treatment, distribution, etc.), wastewater treatment, urban storm water collection and disposal system, monitoring of all water quality (i.e. aquifer, wellfield, treated water, distribution system, wastewater, storm water (various points), recharge basins, disposal systems, discharges by industries, etc.). In a large metropolitan setup such as Cape Town, under which AWRMS now falls, the various functions are distributed over several departments and none of these have the full overview of a water management system such as the one existing at Atlantis. Coordination between Bulk Water, Wastewater, Roads and Storm water, Parks and Forests, and all other relevant structures is essential for the proper functioning of the water supply system. For the City of Cape Town, groundwater as a water supply source is a new venture, and “ownership” has to be embedded into all the administrative avenues.

"The Atlantis scheme demonstrates an innovative and successful approach. But because it is not on a huge scale, it has not attracted the attention it deserves."
Alastair Bishop, interview, 2009.

In the early 1990s when refurbishment of the wastewater treatment works was underway, the water levels in the Witzand wellfield declined while abstraction rates were maintained. This led to over-pumping of the production boreholes which seemed to set off the phenomenon of borehole clogging. Once it started, over-pumping became more severe and the clogging process accelerated. Rehabilitation still seems to be only a temporary solution and this is needed regularly.

In the early stages, financing for capital works and engineering construction was relatively accessible. Operational finance has generally been limited and lately capital works are also not easily funded. These problems hamper the upgrading of the system.

The Atlantis aquifer is unconfined and hence vulnerable to pollution over most of the area. Environmental protection was limited to an environmental management plan for the part of the Witzand farm that belonged to the local authority. A more extended protection plan is needed.

Land ownership is a problem linked to the above as several parts of the land does not resort under the jurisdiction of the City of Cape Town. This makes comprehensive environmental protection even more difficult.

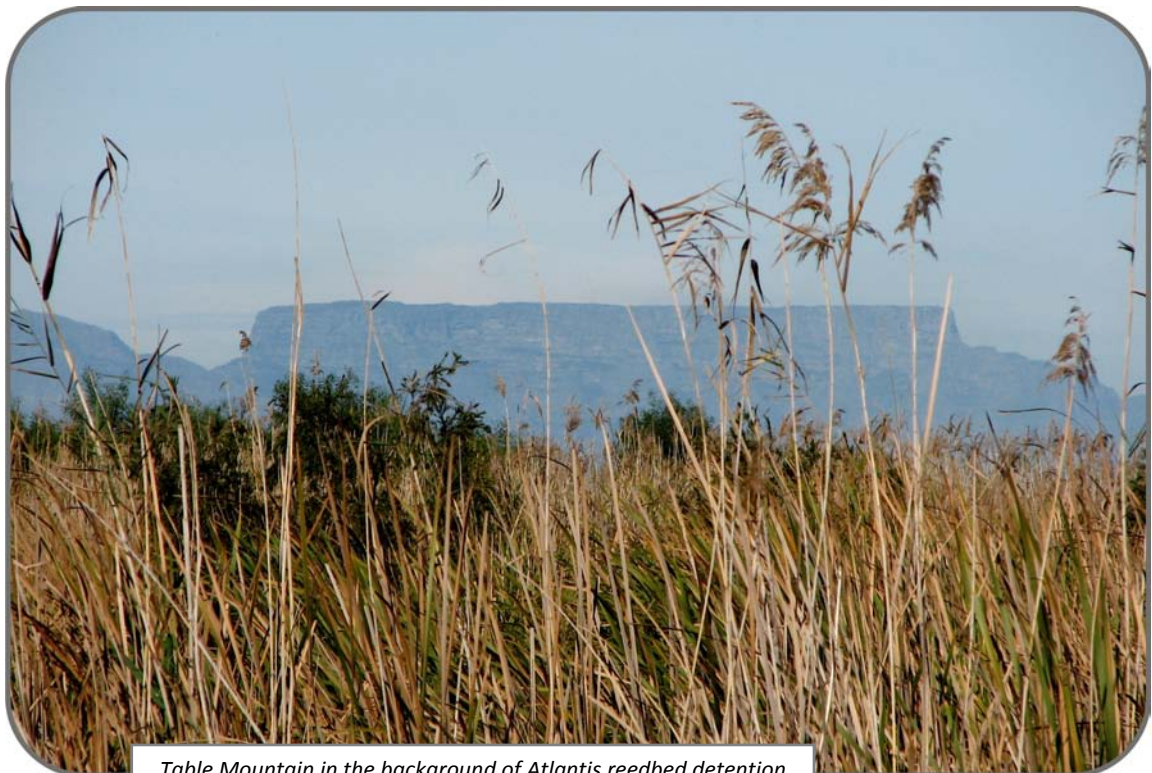


Table Mountain in the background of Atlantis reedbed detention basin.

8 RECOMMENDATIONS TO OPTIMISE EFFICIENCY OF THE SCHEME

Based on the nearly thirty years of experience in operating, managing and monitoring the Atlantis Water Resource Management Scheme, various recommendations can now be made towards ensuring the scheme's long-term sustainability.

- 1) The Atlantis scheme needs an updated, comprehensive database covering all aspects of water quantity and quality relating to each component of the scheme.
- 2) An integrated scheme requires integrated management. The current management structure for the AWRMS fragments the management of the different components. Different responsibilities rest with three different departments: Roads and Storm water; Wastewater; and Bulk Water (responsible for the recharged water). Additionally, the cooperation of the town planners is also required.
- 3) The Atlantis scheme faces several water quality management challenges, ranging from the control of saline water encroachment to industrial pollution threats and biofouling of production boreholes. The thin unsaturated zone at Basin 7 limits the attenuation capacity of the soil-aquifer system during basin recharge. The attenuation capacity will need to be enhanced by redesign of recharge Basin 7 into an number of sub basins allowing alternate wetting and drying cycles.
- 4) An aquifer protection zone study is required to trace the fate of pollutants, using particle tracers, to the coastal basins.
- 5) Monitoring requirements include water level, flow, and EC measurement of recharge inputs at all basins, i.e. #7, #12, and coastal recharge basins. Regular water level measurements at strategic points in the aquifer, e.g. at the recharge basins, up-gradient, within, and down-gradient of the wellfields, in and around the natural recharge areas, are essential for aquifer management.
- 6) The treated domestic wastewater is of excellent quality and needs to bypass Basin 6 and only blend with the storm water after the latter has passed through the reed bed in Basin 6.
- 7) A regular maintenance programme is needed for Basin 6 sediment and litter removal.
- 8) In view of the poor quality surface runoff at Basin 9 in the industrial area, the discharge should be re-routed from Basin 6 to the noxious trade area Basin 10.

"The contrast between the way we operate, and the way they operate in Perth, is that they can react in hours.

The lesson to be learned is that you need to have an integrated system and coordination between the main actors."

Rodney Bishop, interview, 2009.

- 9) Basin 5 drains the industrial area and seems to have a significant “first flush” effect. The “first flush” and dry season low flow should be diverted by a suitable structure not to enter the main storm water system linked to Basin 6.
- 10) In order to enhance the operation of the reed beds in the wet detention basins (5, 6, 9 and 10) a harvesting programme for the reeds is required at the relevant detention basins.



Reeds in detention basin.

- 11) The use good quality water from Basin 6 at the sand mine needs to be investigated and replaced with treated industrial wastewater if at all possible.
- 12) The regular maintenance of the storm water collection system is essential for reducing water losses in the storm water detention basins and facilitating optimal flow of water to the recharge basins.



Litter-clogged inlet in storm water system.

- 13) A storm water system water quality monitoring is needed, possibly also employing continuous EC recording at strategic points for identifying high salinity inputs and spills.

- 14) A wellfield abstraction optimisation programme is needed for constant low rate withdrawal from production boreholes.
- 15) A regular production borehole maintenance programme has to be instituted including regular step drawdown tests, camera logging, and rehabilitation when needed.
- 16) A research programme has to be initiated on borehole clogging at Atlantis with the aim of controlling of organic compound inputs and dissolved iron removal from groundwater.
- 17) The development of appropriate groundwater flow and mass transport models is needed for balancing the use of low salinity surface water with groundwater abstraction to ensure optimal use of the wellfield together with maintenance of lower salinity in the aquifer.
- 18) An aquifer protection programme has to be developed for identifying, monitoring and managing all hazards that may threaten the water supply in any way.
- 19) Known pollution threats need to be monitored, e.g. the closed waste site, the small holdings (above Silwerstroom), while a R27 transport spill emergency programme and an oil pipeline leakage action plan will need to be developed. Data on the monitoring of the groundwater quality at the Ankerlig Power Station can be obtained from Eskom.
- 20) Saving of groundwater abstraction from borehole G30966 for dilution of brine from Softening Plant needs to be investigated. Dilution with treated industrial wastewater or another source may be economically feasible.
- 21) There is a dire need for an operation manual for the Atlantis Water System management covering the above matters and all other operational matters.

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APPENDIX 1:

DETAILED CHRONOLOGY OF AWRMS DEVELOPMENT/...

Appendix 1

Detailed chronology of AWRMS development

The Atlantis Water Resource Management Scheme: 30 years of Artificial Groundwater Recharge

YEAR	EVENT
1972	First hydrogeological investigations in the Atlantis area - Geological Survey
1974-1980	Drilling of exploration and production boreholes - Dept. of Water Affairs
1975	Atlantis declared a de-concentration point - National Physical Development Plan
1976	Initial water supply from Silwerstroom spring
1978	Production boreholes commissioned at Silwerstroom wellfield
1978	Commissioning of activated sludge plant for wastewater treatment
1980	Construction of artificial recharge basin 7
1982	Production begins at Witzand wellfield
1982	CSIR appointed hydrogeological consultants for artificial recharge management
1982-1986	Artificial recharge of all storm water runoff and treated wastewater via basin 7
1983	Groundwater monitoring network constructed around basin 7
1983	Nine new production boreholes commissioned at Witzand wellfield
1985	Regular monitoring of groundwater levels begins
1986	Artificial recharge basin fills up after heavy rainfall event – water siphoned out
1986	Diversion pipeline constructed from wastewater works to Donkergat river to divert treated wastewater away from recharge basin. Wastewater recharge discontinued
1986-1992	Only storm water used for artificial recharge
1987	Construction of pipeline to coastal recharge basins
1987	Donkergat diversion pipeline connected to main storm water pipeline. Sluice installed to allow diversion of all storm water baseflow away from basin 7
1988	Closure of Atlantis solid waste disposal site due to groundwater pollution threat
1988	Monitoring network upgraded around basin 7
1988	Initial filling of primary coastal recharge basin
1988	Commissioning of domestic wastewater treatment works for separate treatment of higher quality wastewater
1989	Basin 7 dried out and cleaned
1989	G30966 used to dilute Softening Plant brines for disposal in coastal basins
1989	Industrial wastewater works closed down for refurbishment. Industrial flow diverted to the domestic works and all treated effluent discharged to Donkergat river
1989	Eight new production boreholes drilled, in the Witzand and Silwerstroom well fields
1992	Completion of repairs to industrial works. Treated domestic sewage effluent combined with storm water runoff for artificial recharge
1992	Increased volumes from industrial treatment works. Flow diverted into secondary coastal infiltration basin 2
1993	Twelve new production boreholes drilled, in the Witzand and Silwerstroom well fields
1993	Flow separation of different quality storm water and treated effluents achieved
1994	Seven new production boreholes constructed, in the Witzand and Silwerstroom well fields

The Atlantis Water Resource Management Scheme: 30 years of Artificial Groundwater Recharge

YEAR	EVENT
1994	Construction of new artificial recharge basin 12 and installation of monitoring network
1994	Environmental Impact Assessment undertaken for Witzand Farm - Knight Hall Hendry
1995	Inaugural use of artificial recharge basin 12
1996	Seven new and replacement production boreholes drilled, in the Witzand and Silwerstroom well fields
1998	Construction of surface water pipeline to bring surplus water from Melkbosstrand
1999	Appointment of Environmental Officer for management of Witzand Farm
1999	Three month shut-down at Silwerstroom and Witzand wellfields
1999-2002	Rehabilitation of production boreholes clogged by iron biofouling – MoreWater cc
2007-2008	CSIR participation in European Union supported project “Reclaim Water” evaluating longer term sustainability of water recycling at Atlantis

APPENDIX 2:
FIELD TRIP GUIDE /...

Appendix 2

Field Trip Guide

FIELD TRIP OVERVIEW: ATLANTIS WATER RESOURCE MANAGEMENT SCHEME (AWRMS)

	SITES:	DESCRIPTION	TIME ESTIMATE
1	Basin 3: Domestic storm water detention basin	Residential storm water collection and groundwater transfer basin. Coordinates: 33.57532°S; 18.50303°E	10 minutes on-site
2	Wastewater Treatment Works	A key development of the AWRMS. Two parallel treatment works for (1) domestic wastewater and (2) industrial wastewater were developed and came on line in mid-1990s. Coordinates: 33.60579°S; 18.48141°E	5 minutes on-site
3	Basin 9: Industrial storm water detention basin	Industrial storm water collection basin that is also a reed bed. Neil Hare Rd turn off: 33.60492°S; 18.47399°E Basin 9 Inlet: 33.60405°S; 18.47197°E	10 minutes on-site
4	Basin 6: Silt reduction and holding basin	A basin that brings together all of the domestic storm water, most of the industrial storm water, and the treated domestic wastewater. It was modified in 1988 to also act as a silt reduction point. From Basin 6, the water flows to recharge Basins 7 and 12. Coordinates: 33.61188°S; 18.47416°E	15 minutes on-site
5 (a)	Softening Plant	City-operated weak base ion exchange groundwater Softening Plant that was built in 1986 largely to meet the water quality needs of industry but also to the advantage of domestic users. Coordinates: 33.62657°S; 18.44334°E	30 – 45 minutes visit: A tour of the plant by staff must be arranged in advance. (See contact details below).
5 (b)	Borehole	A borehole in the Witzand wellfield that abstracts groundwater, which is then treated in the nearby Softening Plant before being piped to the residential and industrial areas of Atlantis. Coordinates: 33.62719°S; 18.44113°E	15 - 20 minutes on-site visit, including walking time
6	Infiltration Basin 7	The main recharge basin for treated domestic wastewater and storm water runoff of the AWRMS. Water infiltrates down through the basin, up gradient of the main wellfield, and reaches the production boreholes in a period of 18 months to 2 years time. Basin 7 entrance: 33.62858°S; 18.44154°E	20 minutes on-site. This must be arranged in advance with CoCT's approval. A key to the gate must be obtained from the Softening Plant.
7	Coastal Recharge Basins	Coastal basins in Eskom-owned nature reserve that are recharged with treated industrial wastewater and storm water, as well as the regenerant brine from the Softening Plant. The water that infiltrates here, down gradient of the main aquifer, serves to raise the water table and prevent seawater intrusion into the main aquifer. Basin 1a inlet: 33.63554°S; 18.41335°E	30 – 45 minutes (including travel to/from Softening Plant). This trip is only permitted with advance approval from CoCT and a guide.
<i>Total on-site time including travel between sites</i>			3 – 4 hours
<i>Total time including return travel from Cape Town CBD</i>			5 – 6 hours

To arrange a tour of the Softening Plant and to arrange permission to visit Recharge Basin 7 and the coastal recharge basins: Contact Mr John Charles, Manager: Atlantis Water Scheme Utility Service – Bulk Water (john.charles@capetown.gov.za), or Mr Paul Wyngaard, Senior Superintendent (paul.wyngaard@capetown.gov.za), in Atlantis on 021 577 5000 /2 /3 /4.

INTRODUCTION

The town of Atlantis is located 50km north of the centre of the City of Cape Town on the dry west coast. It has a population of approximately 57,000 people and presently forms part of the metropolitan area of Cape Town.

Initially prompted by the need to find an alternative to marine wastewater discharge, Atlantis began recharging its wastewater into its sandy soils in the late 1970s. With the recognition that the natural groundwater yield of the aquifer was not sufficient to meet the long-term needs of the town, the focus shifted to *recycling* water and *recharging* the aquifer. The addition of storm water to the recharge system was a major development, as was the eventual separation of domestic and industrial effluent that was done in order to allow recharge of the highest quality water in the areas of the greatest importance. Currently, treated domestic effluent, all of the domestic storm water, and most of the industrial storm water is used for recharging the aquifer upgradient of the wellfields into two retention basins. Industrial effluent, some of the industrial storm water, and the regenerant brine of the Softening Plant are diverted to the coast downgradient of the main aquifer to coastal recharge basins in order to raise the water table and prevent seawater intrusion into the main aquifer. The overall scheme is referred to as the Atlantis Water Resource Management Scheme (AWRMS) (refer Google image below).



Google Map overview of the Atlantis Water Resource Management Scheme.

The Atlantis Water Resource Management Scheme has successfully recharged and recycled water for almost three decades. It is estimated that on average, approximately 7500 m³/d of storm water and wastewater is currently recharged up gradient of the well field, thereby augmenting the water supply by more than 2.7x10⁶ m³/a (i.e. approximately 25 - 30% of Atlantis' groundwater supply is augmented through artificial recharge). Some 4000 m³/d higher salinity industrial wastewater is treated and discharged into the coastal basins down gradient of the well field close to the ocean.

The AWRMS provides a local South African example of a cost-effective artificial recharge solution that has been proven over time, successfully supplying water to both the residential and industrial areas of Atlantis for nearly 30 years. A renewal of careful management of the water sources and aquifer is now required to ensure its future long-term sustainability.

THE ROUTE

1. Basin 3: Residential storm water collection (33.57532°S; 18.50303°E)

Directions: Basin 3 is located within Atlantis town. The inlet can be seen from the corner of Reygersdal Dr. and Kerria Ave.; the outlet is at the diagonally opposite corner of the basin in Acacia Crescent. To get here, take the N7 from Cape Town travelling north; take the R304 exit to Atlantis. Follow the R304 into Atlantis, past the informal settlement area on the left, into the town (the R304 turns into Regersdal Dr.). At the first little circle turn left into Kerria Ave and then left into Acacia Crescent. If you park at the end of the road (before it turns to the right), and climb up the embankment, you will see the concrete outlet structure (see Google image below).

Time required: ~10 minutes.



Google Map view of surroundings of Storm water Basin 3.

Basin 3 is a part of the storm water management system (i.e. artificial recharge does not happen at this site). It is a detention basin and its purpose is to collect water from that area of residential Atlantis from storm events and to slow down peak flow (by spilling into the basin and seeping back into the canal when the peak flow subsides) – it is thus a ‘dry pond’ i.e. it is not designed to retain water, simply to slow it down. This regulated flow is then taken by pipeline to Basin 6, from which it is then piped to Basin 7 for artificial recharge.

Basin 3 works as an initial ‘polishing’ stop (i.e. settling out sediment); it allows some recharge; and in the dry season it is used as a sports field because grass continues to grow on it. It was thus designed (and works) as a multi-function area, providing public open space, play space, and storm water detention.



Basin 3: Storm water inlet.



Basin 3: Low level flow channel.



Basin 3: Storm water outlet.



Basin 3: Storm water outlet.

2. Wes-Fleur Domestic and Industrial Wastewater Treatment Works (WWTW)

From Acacia St., turn left into Kerria and drive to the end of this road. Turn left into Charel Uys Dr, and then left into Neil Hare Rd (at this point there is a road sign that says R304/N7/Cape Town/Malmesbury). Drive through the industrial area continuing with Neil Hare Rd (and not turning left towards the R304/N7). You will pass Basin 5 on your left at the traffic circle (optional stop – see notes below). Continue on Neil Hare Rd; after the rise in the road, look for an immediate left into Perkins Rd. This leads to the WWTWs. Facing the WWTW, the plant on the right hand side treats industrial wastewater only, and the one on the left hand side treats domestic wastewater only (refer Google image below). (Coordinates: 33.60579°S; 18.48141°E)

Time required: 5 minutes (if not visiting inside facilities). If you wish to visit inside the facility, an advance arrangement with the Manager: Jacques Basson on 021 577 2411 must be made.



Google Map of WWTW, Basin 5 and Basin 9 area.

By 1986, water quality concerns about the inclusion of the industrial wastewater in the artificial recharge system resulted in the development of a 2nd parallel wastewater treatment plant. This enabled domestic wastewater and industrial wastewater to be treated separately, and the effluent from each to be distributed independently. The effluent from the domestic wastewater plant is diverted into the artificial recharge system (i.e. it goes to Basin 6 en route to Basin 7). The effluent from the industrial wastewater plant was initially diverted to the Donkergat River, and then later (and currently) diverted to the coastal recharge basins. Both treatment works use natural processes i.e. activated sludge processes based on micro-organisms breaking down waste. Anything very noxious would kill these organisms and thus cannot be put into the system.

Storm water (via Pond 10) emanating from the noxious trade area goes into the treated waste flow from the industrial treatment works (and then on to the coastal recharge basins).



Industrial Wastewater Treatment Works.



Entrance to Wes-Fleur Wastewater Treatment Works with domestic WWTW in background.

Basin 5: Storm water detention basin (optional stop): Basin 5 is a storm water detention basin that was modified into a wet pond so that reeds would grow. This was done by installing an outflow control valve so that outflow would occur only after the pond had filled up. This pond receives approximately half the storm water flow from the south-western part of the industrial area excluding the noxious trade area. The storm water it receives may carry dye and salts illegally discharged into the storm water system. The reeds are very useful for removing suspended solids from the water. The reeds need to be harvested as required so that they don't grow too thick and impede the flow. The groundwater in this area is more saline as it is located closer to the shale. This pond drains to Basin 6 for further polishing and blending with domestic effluent before it goes on to Basin 7 and Basin 12 for artificial recharge. (Basin 5 along Neil Hare Rd: 33.59661°S; 18.48518°E)

3. Basin 9: Industrial storm water detention basin (33.60405°S; 18.47197°E)

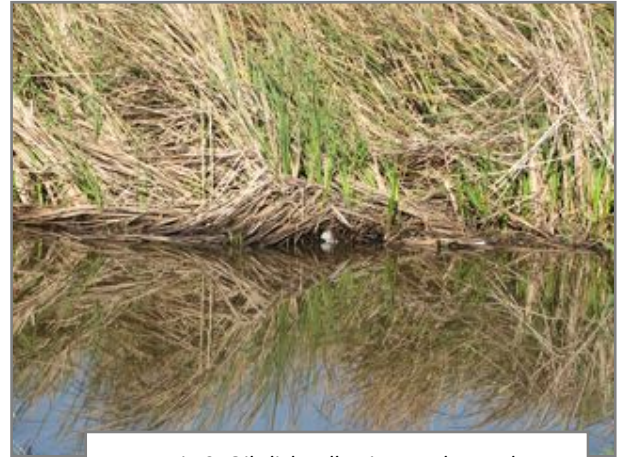
Return to Neil Hare Dr from the WWTW, turning left on this road. Go about 300m and turn into your first right, which is a smaller road with no name (33.60492°S; 18.47399°E). After about 200 m you will see Basin 9 on the left hand side (see Google image above).

Time required: 10 minutes

Basin 9 receives the remaining storm water from the south-western part of the industrial area of Atlantis (excluding the noxious trade area) and thus forms part of the storm water management system. Its purpose is to collect water from the industrial area from storm events and to slow down peak flow i.e. it is a 'detention' basin. Note that this water is often noticeably oily and more contaminated than the residential storm water. It also receives dirtier industrial storm water than Basin 5 as it drains the area with heavy industries. This pond was designed and is operated as a "wet" pond. The reeds growing in this basin were encouraged to grow for quality improvement and assist in further slowing down this storm water, as well as breaking down organic matter from the industrial run-off. While dark water flows into this pond, clear water exits from this basin and flows to Basin 6 where it joins both the cleaner residential storm water run-off, as well as the much cleaner treated domestic wastewater, before continuing to Basin 7 for the purposes of artificial recharge. Ideally, the Basin 9 outflow should be diverted away from Basin 6 and not used as part of the flow for recharging Basin 7.



Basin 9: Industrial storm water detention.

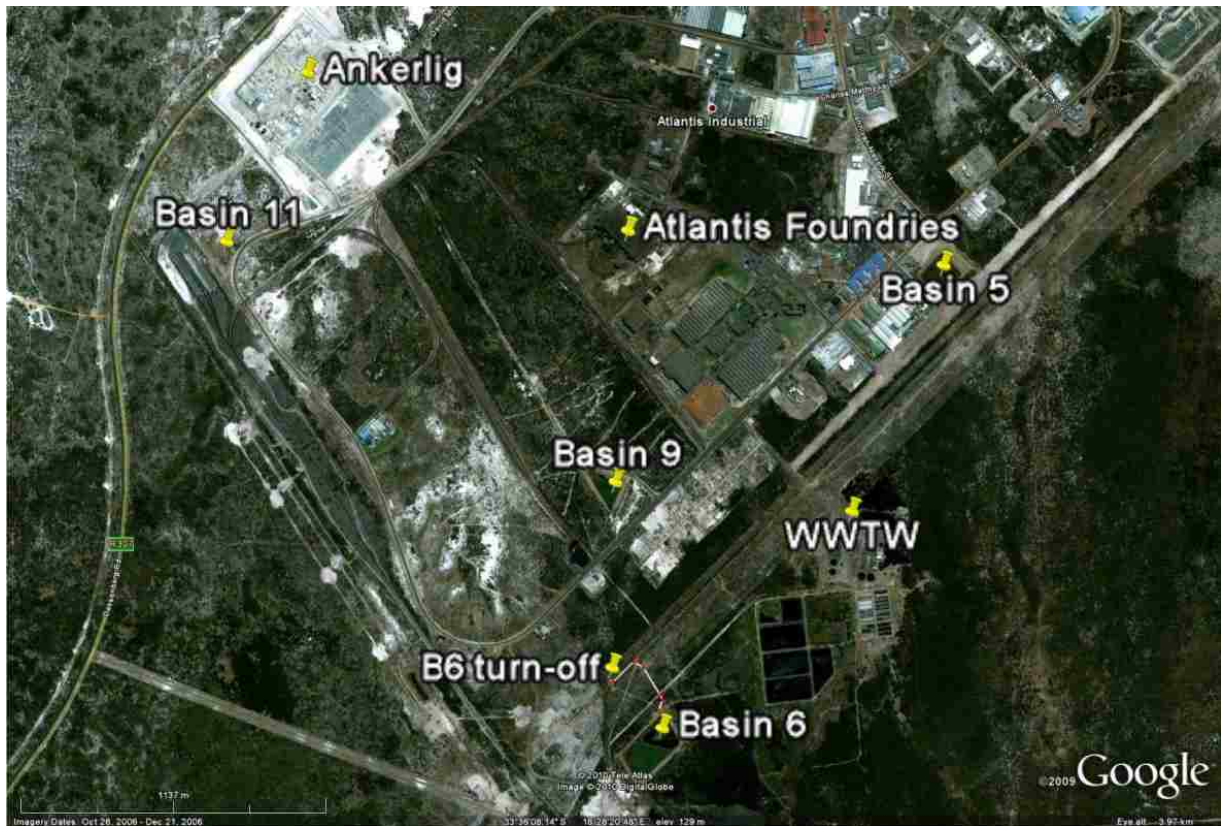


Basin 9: Oil slick collecting on the reeds.

4. Basin 6: Silt reduction and holding basin (33.61188°S; 18.47416°E)

Directions: Return to Neil Hare Dr and turn right. Go south on Neil Hare Rd through the industrial area of Atlantis for less than 1 km. Turn into your first left onto a small tar road (just before the MSA building on your left). The tar soon turns to gravel; travel approximately 100m on the gravel and then (33.61088°S; 18.47220°E) take the left track (staying left), take the first turn to the right about 80 m further until you arrive at Basin 6 (refer Google image below).

Time required: 15 minutes



Google Map showing the WWTW and several basins in the industrial area.



The car (returning from Basin 6) shows where to turn to get onto the track that leads to Basin 6 (coordinates: 33.61088°S; 18.47220°E).

Basin 6 acts primarily as a silt reduction unit for peak flow reduction of storm water. Because Atlantis is built on sand, the storm runoff collects significant volumes of sand which needs to be settled out prior to diversion to the infiltration (recharge) basins. Basin 6 is divided in half and the first half is a key component of the management system of the AWRMS as it is used for final 'polishing' (i.e. removing sediments). It brings together water from several different sources: (1) all the residential storm water; (2) most of the industrial storm water; and (3) the treated domestic wastewater (i.e. effluent from the domestic wastewater treatment plant). Basin 6 thus receives water from Basins 2, 3, 4, 5, and 9. The water reaches the second half of the basin by flowing over an embankment. The whole basin serves as a reed bed. When the water leaves Basin 6, it then flows to Basin 7 for the purpose of artificial recharge.

Note that the following basins do not drain to Basin 6: Basin 8 located north of the Ankerlig Power Station has not yet been built; Basin 10, which drains the noxious trade area and groundwater that is high in sulfate, is diverted to the coastal recharge basins; and Basin 11 drains into the field to the south-west of the Atlantis railway station.



Basin 6: Storm water inlet with entrance covered to prevent children playing inside.



Basin 6: Inlet from treated domestic effluent (centre) and large diameter inlet from storm water collection system (right).

5. (a) Softening Plant (33.62657°S: 18.44334°E)

Directions: Return to Neil Hare Rd from Basin 6 and turn left. This takes you through the noxious trade area of the Atlantis industrial area. Pass the large Pro Meal factory and pass under the train bridge. As the road curves right, note Basin 11 on your left (coordinates: 33.59714°S; 18.45698°E; optional stop – see notes below). Take your first left towards the R307 (direction Cape Town / Darling), which will take you past the side boundary of the Eskom Ankerlig Power Station. At the t-junction, turn left onto the R307 (direction Cape Town and Table Mountain), called Dassenberg Drive. Note the non-vegetated white dunes some distance to the right. These dunes are important for the natural recharge of the aquifer. Drive approximately 4.5 kms on the single lane highway. Turn right into the gate of the Witzand Water Treatment Plant and Pump Station to sign in and park.



En route to Softening Plant.

Time required: Optional depending if the group is to be received by staff from the Softening Plant (also see Google image below).

Contact Mr John Charles (Manager: Atlantis Water Scheme Utility Service – Bulk Water) 021 577 5000 /2 /3 /4 - john.charles@capetown.gov.za or Mr Paul Wyngaard (Senior superintendent) 021 577 5000 /2 /3 /4 - paul.wynqaard@capetown.gov.za.



En route to Softening Plant: Eskom Ankerlig Power Station.



Google Map showing relative locations of the Softening Plant, Basin 7 and the Coastal Recharge Basins.



Softening Plant Office Block.

The Softening Plant was put in place in 1986 in order to supply a consistent quality of water to the various users to the standard defined by what is now called SANS 241 regarding the quality of potable water. This standard states that the maximum water hardness allowed is 200 mg/L as calcium carbonate. The natural level of hardness from the Witzand wellfield ranges from 200 – 275 mg/L as calcium carbonate. The Softening Plant treats groundwater abstracted from the boreholes that supply Atlantis. In view of the natural salinity of the water a weak base ion exchanger was selected, which actually reduces the total salinity somewhat. The water is softened to give the required quality before it is piped to the residential and industrial areas of Atlantis for domestic and industrial use. Bypassing of part of the flow is possible to retain a low level of hardness in the final water.

Laboratory facilities are on-site at the Softening Plant and the water is tested at three stages: the blended raw water received from the borehole network; the softened water that has been sent through the ion exchange process; and the final blended water of both softened and raw water.

Staff at the Softening Plant offer tours of the facilities to school children and visitor groups if arranged in advance.



Water softening plant: water level monitoring.



Raw groundwater blending tank at Softening Plant.



Waste acid pond: backwash brine from regeneration process (right); dilution water from borehole (back right); disposal pipeline suction (black pipe).



Basin 11

Basin 11: Industrial storm water detention basin (optional stop): Basin 11 collects industrial storm water, primarily run-off from the nearby large Eskom plant. The water from this basin is discharged into the field to the south of the railway line where it will naturally recharge. (Coordinates: 33.59714°S; 18.45698°E).

(b) Borehole G30966 (33.62719°S; 18.44113°E)

Directions: One of the many production boreholes can be seen on the west (sea) side of the Softening Plant's enclosure. If you walk up the road that turns to the left on entering the Softening Plant area, you will see the borehole outside the fence.

Time required: 15 - 20 minutes (including walking time)

Borehole G30966 is dedicated to irrigation onsite and regeneration waste dilution to prevent precipitation of calcium sulphate in the brine pipeline from the Softening Plant.



Peter King, Rodney Bishop and John Charles at Borehole G30966.

With regards to the production boreholes, they pump into a network of pipes that feed into the raw water blending tank at the Softening Plant where the water is analysed for certain parameters. Depending on the results, a certain percentage of the flow is pumped through the ion exchange units, then the de-gassing unit and then blended with the balance of the raw water to achieve the desired hardness of 175 mg/L. This water is then pumped up to holding reservoirs for the residential and industrial areas of Atlantis.



De-gassing chamber.

There are various operational problems associated with the use of multiple production boreholes. Characteristics of groundwater and surface water are completely different and require different abstraction and treatment processes. Borehole clogging has been one of the main issues with the AWRMS over the years. The boreholes have lost efficiency over time, and this is likely due to them being operated at too high rates. When pumped at too high a rate, the water levels in and around the boreholes drop too much, which allows for the ingress of oxygen into the borehole and the gravel pack and the aquifer around the borehole that can result in iron-related borehole clogging problems. This can be minimised (but not eliminated) by limiting the water level draw down by decreasing the pumping rates and increasing the pumping hours. Effective management, monitoring, and regular rehabilitation programmes are key to the success of multiple production borehole schemes.



A. Hön sampling the clogging material on the borehole pump.

6. Basin 7 (main recharge basin): (entrance coordinates: 33.62858°S; 18.44154°E)

*Directions: A key that is kept at the Softening Plant is needed to enter the gate that leads to Basin 7. From the Softening Plant, turn right into the R307 and continue for 200 m until you see a gate/track on your left hand side (you will need to have the key to the gate). Drive to the end of the track, then onto the embankment passing alongside the Basin on the left, to see the **splitter box** (33.62730°S; 18.45206°E). On the way back, note the **stilling basin**, and then continue back for good views of Basin 7.*



Basin 7: Parking spot and viewpoint.

Time required: 20 minutes

Basin 7 is the main recharge basin of the Atlantis WRMS. A second basin, Basin 12, where the natural groundwater quality is better than at Basin 7, was added in 1994. It receives the highest quality recharge water (mainly in winter). Basin 7 is fed by Basin 6 and thus receives the final effluent from the domestic wastewater treatment plant, all the residential storm water, and most of the industrial storm water.

About 80 m above the inlet to Basin 7, the *splitter box* (33.62730°S; 18.45206°E) is designed to separate episodic storm water peak flow that is of better quality (i.e. less saline) to Basin 12 (the 2nd recharge basin), and perennial poorer quality storm water baseflow (more saline than peak flow) and treated domestic wastewater into Basin 7.

The stilling basin is designed to allow measurement of the inflow over the weir but it also gives an additional opportunity for any sediment to settle out.

Basin 7 is a natural depression with two built embankments. The location of the main recharge basin was thus based on topographical considerations and not on infiltration rates i.e. the water flow to Basin 7 is based on gravity, but note that higher infiltration rates would have been gained if the basin had been built on the top of the dunes.



Recharge Basin 7.

Two key issues with recharge schemes are thus the following:

- 1) Infiltration rate (i.e. the speed at which the water will go into the ground): In a continuous recharge situation, this is governed by the **hydraulic gradient** away from the basin.
- 2) Water quality: The quality of the water being infiltrated into a recharge basin is a critical concern that requires close monitoring.

In the case of Atlantis, the rate of infiltration decreased over the years in Basin 7. Additionally, Atlantis grew and hence there was increased run-off from the developed area. Also, new boreholes were developed on the inland side of the West Coast road. To address this situation, a decision was made to develop a 2nd recharge basin (Basin 12).

Additionally, during the period that the industrial wastewater treatment works was being built, all wastewater went through the domestic WWTW. Because there were concerns about using this water for artificial recharge, this combined effluent was discharged into the Donkergat River. During this period, Basin 7 could be dried out. Once it was dried out in the summer of 1989 when storm water flow was limited and also diverted to the Donkergat River, a front-end loader was used to scrape away the bottom layer of sediment (mud, debris and other matter that accumulates and slows down the infiltration process) and this improved infiltration dramatically once it was put back into use. (This was the only time Basin 7 has been dried and scraped out in its 20+ years of operation. Ideally, this should be done every 15 years under the present conditions). Note that during the time that Basin 7 was bypassed, 3500 megalitres was lost to the artificial recharge system. This resulted in a significant drop in water levels in the Witzand area and adversely affected the rate of clogging in the boreholes.

Both Basin 7 and Basin 12 recharge the aquifer at a rate of about 1.5 to 2.5 Mm³/a.

With regards to water quality, a guiding principle of the AWRMS from its inception has been that the recharge water must be of the same or better quality than the water in the aquifer that is being recharged. These concerns (ie the presence of persistent organic compounds, colour and heavy metals in the industrial wastewater together with the higher salinity) led to the separation and diversion away from Basin 7 of the treated industrial wastewater.

7. Coastal Recharge Basins (33.63554°S; 18.41335°E)

Directions: From the Softening Plant turn right onto Dassenberg Dr / R307; travel 0.5km to the t-junction and turn right on to the R27; travel 0.6kms to the gate of the Eskom nature reserve on the coastal side (you will need the key from the Softening Plant). Once inside the gate, turn right following the fence line; pass various boreholes. At the "Trail's End" rest spot, follow the dirt track left-ish. Follow the winding dirt road in the direction of the 'bird' trail signs. After 3.1km's continue straight (off the bird trail) to immediately stop and see the inlet of coastal basin 1a.

To continue on, return to following the bird trail signs to the coast. When the bird trail turns off the dirt road to a walking trail, continue on the road, which will loop around smaller, empty basins.

On the return, turn right when you reach the t-junction with mountain bike signs; then left at the t-junction with a "30" sign; keep right after this and then you will be back to the bird trail you came in on (continue against the direction of the bird signs to return to the gate).

Time estimate: 30 – 45 minutes including driving from Softening Plant

These coastal recharge basins are recharged with treated industrial wastewater from the industrial wastewater treatment works; the Softening Plant waste; and storm water from the noxious trade area (via Basin 10).

Early in the development of the AWRMS, it was determined that the industrial effluent was not of adequate quality to be used for artificial recharge of the main aquifer. Parallel treatment works were thus established so that the industrial wastewater could be treated separately and disposed of independently. While the industrial effluent was initially diverted to the Donkergat River, further innovations to the AWRMS consisted of developing the coastal recharge basins and redirecting the industrial effluent there. The purpose of these recharge basins is to raise the water table in the area and prevent seawater intrusion into the main aquifer. These basins also provide a safe means for disposing diluted backwash from the water Softening Plant, treated effluent from the industrial wastewater plant and storm water from the noxious industrial area.



The bird trail signs.



Coastal Basin 1A.

A positive side effect from these recharge basins is that the groundwater level upstream of the coastal recharge basins has risen. Eskom also sees the bird life that developed around the coastal recharge basins as a plus point for the nature reserve.

Return the keys to the Softening Plant and then return to Cape Town on the R307, connecting to the R27.