SECTION C: IMPLEMENTATION AND AUTHORISATION

C.1 CRITERIA FOR SUCCESSFUL IMPLEMENTATION

This section summarises the key factors that the potential for implementing a successful artificial recharge project. It draws on a number of documents and reports, including the Water Research Commission Report entitled, *"Artificial Recharge: A Technology for Sustainable Water Resource Development"* (Murray and Tredoux, 1998).

Since most artificial recharge concerns, and therefore research, revolve around water quality and clogging issues, they are discussed in far greater detail than other issues. Although there are numerous factors that affect the viability of artificial recharge schemes, it appears that, in most international cases, an understanding and an ability to deal with water quality and clogging issues are essential for the successful operation of a scheme.

In South Africa, this is likely to be the same for unconsolidated, sandy aquifers. While both water quality and clogging issues will also be a concern in hard-rock aquifers, the nature of the sub-surface flow will likely be of equal or greater concern. This is because the heterogeneity of fractured aquifers offers the additional complication of "where is the water going to?" and "where will it be best to re-capture it?" Fortunately, a large component of groundwater research in South Africa has been conducted on flow in fractured aquifers, and thus our scientists are well equipped to deal with such issues.

The key issues have been divided into:

1. The need for an artificial recharge scheme
2. The source water
3. Aquifer hydraulics
4. Water quality (including clogging)
5. The artificial recharge method and engineering issues
6. Environmental issues
7. Legal and regulatory issues
8. Economics
9. Management and technical capacity
10. Institutional arrangements

All artificial recharge Pre-feasibility and Feasibility Studies should include information on the above ten "success criteria".

C.1.1 A clearly defined need

Artificial recharge schemes generally serve a primary need and one or more secondary needs. The objectives of an artificial recharge scheme must be clearly articulated and an approach to assess its success defined, such as defining key performance indicators.

Most schemes throughout the world have been implemented to address a localised water-related problem, for example, water supply for a town or a farming area. This will probably continue to be the case in South Africa; where a localised problem exists, and where both the water source and the aquifer are suitable for artificial recharge. On a regional scale, however, there are areas where both the surface and groundwater resources are nearly fully developed and utilised (e.g. in a number of WMAs in the northern part of the country), and over-exploitation occurs in some localised areas (NWRS, 2004). There is a need to maximise water conservation measures in these areas, and artificial recharge could play an important role where the conditions are favourable for its implementation.

Water supply authorities often think that artificial recharge will solve their problems whereas there may be other measures that could be implemented prior to considering artificial recharge, such as water demand management (WDM), extending existing wellfields or developing new wellfields. Most municipalities in South Africa do not adequately monitor groundwater levels and abstraction, and therefore have little, if any knowledge on how their aquifers are performing. The common statement that “our boreholes run dry” is frequently a statement of mismanagement and an indication that the boreholes are pumped at too high a rates – and not necessarily that the aquifers have been dewatered. That is, the rate at which water can enter boreholes from the aquifer is less than the rate at which they are pumped. By monitoring water levels in both production boreholes and non-production boreholes located away from the pumped boreholes, it would be possible to establish whether aquifers’ are indeed stressed, and/or whether borehole pumping rates are too high. Artificial recharge is only required for water supply purposes if aquifers are stressed or have potential to be stressed.

During the artificial recharge pre-feasibility study (described in Section C.2), all existing groundwater level and abstraction data must be assessed, and if there is a lack of such data, then a monitoring programme has to be implemented immediately. At the very least, a full year of groundwater level data is required to establish whether artificial recharge is necessary or not.

Groundwater level data is critical to assess whether artificial recharge is necessary.

As soon as an artificial recharge project is conceived, start monitoring groundwater levels and abstraction; and establish seasonal groundwater and artificial recharge source water quality.

C.1.2 The quantity and reliability of the source water

The quantity, reliability and quality of a water source determine whether or not it is suitable for artificial recharge. This section discusses quantity and reliability, and the following section address water quality. Recharge water can be obtained from a variety of sources, but mostly from surplus surface water, which cannot be used or reused directly for a variety of reasons, and is lost as outflow to the sea, or through evaporation.

The total available surface water yield (at a 98 percent assurance of supply) for the country is estimated to be 10 240 Mm3/a derived from a natural mean annual runoff (natural river flow) of 49 040 Mm^3/a (NWRS, 2004). There is therefore plenty of water available on a national scale for sub-surface storage. Even in areas such as the northern parts of the country, where the water resources are nearly fully utilised, surplus river water is available (the natural river flow far exceeds the reliable local yield). The suitability for AR will likely relate to the timing of the available water (seasonality) together with other factors such as water quality, ability of the local aquifer to receive the water, etc.

It is important that the water for aquifer recharge purposes is of consistently high quality and has fairly predictable quantity over time. Water quality is covered in the following section. In most artificial recharge schemes, there is a reasonable consistency in supply during the infiltration/injection stage, but in schemes that rely on surface runoff, particularly those in arid and semi-arid areas, reliability is a problem. However, the value of opportunistic artificial recharge can still significantly increase the security of supply.

Table C.1 provides a comparison of the quantity, reliability and quality of various water sources. In regards to rivers and dams, quantity and reliability are related to size, existing allocations and geographic location (climatic region).

Table C.1: Water sources for AR

Source water	Quantity	Reliability	Quality
Rivers	Variable	Variable	Variable
Dams	Variable	High	Low - High
Treated municipal waste water	Consistent	High	Low - High
Aquifers (i.e. transfers from other sub-surface reservoirs)	Consistent	High	Consistent
Urban runoff	Variable	Moderate - High	Variable
Agricultural return flows	Variable	High	Low
Rainfall harvesting	Variable	Moderate - High	High

C.1.3 Aquifer hydraulics

Two main physical characteristics determine whether or not an aquifer is suitable for accepting, storing and recovering artificially recharged water. These are the aquifer's hydraulic conductivity and its storage capacity. A third important factor is the aquifer's hydraulic gradient and the natural geological barriers to flow. These relate mostly to the recovery of the recharged water. The key questions are:

- Will the recharge water be able to flow into the aquifer (permeability/hydraulic conductivity)?
- Will the aquifer have sufficient space to accept the water (storage)?
- Will the water be recoverable?

Aquifers which have high hydraulic conductivity and which have high storage capacity are more suitable for receiving additional recharge water than those which have low conductivity and capacity (Figure C.1). Highly permeable aquifers, however, are not always ideal for artificial recharge if high quality water is stored in a saline aquifer, as this may result undesirably high blending ratios. Aquifers with high hydraulic conductivity and high hydraulic gradient may also be problematic, as water will flow rapidly away from the point of recharge and may be difficult to recover. This problem is greatest in fractured aquifers and can be averted either by placing recovery boreholes down-gradient of the recharge facility, or by applying ASR principles and reversing the hydraulic gradient during pumping so that water flows back towards the initial point of recharge.

The key issues of storage and hydraulic conductivity are depicted in Figure C.1

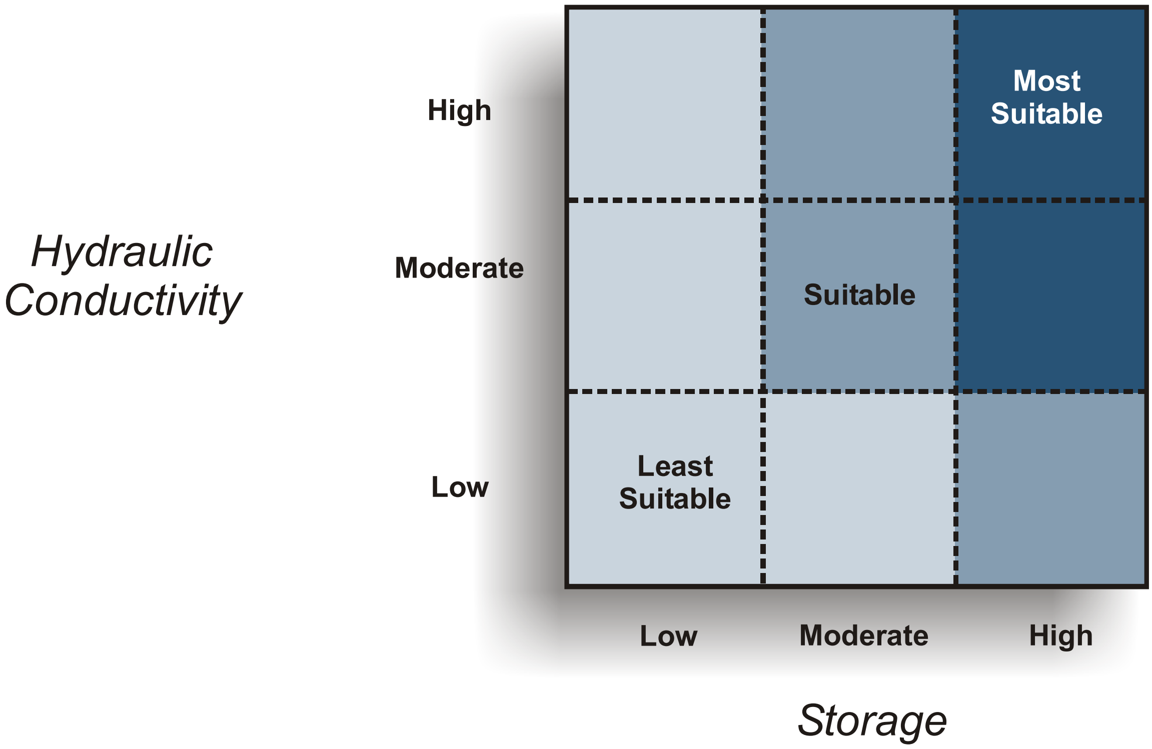


Figure C.1: Suitability of an aquifer to receive artificially recharged water (Murray and Tredoux, 1998)

C.1.3.1 Aquifer geology and geometry

The first step in establishing the hydraulic characteristics of the aquifer is to develop an understanding of its the geological setting. This includes defining which geological formations comprise the aquifer or aquifers targeted for artificial recharge. It requires developing a conceptual flow model for the aquifer based on its geological setting (including its boundaries) and an assessment of the natural recharge and discharge areas.

C.1.3.2 Storage potential

Unconsolidated, inter-granular aquifers have a greater storage capacity than hard-rock aquifers. Their coefficient of storage, which is related to porosity, is generally one to three orders of magnitude greater. For this reason, alluvial aquifers, coastal sands and the infrequent thick inland sandy deposits are prime targets for the storage of considerable volumes of water. These environments also provide good media for basin recharge and water treatment (SAT).

In South Africa, many aquifers are filled up during the rainfall season. Groundwater levels are commonly within 10 – 20 m of the land surface, and groundwater discharges as springs and seeps. In many areas, the elevated wet-season water levels in rivers, dams and wetlands, are due to overflowing groundwater. Under these conditions, it makes no sense to artificially recharge groundwater. However, artificial recharge creates the opportunity to modify groundwater management practices and to abstract groundwater at rates over and above the naturally sustainable rate – provided that this does not have major environmental or social impacts. The most common impact is caused by lowering the water table, and this can reduce groundwater outflow to areas that previously received a perennial supply (from springs and seeps). It can also cause land subsidence in vulnerable geological environments and boreholes to go dry.

Boxes B.1 and C.1, adapted from DWAF's Groundwater Resource Assessment II Project (DWAF, 2005), provide an overview to the issues related to maximising groundwater use. A key message is that, by applying scientific tools, it is possible to obtain reasonable estimates of sub-surface storage However, in many instances, it remains a management decision, based on prevailing policies, that determines the proportion of the storage volume that can be allocated for use.

Based on particular management criteria, the volume of storage available for use in an artificial recharge scheme will need to be determined. In some cases, where the environmental and social costs are high, it may not be possible to utilise static storage. In other areas, where the environmental and localised social costs are small, and where the broader social needs of having access to water, and the economic gains of having a secure supply outweigh the environmental costs, the allocatable storage may also include the static component.

In Section B.4, a regional scale GIS-based approach is used to assess the artificial recharge potential that includes an assessment of available storage.

Box C.1 Groundwater use: An issue of science, policy and terminology

The volume of water held in sub-surface storage is variable depending on how full the aquifer is, which is a function of inflows and outflows. The reason for quantifying groundwater is to know how much water on a time basis can be abstracted from a specific area to meet certain requirements. That is, it is time-based, and it is requirements-based. From this definition, the quantity of groundwater that should be pumped over a given period could range from none (the requirement, for example, may be to strive towards pristine conditions) to as much as possible, where the requirement, for example, may be to mine the water as an emergency need whilst another source is being developed for the long-term supply.

This approach takes into account both the procedures of science and guidance of policy. Put simply, science can provide an estimate of how much water is available for use, and policy dictates how much of that must be “left alone” or “used” to meet specific environmental and social requirements.

It is worth noting that there has been considerable debate ever since the first negative effects of large-scale groundwater abstraction were noticed. In 1920, the concept of safe yield was introduced after large-scale abstraction in the western USA was made possible with deep boreholes and electricity-driven turbine pumps. Since then the safe yield concept has been modified and numerous papers have been written on approaches to quantifying groundwater. Some of the terms and concepts that have been developed since the early 1900s are:

- Safe yield
- Sustainable yield
- Groundwater availability
- Exploitation potential
- Abstraction potential
- Harvest potential
- Optimal yield
- Consensus yield.

Added to these terms are those that are commonly used without precise meaning or definition:

- Groundwater overexploitation, over-use, over-extraction and over-development
- Groundwater mining
- Stressed aquifer
- Unsustainable use.

This latter group of terms is used particularly in areas where groundwater is intensively exploited, but the terms are also being used to refer to problems of simple interference between boreholes or mismanagement.

C.1.3.3 Hydraulic conductivity

Hydraulic conductivity of a soil or rock defines its ability to transmit water. It is dependent on a variety of physical factors, which for sandy aquifers, includes porosity, particle size and distribution, shape of particles, arrangement of particles, etc. In hard rock aquifers, the factors include density, apertures and roughness of the fractures.

For the successful application of infiltration and injection artificial recharge schemes, hydraulic conductivity needs to be sufficient both at the point of recharge and further afield. In hard rock environments, this means that the fractures need to be reasonably extensive and interconnected.

The GIS study in Section B.4 takes hydraulic conductivity indirectly into account by prioritising areas with high yielding boreholes.

C.1.3.4 Hydraulic gradient and flow directions

The hydraulic gradient determines where the water will flow once it has entered the sub-surface. This is important to know for locating the recovery boreholes. In many cases, it may be possible and cost-effective to recover the water at the point of recharge (eg using ASR boreholes). Depending, for example, on the planned storage residents times, or whether in situ treatment (eg SAT) is needed, it may be preferable to abstract the water down-gradient of the recharge point.

C.1.4 Water quality

The introduction of artificial recharge generally addresses problems such as the over-exploitation of water resources, saline water intrusion, and a whole series of other issues threatening the continued use of the resource. However, artificial recharge can only succeed if the longer-term sustainability of the practice can be assured. In this respect, experience gained over many decades has demonstrated that the quality of recharge water is the key issue. As a result, extensive pre-treatment of recharge water has been developed for reducing the dependence on purification and blending in the aquifer for quality improvement.

Ecological sustainability issues currently seem to be the most important concern of artificial recharge applications abroad. Pressures are exerted to restore the hydrological systems to their more natural state and to concentrate artificial recharge activities on more confined areas (Olsthoorn & Mosch, 2002). These perspectives need to be taken into account in the development of local artificial recharge schemes, implying that artificial recharge schemes should not overly rely on subsurface water quality improvement but rather be mainly designed for the storage or banking of water. Subsurface storage of water generally adds a safety/protection “barrier” for drinking water supply systems but, where relevant, any water quality improvement in the subsurface should be considered a bonus.

Dillon (2005) sets out a number of objectives for the ASR Code of Practice being developed in Australia. Six of the aims of the primary objective specifically relate to water quality and state the following:

- Protect or improve groundwater quality wherever ASR and ASTR is practised
- Ensure that the quality of the recovered water is fit for its intended use

- Prevent problems such as clogging and excessive recovery of aquifer material
- Ensure that the impacts on surface waters, downstream of ASR and ASTR operations, are acceptable and are taken into account in catchment water management
- Ensure that an appropriate public and environmental health risk assessment and management strategy is in place to deal with potential variations in water quality of injectant.

These objectives are generally valid for all artificial recharge schemes and these form the basis for the water quality aspects discussed below.

C.1.4.1 Quality of groundwater

One of the objectives of artificial recharge is to protect or improve groundwater quality. In the majority of cases where groundwater is utilised as a potable supply, or for stock-watering, irrigation or other purposes, the objective would be to recharge with good quality water that would maintain the existing use or even elevate it to a higher level. The recharge water quality would then not be worse than that of the natural groundwater in the particular aquifer. This principle should be adopted as a general rule and exceptions should need individual investigation and approval. An example of an exception would be the recharge of wastewater into highly saline aquifers (e.g. for disposal).

The natural quality of groundwater will also determine the extent to which blending with compatible water is possible without affecting the aquifer and the usability of the water.

Converting saline aquifers to useable water resources by means of artificial recharge is becoming increasingly popular. Suitable "brackish" aquifers in South Africa need to be identified where recharge with good quality water would gradually dilute or replace the ambient saline groundwater and make them usable.

C.1.4.2 Blending of source water and natural groundwater

Surface water used for recharge in an artificial recharge scheme is usually saturated with oxygen. Most groundwater, on the other hand, may still contain dissolved oxygen, but in general, deeper layers of the aquifer are more anoxic or even anaerobic. Thus, the relevant hydrochemical species such as iron, manganese and other metallic ions, as well as nitrogen and sulphur compounds, will be in the reduced form. The oxidation-reduction potential (Eh) of the recharge water will therefore differ significantly from that of the groundwater.

The oxygen content and Eh of groundwater vary from humid to arid regions. This is largely due to the presence of organic compounds that are more abundant in humid areas. The oxidation of such compounds consumes oxygen, causing reducing conditions at shallower depths in humid regions. Pyne (1995) describes Eh as one of the most important measurements for in situ groundwater, particularly when the iron and manganese concentrations are more than 0.1 mg/L. Likewise, dissolved oxygen (DO) is an important field measurement for both groundwater and surface water (Pyne, 1995). In the case of chlorinated surface water, the Eh may be elevated and the DO value may be more meaningful.

Groundwater abounds with micro-organisms that mostly originate from the soil horizon. Although chlorination may sterilize the recharge water, the microbiological activity in the aquifer is sufficient to promote bacterially-mediated reactions such as nitrification, denitrification, and reduction of sulphate, iron, and manganese when recharge water blends with groundwater. It may be impossible to modify the oxidation-reduction potential in the subsurface but compounds that will cause changes in the subsurface hydrochemistry can be eliminated. In this way, the recharge water can be made more compatible with the ambient groundwater.

C.1.4.3 Water-rock interactions

As indicated above, high quality surface water is generally well-aerated, that is, saturated with oxygen. Injection of such water into the aquifer introduces oxygen into areas which are less oxidising or even reducing. Similar to the interaction with the ambient groundwater, the significant change in oxidation-reduction potential has to be accepted, the only possibility being to limit the concentration of compounds that are sensitive to changes in Eh.

The geological material of primary aquifers is often deposited from lakes and other water bodies including marshes. This causes the material to be inherently reducing, as it will contain reduced ions and compounds such as ammonium, sulphide, and organic constituents. Oxidation of pyrite occurring in the aquifer matrix (also bacterially mediated) will increase the sulphate concentration of the groundwater and will also bring iron into solution. Should the recharge water also contain nitrate, it may be denitrified, but the reaction will enhance the oxidation of sulphide. These characteristics are also found in fractured aquifers of sedimentary origin (e.g. the quartzite in the Windhoek aquifer). Igneous rocks or intrusions, containing ammonium ions in the rock matrix, may also give rise to aquifers of reducing nature. In addition, unwanted constituents forming part of mineral assemblages in the geological matrix (e.g. arsenic present in pyrites) will also enter into solution. This is the case with the Calvinia breccia pipe which is highly alkaline and has strong reducing properties (Cavé & Tredoux, 2002).

In carbonate aquifers, the removal of calcium carbonate may be substantial. This may compromise the stability of the aquifer in the longer term (example: Vanderzalm *et al*., 2002).

The sustainability of the intended artificial recharge scheme can be tested using the approach by Stuyfzand (2002) to predict and quantify the hydrogeochemical impact and sustainability of artificial recharge schemes.

C.1.4.4 Clogging

Clogging, or “plugging”, (Pyne, 1995) refers to the reduction in permeability of the filtration surface of the recharge facility, or, the reduction in available pore volume and permeability in the aquifer. This phenomenon is complex and is due to a combination of physical, biological and chemical processes (Pérez-Paricio, 1998). The effect of filtration surface clogging can be observed readily in the reduction of the infiltration / injection rate. Aquifer clogging is more difficult to detect as it generally occurs gradually. In the case of injection boreholes, the surface area is relatively small and the phenomenon of clogging can be rapid and irreversible. It is generally more easily managed in basin recharge.

Various forms of clogging, each of which could be a combination of physical, biological and chemical processes, have been listed (Dillon & Pavelic, 1996; Pyne, 1995):

- Filtration of suspended solids
- Microbial growth
- Chemical precipitation
- Clay swelling and dispersion
- Air entrapment (or entrainment)
- Gas binding (release of dissolved or generated gases)
- Mechanical jamming and mobilisation of aquifer sediments.

Clogging is an operational problem largely related to the quality of the recharge water. However, site-specific conditions, such as aquifer and groundwater characteristics, borehole construction and recharge facility design, all influence the clogging process (Pyne, 1995). According to Rinck-Pfeiffer *et al* (2002), clogging remains the main factor affecting the feasibility of new ASR projects using low-quality source water. Biological clogging is considered to be of primary importance when nutrient-rich reclaimed water is injected into boreholes.

According to Dillon & Pavelic (1996), some 80 percent of ASR sites surveyed reported clogging problems. Half the sites reported physical clogging due to filtration of suspended solids. Microbial growth was a problem at 15 percent of sites and chemical precipitation caused clogging at 10 percent of sites. Other causes of clogging included air entrapment (10 percent), clay swelling and dispersion (5 percent) and mechanical jamming and mobilisation of aquifer sediments (5 percent).

Over the longer term, almost all artificial recharge schemes will be affected by clogging, although the rate and intensity of the problem will vary. For this reason, all schemes should make provision for remedial measures. However, Pérez-Paricio (1998) stated that prevention remained the best approach, in spite of the existence of sophisticated redevelopment techniques. Recharge water quality is the key factor and suspended solids are listed as the main criterion for both surface infiltration schemes and borehole injection. Other important parameters include pH, organic carbon concentrations and nutrients. In the case of artificial recharge by injection, air entrapment or gas generation should be avoided.

Adequate and timely identification of clogging generally leads to the opportunity to restore the initial capacity of the scheme by using a suitable redevelopment method (Pérez-Paricio, 1998). However, the prediction of clogging remains uncertain, despite many attempts at using parameters such as total suspended solids and turbidity for physical clogging, and total organic carbon, dissolved organic carbon and assimilable organic carbon for biological clogging.

The practical approach, as advocated by Pyne (1995), (Pérez-Paricio, 1998) and confirmed by Bouwer (2002), calls for site-specific pilot recharge tests for determining clogging potential of a duration of up to two years or more. Buik & Willemsen (2002) meanwhile developed an approach using a Fouling Index (called the MFI) for deriving physical clogging potential and demonstrated that the calculated values closely approximated the actual field data. They are of the opinion that all other forms of clogging (i.e. those caused by gas bubbles, bacteria and chemical reactions) can be prevented, and they state that physical clogging can be predicted and controlled.

In addition to clogging of the filtration surface and the aquifer, clogging of recovery wells may also occur (Moorman *et al*., 2002). In the Amsterdam dune area, treated Rhine water with high oxygen content was injected into a deep aquifer with naturally anoxic water. The native groundwater had a relatively high iron content of 3 mg/L as well as other reduced chemical species. The recovery well clogged suddenly after two years' operation. The clogging material consisted mainly of ferric (hydr)oxides and ferric hydroxyphosphates, with hydroxyapatite as accessory deposit. Incompatibility of injected and aquifer water is discussed in paragraph C.1.4.2 above and water-rock interaction in paragraph C.1.4.3. Such interactions may be partially responsible for the mobilisation of the iron, although the native groundwater in the above example already had a high iron content. Although iron clogging occurred in the recovery borehole, such clogging is not limited to artificial recharge schemes but also occurs in wellfields where natural groundwater is abstracted.

C.1.4.5 Pre-treatment prior to artificial recharge

The extent of pre-treatment required will depend on:

- The type and quality of the source water
- The type of artificial recharge system employed
- The sustainability requirement of aquifer use
- The intended use of the recovered water.

The type of artificial recharge system and the clogging potential of the water will be important criteria in setting the treatment requirements for recharge water. The removal of suspended solids by flocculation and filtration would be widely applicable for reducing clogging potential. Further, water quality guidelines exist for all types of water use and these will determine the extent of required treatment. However, the interaction between the recharged water, the aquifer material and the ambient groundwater will determine the longer-term sustainability of using an aquifer for AR.

Following the above discussion on blending reactions and the hydrochemical water-rock interaction, pre-treatment principles need to be defined. The principles should include protection of the aquifer, taking potential interactions between the different components into account, and setting limits to any possible degeneration.

C.1.4.6 In situ treatment (including soil aquifer treatment)

The early artificial recharge schemes relied to a considerable extent on the soil/unsaturated zone and hydrochemical reactions in the saturated zone for in situ improvement of recharge water quality. Soil aquifer treatment (SAT) schemes generally rely on the ability of the soil to transform or remove from the recharge water contaminants that may affect groundwater quality (ASCE, 2001).

The Dan Region Project in the coastal region of Israel is the largest water reclamation scheme in the country and relies on SAT as an integral part of the wastewater treatment process (Idelovitch & Michail, 1984). However, the abstracted water from the Project was not intended for indirect recycling of treated wastewater, and the use of abstracted water for potable purposes was discontinued once the recycled water constituted more than 5 percent of abstracted groundwater. As a result of the limited pre-treatment with high lime dosage in the early stages of the project, breakthrough of contaminants occurred relatively soon. Subsequently, the reclaimed water was used for non-potable purposes, particularly unrestricted irrigation in the south of the country (Kanarek & Michail, 1996). In contrast, where potable recycling is intended, the natural processes during SAT are only relied on to “polish” treated wastewater (Fox, 2002).

Kopchynski *et al*. (1996) studied the effects of soil type and effluent pre-treatment on SAT, using different soils and effluents in soil column studies. The authors confirmed the need for wetting and drying cycles for optimum purification but found that low concentrations of residual organic carbon remained in the water despite variations in conventional pre-treatment. This leads to the conclusion that pre- or post-treatment may need to involve activated carbon adsorption or membrane filtration for removing organic compounds.

The extent to which an aquifer can serve to remove other constituents, such as heavy metals, will depend on policy decisions regarding the acceptable use of the soil-aquifer system and whether any degeneration should be allowed. Re-mobilisation of the pollutants is possible once the oxidation-reduction conditions in an aquifer change. Approaches by different countries are divergent but, in the Netherlands, pressures exist to reduce the “footprint” of artificial recharge activities, and even to restore hydrological systems to their more natural state (Olsthoorn & Mosch, 2002).

The application and effectiveness of in situ treatment relies largely on:

- The type of source water (and potential contaminants)
- The type of aquifer
- The final use of water
- The long term sustainability of the in situ treatment process
- The need for aquifer protection.

C.1.4.7 Post-treatment

The quality of the recovered water, and hence the need for post-treatment will depend largely on:

- The quality of the recharge water
- Interaction of the recharge water with the natural groundwater
- Rock-water interaction in the aquifer with the potential introduction of unwanted species into solution
- The subsurface retention period
- The intended use of the recovered water.

C.1.4.8 Water quality monitoring strategy

Water quality monitoring will need to fulfil a number of objectives:

- Provide detailed information on recharge water quality
- Demonstrate the efficiency of pre-treatment processes
- Provide details of background water quality in the aquifer
- Demonstrate that groundwater quality in the aquifer is maintained or improved
- Monitor the recovered water quality according to criteria for the intended use.

C.1.4.9 Public and environmental health risk

ASCE (2001) warns that failure to research the legal factors early in the process can lead to unnecessary delays and possible failure of the project. Careful attention to the identification of environmental impacts, as well as open communication with environmental groups, is necessary during the entire process. Two of the legal issues to be addressed are (ASCE, 2001):

- Controls on the use of reclaimed wastewater
- Liabilities associated with water quality issues.

Associated risks include, as an example, the use of reclaimed wastewater for any purposes that were not intended. Controls are necessary to prevent such an eventuality. Other risks may involve discharge into the environment of water unsuitable for recharge due to poor quality. Unforeseen discharges into the environment may also occur due to high water levels in the receiving aquifer. Other examples may include unforeseen quality variations of recovered water.

The risk assessment should cover the entire life cycle of the project, including decommissioning.

C.1.5 Artificial recharge method and engineering issues

The types of artificial recharge are described in Section B.1. This section describes the components of artificial recharge schemes and identifies some of the key issues relating to the recharge method and technical design. Successful schemes are well designed – both in terms of the effectiveness and efficiency of the infrastructure and the ease of operation and maintenance.

The key infrastructure components that form part of artificial recharge projects are shown in Figure C.2.

The primary engineering function in artificial recharge scheme design is the sizing and matching of the various components:

- Source abstraction works
- Pump stations and pipelines
- Pre-injection treatment works
- Injection supply pumps and pipelines
- Injection boreholes and well head works
- Infiltration basins/trenches
- Abstraction boreholes, pumps and pipelines
- Post-injection treatment works
- Storage and distribution

The **source water** to supply the scheme is usually surface water, but can be groundwater (groundwater transfer scheme) or treated wastewater. Usually there is a seasonal fluctuation in the water availability and artificial recharge schemes are designed to store the excess water from the high flow periods. With this scenario, no new abstraction works are needed and the artificial recharge scheme can help to increase the use of the existing abstraction works, pump stations and pipelines.

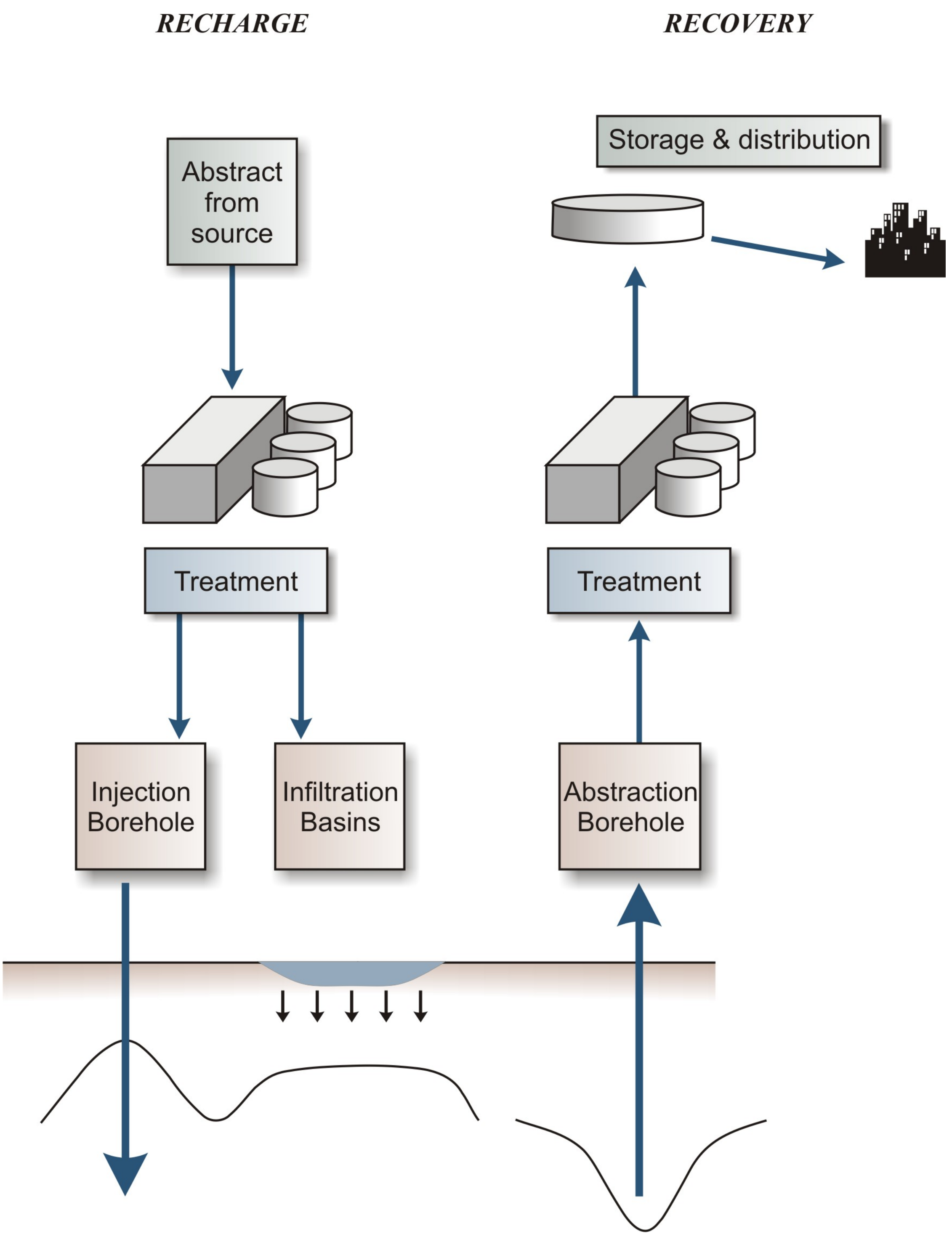


Figure C.2: Infrastructure components of artificial recharge schemes

The extent of **water treatment** required prior to recharge relates to the quality of the source water, the type of artificial recharge system employed and the intended use of the recovered water. Minimising clogging is a key design factor, and this relates directly to the quality of the recharge water and the type of artificial recharge scheme (see Section C.1.4). Post-recharge treatment requirements depend on the intended use of the recovered water.

Key engineering issues are:

- Which artificial recharge method is most efficient and cost-effective?
- Are the engineering logistics practical and cost-effective regarding the transfer of source water to the point of recharge; and from the point of abstraction to the point of consumption?
- How can the scheme be designed to minimise clogging?
- The design must be appropriate for the operation and maintenance skills levels.

Artificial recharge method. The most efficient artificial recharge method to be used must be assessed based upon the site-specific conditions that include:

- The quality of the water used for recharge.
- The hydrogeological environment.
- Existing infrastructure and the costs of additional infrastructure required.
- The management and technical capacity needed to operate the scheme.

Cooperative planning between the engineering, hydrogeological and geochemical disciplines during the conceptual design stage is the best approach to ensure that the artificial recharge scheme is well planned and makes maximum use of available resources.

In order to design a cost effective scheme that makes best use of existing infrastructure, it is necessary to establish the capacity and operating procedures of existing water supply infrastructure. Understanding the capacity and level of use of the different components of the supply system will assist in designing an artificial recharge scheme that optimally uses existing infrastructure and minimises new infrastructural required. This is particularly true of pipelines, above ground storage and treatment facilities.

In Plettenberg Bay, where the feasibility of artificial recharge is being assessed, an additional benefit to water supply during their high summer peak demand period, is that with artificial recharge, they would use their existing water treatment plant to capacity during the low-demand period, and thereby extend its design life. Treated water would be stored in the off-peak winter months, to be used in the summer months without having to pass through the treatment plant again. The treatment plant can operate at higher capacity during low-demand times, and not be stretched to capacity throughout the high-demand times.

Incremental development. Artificial recharge schemes are usually developed incrementally, where increases in capacity are based on the performance of the system during initial operation. Thus infrastructure planning needs to accommodate the initial artificial recharge development, but must identify the requirements for future increases in scheme capacity. Where new infrastructure such as pipelines and treatment facilities are required, it is usually cost effective to design these for the full capacity of the scheme.

Borehole and wellhead design. Existing boreholes are often suitable for injection, however, if new boreholes are planned, the following requirements must be taken into account:

- Material for piping both above and below ground should be non ferrous to minimise the potential of to minimise the potential of corrosion and rusting.
- Provide facilities for pipeline flushing and waste flow discharge.
- Provide sampling taps for water quality sampling of both recharge and recovered water.
- Design down-hole flow control (either fixed or variable) to ensure that cascading does not occur.
- Remove or minimise air from the recharge water prior to injection.
- Ensure that the pipelines remain under a positive pressure or design for negative pressure pipelines to avoid pipeline collapse.

C.1.6 Environmental issues

Artificially recharging groundwater can have both detrimental and positive impact on the environment. These are listed and briefly described in Section B.1. A common motivation for artificial recharge schemes is the rehabilitation of impacted environments. In South Africa this would typically be recharging of aquifers that were previously overexploited or mined. In other parts of the world artificial recharge schemes have been used to rehabilitate groundwater dependent ecosystems like in the case of the Florida everglades (Pyne, 2005).

The main environmental concerns associated with artificial recharge schemes relate to the lowering and raising of water tables (or piezometric levels) over and above those of existing use, and issues associated with water quality changes within the aquifers. Table C.2 lists key potential negative impacts.

Table C.2: Potential negative environmental impacts of artificial recharge schemes

Effects	Consequence
Raised groundwater levels	**Vegetation dieback** Raising the water table close to the soil surface may cause vegetation dieback as a result of soil saturation or the establishment of invasive alien plants. **Damage to structures** Destabilize or damage structures such as roads or buildings. **Pollution** A raised water table is more vulnerable to contamination by industry, wastewater disposal facilities, cemeteries etc. **Flooding** Raising the water table may exacerbate flooding during wet periods due to surface saturation and reduction in the ability of water to infiltrate. **Discharge of foreign water into wetlands and rivers** Changes in the wetland environment such as water temperature, oxygen levels, pH, turbidity, salinity, maximum and minimum water depths, could have an effect on groundwater-dependant species (fish, invertebrates, amphibians) and ecosystems (Brownlie, 2005). The pH, turbidity and salinity of the groundwater is often fairly constant due to long retention times and the organisms that depend on this water can be sensitive to fluctuations in water quality. **Salinisation by increased evaporation** The salinity of water in near-surface water tables can increase due to evaporation.
Lowered groundwater levels	**Wetlands and rivers** Depending on the relationship between surface and groundwater, the lowering of groundwater levels could affect river flow regimes (including baseflow), and wetland and riverine ecosystems. Seeps may be important breeding or feeding areas for birds and other wildlife. Changes in water level or water quality may affect habitat quality and wetland function (e.g. flood control). **Trees** Roots of some large trees reach aquifers. Rooting depths of tropical savanna trees averages 15 m, for desert trees 10 m, and riparian trees such as Acacia karroo have roots at 10-25 m below ground level (Canadell *et al*. 1996). Dewatering, or large fluctuations in the water table may change vegetation structure and composition by causing dieback of riparian trees (Le Maitre *et al* 1999). This in turn will change habitats for birds and other animals that depend on woodland patches, particularly in arid environments. Drainage line woodlands are movement corridors for many animal species. Woodland dieback may reduce the stability of alluvium during floods. Woodland dieback has aesthetic as well as biodiversity consequences. **Land subsidence** Land subsidence can occur in particular environments (especially in unconsolidated sediments) if groundwater levels are significantly lowered. Dolomitic aquifers are vulnerable to sinkhole formation. **Drying up of boreholes** Other groundwater users could be affected.

Effects	Consequence
Water quality issues	**Clogging** This refers to the clogging in and around recharge boreholes due to chemical precipitation or microbiological growth. This has consequences for recharge capacity and borehole rehabilitation or replacement costs. **Mobilising undesirable chemical constituents** Determinands such as existing arsenic in an aquifer can be mobilized by lowering the water table and creating an oxidising environment. The health of groundwater users (domestic, industry, livestock and irrigation) could be affected by the release of such constituents. **Aquifer organisms** The transfer of foreign water into an aquifer with different characteristics and quality could be problematic for the aquifer organisms. This applies particularly to water of impaired quality and treated waste water. There may be residual concentrations of chemicals such as chlorine in the water, which could have a detrimental impact on organisms in the aquifer.

The extent and significance of the abovementioned impacts would depend on numerous site-specific factors. In environmentally-sensitive areas it may be necessary to place operational restrictions on schemes, like only allowing water level fluctuations between a few metres below the top of the aquifer and the lowest natural water levels.

In the environmental study that forms part of an artificial recharge feasibility assessment, potential environmental issues need to be identified and where appropriate, baseline ecosystem data collected and ecological monitoring requirements identified. The risk and reversibility of environmental impacts should be discussed. Risks relates to the significance of the potential impacts, and the likelihood of those impacts occurring. Depending on the extent of available data, it may not be possible to adequately define risks, and a comprehensive monitoring plan may be needed.

Aquifers which are well monitored and well understood carry less risk, and it is easier to predict the consequences of artificial recharge and make informed management decisions. Environmental risks depend on a number of factors inter alia the nature of the source of the water, the volume of recharged water, aquifer parameters, the sensitivity of groundwater-driven ecosystems and the extent and nature of existing aquifer use.

The concept of reversibility is critical when considering the significance of an impact. Determining how quickly a component of the environment could recover from a particular stress due to groundwater recharge is challenging. If impacts are irreversible or only reversible over long periods of time, the significance of the impacts are that much greater, and may be considered to be unacceptable. Impacts on the built environment are more easily and quickly reversible through engineering solutions than impacts on the biophysical environment. However, impacts on the biophysical environment can be more challenging to reverse, and commonly happen over a longer period of time.

A risk management approach to implementing artificial recharge schemes based on the informed precautionary principle should be adopted after identifying all potential problems (Dillon, 2005).

The extent, magnitude and significance of environmental risks associated with artificial recharge schemes need to be discussed (in the feasibility study) in relation to the benefits of the scheme (both water supply and environmental), and compared with alternative water supply options.

C.1.7 Legal and regulatory issues

All artificial recharge schemes need to need licensed. Obtaining the necessary permits is thus crucial to the success of new projects. Section A.2 provides the legislative framework, and Section C.2 describes, in detail, the artificial recharge authorisation process and associated legal matters. This section identifies the key legal issues (which are dealt with in depth in Section C.2).

The key legal issues regarding the assessment and operation of artificial recharge schemes include:

- Water use licensing for artificial recharge schemes
- Environmental authorisation requirements for both testing and implementing the scheme (i.e. Basic Assessment or Environmental Impact Assessment)
- Environmental Management Plans (EMPs)
- Compliance with regulations (e.g. relating to water reuse)
- Rights associated with the use of artificially recharged water.
- Compliance with the conditions and reporting requirements of the water use licence and environmental authorisation.

South Africa's water use and environmental legislation have not yet been tested with the processing of applications for artificial recharge schemes. However, both the National Water Act and the NEMA provide the framework for processing artificial recharge applications (see Section C.2).

C.1.8 Economics

Unused aquifer storage capacity can often be developed at a significantly lower cost than surface storage facilities, and without the adverse environmental consequences frequently associated with surface storage (Pyne, 1995). In relation to water treatment, natural attenuation of waste water using aquifer media is a cost-effective means of improving water quality.

When undertaking economic option analyses, it is important to evaluate all options on the same basis, and to include all capital and operational costs. The Windhoek case study in Section B.3 provides a good example of a comparative cost assessment.

In the Windhoek economic assessment, the proposed artificial recharge scheme was compared to alternative water supply options for Windhoek and other recent or planned projects in the central region of Namibia (SWECO, 2002). Windhoek's priority was to increase the security of supply and on that basis the following four factors were evaluated:

1. Present worth cost including the following costs and revenues:

- Initial capital investment cost
- Annual depreciation and residual value (discounted to present value)
- Average incremental annual pumping cost
- Average incremental annual operation and maintenance cost

2. The incremental security of supply (ISS). The study modelled the supply for each scenario as well as a baseline "do nothing" scenario. The ISS is the difference between the expected annual shortfall of the particular scheme scenario and the "do nothing" scenario during a 10 year planning period. The ISS is measured as a volume per year.

3. Water Saving (or scheme efficiency) based on evaporation losses for each alternative scheme

4. Ratio of cost to ISS (in R/annual volume).

Other factors that could be assigned an economic value include:

- The strategic value of drought mitigation measures
- The efficient use of local resources compared with developing sources in other distant areas

An economic study should compare the cost per cubic meter of water supplied for each alternative supply option. It is important that the same method be used to price water. This is particularly important when water is purchased from a bulk water provider such as a water board or when compared with existing schemes, as the price of water may be subsidised.

Figure C.3 describes the different levels of water pricing adopted in the Windhoek economic assessment (SWECO, 2002). In many cases water is priced only on the financial cost, but ideally, an accurate comparison should be based on the total water supply cost.

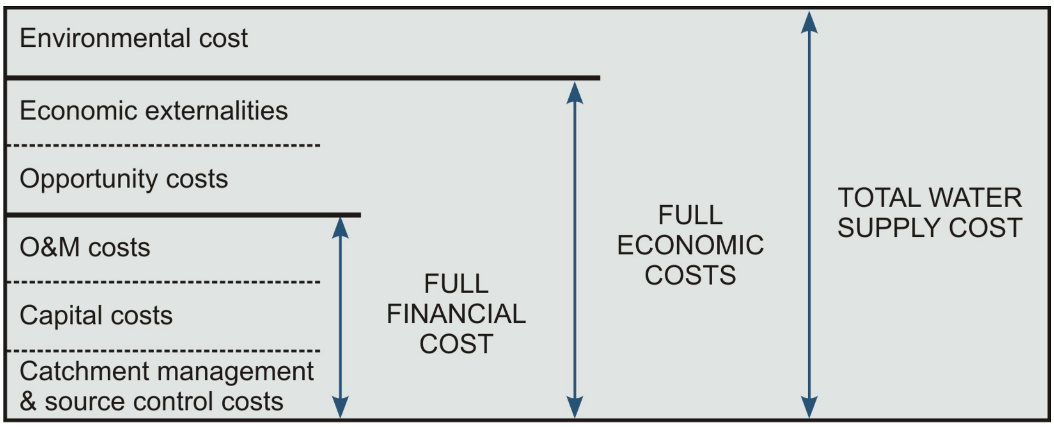


Figure C.3: Levels of water pricing (after Heyns, 1998)

For small to medium municipal scale projects, DWAF's Typical Unit Cost for Water Services Development Projects: A Guide for Local Authorities (DWAF, 2003) provides a uniform tool for estimating the cost of water supply options.

C.1.9 Management and technical capacity

The successful operation of an artificial recharge facility depends largely on an effective management strategy and on the availability of sufficiently skilled or competent staff to carry out the necessary tasks. Maximum benefit from an artificial recharge scheme involves integrating the scheme into the planning and management of the overall water supply system. Depending on the scale of the artificial recharge scheme, this can include management of the entire catchment. The overall aim is to optimise both surface and groundwater resources and their storage capacities.

Artificial recharge schemes commonly involve surface or waste water capture, treatment, pumping, water quality monitoring and clogging control. Careful planning and management is required to ensure that these processes are efficient. This assumes the availability of competent personnel who, in the case of large facilities, need to be dedicated solely to the task of managing the scheme. In such cases, the responsibility of operating the scheme should not be viewed as just another task of the water supply engineer, but rather as another water resource that requires a manager.

In some cases, management requirements are minor, such as the Kharkams scheme in Namaqualand where weekly inspections during operations are sufficient. In other cases, and in particular where water quality management is critical for clogging or health reasons, relatively high-level technical management is required. In both cases, however, artificial recharge management is critical for the successful operation of the scheme.

Knowledge of the following subjects may be needed to operate an artificial recharge scheme successfully:

- Hydrogeology of the basin
- Integrated water cycle of the catchment and source water supply
- Recharge and recovery technology
- Groundwater level monitoring
- Water treatment and water quality management
- Water supply engineering.

There is currently a shortage of technical skills in South Africa, especially at the municipal sphere of government. Artificial recharge project feasibility studies must identify the technical and management skills required to operate the scheme and from where the skills will be sourced and funded.

The technical skills required to assess the feasibility and to design an artificial recharge scheme vary with the type and size of the scheme and may include:

- Geology
- Hydrogeology

- Aquifer simulation modeling
- Hydrology
- Geochemistry
- Environmental impact assessment
- Pipeline hydraulics
- Borehole and pump station design
- Water treatment

Other skills may be required to address legal and regulatory issues. Failure to accommodate all of these disciplines at the planning and conceptual design stages can lead to costly mid-course corrections, or even scheme failure.

C.1.10 Institutional arrangements

Associated with artificial recharge scheme licences are monitoring and reporting requirements. The institutional capacities of both the scheme operator and the regulatory authority need to be sufficient to ensure that the scheme is operated according to design standards. This applies particularly when water of marginal quality is used for recharge. If the scheme operators or regulatory authorities lack the capacity to manage and "oversee" schemes, the schemes will lose efficiency through clogging, poor maintenance, etc, and perform well below design capacities. Reporting and performance monitoring systems need to be in place to maintain optimal scheme operation.

Besides small-scale individual (typically farmer) artificial recharge operations, the responsible authorities for authorising, licensing and operating artificial recharge schemes could include:

- DWAF/CMA
- Water Services Authority (WSA)
- Water Services Provider (WSP), including Water Boards (WB)
- Water User Association (WUA)
- DEAT

While the institutional arrangements are clear with respect to water services provision (DWAF, 2004e), such arrangements have as yet, not been considered for artificial recharge applications. The key issues relate to:

- Licensing
- Monitoring
- Water quality control
- Reporting
- Support.

The institutional framework for artificial recharge management is presented in Table C.3.

	DEAT regional office		Licensee or user		Catchment Management Agency
Key legal responsibilities	Overall environmental resource management	Environmental authorisation conditions Information & reports	Operate schemes according to licence conditions	Licence conditions Information & reports	Overall water resource management within the CMA
Responsibilities with respect to monitoring and management of AR schemes	Support users to establish environmental monitoring requirements Ensure users know their monitoring & reporting responsibilities Review reports and environmental permits	Information & reports Support & monitoring	Manage, operate and monitor schemes within the conditions of the water use licence and environmental permit Collect monitoring data on water quality, water levels, abstraction, injection and environmental aspects Store & process monitoring data and compile reports for the CMA/DWAF and DEAT. Analyse data and recommend operational changes	Information & reports Support & monitoring	Support users to establish the groundwater & AR management needs Ensure users know their monitoring & management responsibilities Draft water use licences to include monitoring, data and reporting requirements Review reports and licences

Table C.3: Institutional framework for artificial recharge management

Many artificial recharge schemes rely on cooperation between water services authorities, bulk suppliers and water resource management institutions. In Windhoek, for example, large-scale borehole injection has been put on hold until agreements between the source water supplier (NamWater) and the manager/user of the scheme (the City of Windhoek) have been finalised.

The seriousness of "getting the institutional arrangements sorted out" cannot be overemphasised. Eight out of ten of the most significant impediments to implementing a cost-effective conjunctive management program in California related to institutional issues (Utah, 2002). The identified impediments are listed below, and should be anticipated in project planning:

- Inability of local and regional water management governance entities to build trust, resolve difference (internally and externally), and share control.
- Inability to match benefits and funding burdens in ways that are acceptable to all parties, including third parties.
- Lack of sufficient federal, state and regional financial incentives to encourage groundwater conjunctive use to meet state-wide water needs.
- Legal constraints that impede conjunctive use, regarding storage rights, basin judgments, area of origin, water rights, and indemnification.
- Lack of state-wide leadership in the planning and development of conjunctive use programs as part of comprehensive water resources plans, which recognize local, regional, and other stakeholders' interests.
- Inability to address quality differences in "put" versus "take"; standards for injection, export, and reclaimed water; and unforeseeable future ground water degradation.
- Risk that water stored cannot be extracted when needed because of infrastructure, water quality or water level, politics, and institutional or contractual provisions.
- Lack of assurances to prevent third-party impacts.
- Lack of creativity in developing lasting "win-win" conjunctive use projects, agreements, and programs.
- Supplemental suppliers and basin managers have different roles and expectations in relation to conjunctive use.

C.2 PROJECT STAGES, LEGISLATION AND AUTHORISATION

C.2.1 Project stages

It is important that artificial recharge projects follow the normal water supply project development stages of planning, design, authorisation and implementation. Artificial recharge schemes cannot be considered simple interventions whereby excess surface water is transferred underground on an ad hoc basis in the hope that this will solve water shortage problems. If the project is not properly planned, it is unlikely that it will have the expected benefits and it could have negative repercussions. For example, the scheme could become inefficient due to clogging, or there may be legal or environmental issues that could lead to scheme failure.

Artificial recharge projects differ from conventional water supply infrastructure development projects in two significant ways:

- A significant period of testing is almost always required prior to developing the design and implementation plan.
- Artificial recharge projects are site specific and each project will have its own particular objectives.

While testing helps to understand the project specific conditions, it is also important to start relatively small and have incremental increases in capacity as the variables of the particular situation are monitored and better understood.

Artificial recharge projects cannot be considered as mere management interventions, as there is always some level of infrastructure development associated with them.

Table C.4 summarises the recommended artificial recharge project stages, key activities and authorisation requirements. The recommended authorisation process is described in detail in Section C.2.3. The project stages have been developed and informed by lessons learnt while assessing the feasibility of the Plettenberg Bay and Prince Albert artificial recharge schemes.

C.2.1.1 Pre-feasibility Stage

The pre-feasibility study for all planned artificial recharge schemes serves three main purposes:

1. It requires the applicant to formulate the proposal.
2. It provides an initial assessment of the scheme's viability.
3. It identifies the authorisation requirements. Applicants must make the initial contact with DWAF and DEAT regional offices to establish which "water uses" will be applicable, the licensing requirements, and the environmental authorisation requirements. This relates to both the proposed scheme and artificial recharge tests (which usually from part of the feasibility stage).

During the Pre-feasibility Stage, the need for the proposed artificial recharge scheme must be justified; the volumes of water to be recharged must be quantified; and the proposed method of recharge described. Based on existing information, the ability of the aquifer to accept and store the water, and the ability to recover the water, must be evaluated. Possible environmental impacts must also be identified.

The pre-feasibility report should include the following:

- The conceptual design of the project
- Existing permits and licences
- Existing data on water availability, borehole water levels and water quality; and existing and planned data monitoring systems
- A report on the viability of the project, taking into account the ten criteria for successful implementation (see Section C.1). The report should identify information gaps and how these will be addressed in the feasibility study
- A report on the listed activities in the testing phase that require environmental authorisation and water use licensing
- The proposed tests to assess the feasibility of the scheme
- The feasibility study plan and cost estimate.

Table C.4: Recommended artificial recharge project stages, key activities and authorisation requirements

Project Stage	Key Activities	Authorisation requirements
Pre-feasibility Stage	Identify the potential AR project and describe the information currently available. Based on existing information, comment on the feasibility of the project. Describe the work required for the Feasibility Stage and estimate the cost of undertaking the feasibility study. Establish existing water use licence conditions and authorisation requirements from DWAF and DEAT.	None
Feasibility Stage	If needed, obtain a water use licence and environmental authorisation for the recharge tests. Conduct the feasibility study. This should include AR testing (eg injection tests, infiltration tests, pumping tests, water quality assessments, etc) Develop a preliminary infrastructure design. Identify the project implementation phases if a phased approach is necessary (eg starting small and expanding after successive recharge cycles). Estimate the costs of the project. Identify funding sources Compile a detailed project implementation plan.	None, or a short-term water use licence for AR testing and possibly environmental authorisation for AR testing
Implementation Stage	Obtain the necessary water use licence and environmental authorisation for the AR scheme. Drilling and testing new injection and abstraction boreholes or infiltration basins Set up the groundwater and recharge water monitoring system Develop the detailed infrastructure design, carry out the tendering processes, and construct the project. Compile monitoring, operation & maintenance procedures.	Water use licence and possibly environmental authorisation
Operation and Maintenance Stage	Carry out performance monitoring during production. Modify operation & maintenance procedures based on scheme performance. Develop final monitoring and reporting system.	Compliance monitoring and reporting.

The pre-feasibility report must be submitted to DWAF. DWAF may need to convene an "Artificial Recharge Authorities Committee Meeting" where the report is discussed amongst the relevant departments (DWAF, DEAT, etc), and the applicant.

If a water use licence is required for the testing stage, the pre-feasibility report should accompany the licence application. If no licence is required, the applicant can continue with the tests, subject to the conditions set by the Artificial Recharge Authorities Committee Meeting.

In order to assess whether environmental authorisation is required for the planned tests, the applicant will need to identify listed activities that trigger an environmental study and establish which activities exceed the trigger limits. The listed activities and their limits are contained in Tables C.6 and C.7. The applicant may need to consult an Environmental Assessment

Professional (EAP). If environmental authorisation is triggered by the planned artificial recharge tests, the applicant should submit the required documentation (Basic Assessment Report or Scoping Report) together with the pre-feasibility report. This is important to ensure that the authorisation process is processed in the shortest possible time.

C.2.1.2 Feasibility Stage

The purpose of the feasibility study is to determine whether the artificial recharge scheme is feasible, affordable and sustainable prior to implementing the scheme. This stage of the study usually involves the testing of the artificial recharge scheme – either at a pilot scale or at full scale.

Once authorisation has been received, testing can commence taking cognisance of the conditions set out by DWAF and DEAT. Besides water quality, water level, injection/infiltration rate and environmental monitoring, the authorities may require a public participation process prior to testing.

Site-specific information needs to be gathered during this stage to assess the ability of the aquifer to receive water, the efficiency of the artificial recharge process, and the hydraulic and environmental effects of recharging the aquifer. Data collected during the feasibility study will provide a baseline against which monitoring data can be compared in future.

Testing usually lasts between two and six months, but may be longer, depending on the duration of the planned production/recharge cycles and the level of confidence required prior implementing the full-scale scheme. Typically, this will involve a period of infiltration/injecting followed by a period of monitoring the aquifer's response after the recharge tests, and then an abstraction period.

The feasibility study should report on the all the items listed in the criteria for successful implementation (Section C.1):

1. A clearly defined need
2. The quantity and reliability of the source water
3. Aquifer hydraulics
4. Water quality
5. Artificial recharge method and engineering issues
6. Environmental issues
7. Legal and regulatory issues
8. Economics
9. Management and technical capacity
10. Institutional arrangements

The report should also include:

- Preliminary infrastructure design
- A detailed project implementation plan
- A funding plan identifying funding sources and requirements
- A comparison with other water supply alternatives.

The applicant should establish the environmental authorisation and water use licensing requirements and submit the appropriate applications together with the feasibility study to DWAF. DWAF may need to convene an Artificial Recharge Authorities Committee Meeting to decide whether the project can proceed to implementation and to set the conditions for implementation.

C.2.1.3 Implementation Stage

Once authorisation to proceed is received by the applicant, the Implementation Stage of the project can commence. This would typically consist of:

- Further groundwater infrastructure development (drilling & testing)
- Setting up the groundwater monitoring system (artificial recharge volumes, groundwater levels and water quality)
- Ensuring that the required water use licence and environmental authorisation is obtained
- Developing detailed infrastructure design, carrying out the tendering process and constructing the scheme
- Compiling the monitoring, operation & maintenance procedures.

C.2.1.4 Operation and Maintenance Stage

During the Operation and Maintenance, or Production Stage, monitoring of the artificial recharge scheme is geared towards optimising the scheme performance and expanding its capacity where feasible. Activities include:

- Monitoring scheme performance and the aquifer response during recharge and abstraction
- Modifying operation and maintenance procedures
- Implementing incremental increases in the scheme's capacity (up to the authorised limits)
- Reporting on information required in terms of the water use licence and environmental authorisation.

C.2.2 Legislation

The legislative framework governing artificial recharge projects is described in Section A.2. This section describes relevant aspects of the key legislation documents.

C.2.2.1 National Water Act (NWA)

The two key points relevant to artificial recharge are:

1. How artificial recharge is defined in the National Water Act
2. Whether artificial recharge needs to be licensed.

Chapter 4 of the NWA refers to the use of water and eleven uses are described in Section 21 of the Act (Table C.5). Two of these "uses" clearly fall within the realm of artificial recharge, namely "storing water", and "the intentional recharging of an aquifer with any waste or water containing waste". Other uses such as "altering the bed, banks, course or characteristics of a watercourse", could be applicable in the case of a bank filtration artificial recharge scheme. Based on the definitions as contained in the NWA, artificial recharge can therefore be considered a water use.

In considering an application for a licence to store water the applicant would have to show that the aquifer ("storage unit") is able to contain the water and that it would not flow away from the capture zone before it is abstracted. Alternatively, licence conditions may require the water to be abstracted within a certain time period after recharge (i.e. prior to leakage out the aquifer or away from the capture zone).

In general a water use needs to be licensed unless it is (NWA, 1998):

- Listed in Schedule 1
- Is an existing lawful use
- Is permissible under a general authorisation, or
- If a responsible authority waives the need for a licence.

Schedule 1 use includes, amongst others, small-scale domestic use, gardening and watering of animals. Most artificial recharge schemes will be geared to municipal or other large scale users and will therefore fall outside of Schedule 1 use. Examples of Schedule 1 use artificial recharge schemes include earth dams that farmers build to enhance groundwater recharge, and rainwater harvesting that involves sub-surface storage.

Existing lawful use refers to a legal water use prior to the commencement of the NWA in 1998. An example of this that relates to artificial recharge is Polokwane, which has historically discharged treated waste water into a river bed which, in turn, enhances recharge (described in Section B3).

Permissible use under a general authorisation is described in Part 6 of the NWA (Section 39). The storage of water underground is specifically excluded from general authorisation in Government Notice No 26187 of 26 March 2004. As a result, all artificial recharge is subject to being issued a water use licence by DWAF.

Artificial recharge schemes need to be licensed because storing water underground is defined as a "water use" in the National Water Act.

Artificial recharge cannot be excluded from licensing under pretext of a general authorisation, as the storage of water underground is specifically excluded from general authorisation.
(Government Notice No 26187 of 26 March 2004)

A responsible authority could only waive the need for a licence if other legal requirements are met, such as those that may be required to meet environmental requirements. A responsible authority may only dispense with the requirement for a water use licence if it is satisfied the objectives of the NWA will be met by the granting of a licence, permit or other authorisation under any other law.

Table C.5: Water uses recognized in Section 21 of the NWA that may be applicable to artificial recharge projects

Section	Water uses
s21(a)	Taking water from a water resource;
s21(b)	**Storing water**;
s21(c)	Impeding or diverting the flow of water in a watercourse
s21(d)	Engaging in a stream flow reduction activity (currently only commercial afforestation)
s21(e)	Engaging in a controlled activity – activities which impact detrimentally on a water resource (activities identified in s37(1) or declared as such under s38(1)) namely: - Irrigation of any land with waste or water containing waste which is generated through an industrial activity or a waterwork; - An activity aimed at the modification of atmospheric precipitation; - A power generation activity which alters the flow regime of a water resource; or - **Intentional recharge of an aquifer with any waste or water containing waste**
s21(f)	Discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit
s21(g)	Disposing of waste or water containing waste in a manner which may detrimentally impact on a water resource
s21(h)	Disposing in any manner of water which contains waste from, or has been heated in any industrial or power generation process
s21(i)	Altering the bed, banks, course or characteristics of a watercourse
s21(j)	Removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people
S21(k)	Using water for recreational purposes

There are sections in South African water law where artificial recharge is either mentioned or implied:

- In Section 37 of the NWA, intentional recharging of an aquifer with any waste or water containing waste is declared a controlled activity; and thus subject to authorisation. This would include recharging with wastewater or wastewater effluent, storm water and water containing any other substance considered waste.
- The storage of water underground is specifically excluded from general authorisation in Government Notice No 26187 of 26 March 2004. While this may refer to the storage of water in disused mine shafts and caves, etc, it nevertheless implies that all artificial recharge is subject to being issued a water use licence by DWAF.

While an artificial recharge scheme may include a number of water uses that require a licence, the physical process of artificially recharging groundwater is not defined as a use in terms of the NWA. However, because in most instances the primary purpose of artificial recharge would be to store water in an aquifer, the “use” associated with artificial recharge projects will be s21(b), “the storing of water”.

It is evident that subsurface storage was not considered at the time of drafting the legislation. Government notice No 26187 defines storage as follows: "storage" means storing water not containing waste, in a watercourse or off-channel storage. Further, the licence application form pertaining to storage (DW774 L2b) describes the storage of water in dams and is inadequate to describe the storage of water in an aquifer.

The dam safety regulation will be applicable in recharge basins where the "dam" can contain more than 50 000 m^3 of water, and which has a wall of a vertical height of more than 5 metres, or which has been declared as a dam with a safety risk.

C.2.2.2 National Environmental Management Act (NEMA)

Regulations published under the National Environmental Management Act (Act 107 of 1998) (NEMA) do not specifically address artificial recharge as an activity, but some of the listed activities could be part of implementing an artificial recharge scheme. For example, authorisation is required for the construction of facilities or infrastructure for the bulk transportation of water in pipelines with an internal diameter of 0.36 m or more, or with a peak throughput of 120 L/s or more. Limits that trigger the need for environmental authorisation that could be applicable to artificial recharge schemes are listed in Table C.6 and C.7.

Activity 13 of NEMA Regulation 386 stipulates environmental authorisation is required when the abstraction of groundwater exceeds the general authorisation volume issued in terms of the NWA. The regulations require a Basic Assessment be undertaken.

Environmental authorisation is required in instances where a listed activity associated with a planned artificial recharge scheme exceeds the limits set out in Tables C.6 and C.7.

Table C.6 Activities that require Basic Assessment, as stipulated in NEMA Regulation 386

Section	Activities
1	The construction of facilities or infrastructure for:
1(k)	the bulk transportation of sewage and water, including stormwater, in pipelines with (i) an internal diameter of 0.36 m or more, or (ii) a peak throughput of 120 L/s or more
1(m)	any purpose in the 1 : 10 yr flood line of a river or stream (or within 32 m from the bank of a river or stream where the floodline is unknown) excluding purposes associated with existing residential use, but including canals, channels, bridges, dams and weirs
1(n)	the off-stream storage of water, including dams and reservoirs, with a capacity of 50 000 m^3 or more, unless such storage falls within the ambit of the activity listed in item 6 of Government Notice 387 of 2006
1(s)	the treatment of effluent, wastewater or sewage with an annual throughput capacity of more than 2 000 m^3 but less than 15 000 m^3
4	The dredging, excavation, infilling, removal or moving of soil, sand or rock exceeding 5 m^3 from a river, tidal lagoon, tidal river, lake, in-stream dam, floodplain or wetland

5	The removal or damaging of indigenous vegetation of more than 10 m^2 within a distance of 100 metres inland of the high-water mark of the sea
6	The excavation, moving, removal, depositing or compacting of soil, sand, rock or rubble covering an area exceeding 10 m^2 in the sea or within a distance of 100 metres inland of the high-water mark of the sea
12	The transformation or removal of indigenous vegetation of 3 ha or more; or of any size where the transformation or removal would occur within a critically endangered or an endangered ecosystem listed in terms of section 52 of the National Environmental Management: Biodiversity Act, 2004 (Act No. 10 of 2004)
13	The abstraction of groundwater at a volume where any general authorisation issued in terms of the National Water Act, 1998 (Act No. 36 of 1998) will be exceeded
15	The construction of a road that is wider than 4 m or that has a reserve wider than 6 m, excluding roads that fall within the ambit of another listed activity or which are access roads of less than 30 m long
20	The transformation of an area zoned for use as public open space or for a conservation purpose to another use.

Table C.7: Activities that require a Scoping Study and an EIA, as stipulated in NEMA Regulation 387

Section	Activities
1	The construction of facilities or infrastructure for:
1(e)	any process or activity which requires a permit or licence in terms of legislation governing the generation or release of emissions, pollution, effluent or waste and which is not identified in Government Notice No. R. 386 of 2006
1(n)	the transfer of 20 000 m^3 or more water between water catchments or impoundments per day
1(p)	the treatment of effluent, wastewater or sewage with an annual throughput capacity of 15 000 m^3 or more
2	Any development activity, including associated structures and infrastructure, where the total area of the developed area is, or is intended to be, 20 ha or more
6	The construction of a dam where the highest part of the dam wall, as measured from the outside toe of the wall to the highest part of the wall, is 5 m or higher or where the high-water mark of the dam covers an area of 10 hectares or more

While some of these activities may be triggered by an artificial recharge scheme, the act of artificially recharging groundwater would not trigger a Basic Assessment or a Scoping Study and EIA. However, under section 28 of NEMA, DEAT needs to comment on (and can set conditions for) any activity that may have a potential environmental impact, even if that activity does not trigger a Basic Assessment or a Scoping Study and EIA.

In some provinces, DWAF and the delegated DEAT authority are developing Memoranda of Understanding regarding their co-operative relationship. These could cater for having a combined process for obtaining both a licence and environmental authorisation.

As is the case with the NWA, under Chapter 5 of NEMA Regulation 385, an applicant may apply for an exemption from any provision described in the NEMA Regulations. The NEMA Regulations stipulate the procedure to be followed when applying for exemption and factors that need to be taken into account when considering an application for exemption.

The NEMA regulation 385 provides timeframes of 14 days for administrative actions, 45 days for the review and decision-making on minor reports and between 60 and 105 days for the review and decision-making on complex reports.

In terms of section 32 of regulation 385 an EIA has to contain a draft Environmental Management Plan (EMP). Section 36 describes what needs to be covered in the EMP.

C.2.3 Authorisation Process

So far, no artificial recharge project has been authorised in South Africa and thus there is no authorisation precedent. Existing schemes were implemented prior to the new water laws and fall within the realm of “existing lawful use”.

What follows is a recommended process that is based on current legislation. The only new development that is envisaged is the formation of an “Artificial Recharge Authorities Committee Meeting” (Authorities Meeting) that is held whenever an artificial recharge application is made. The Authorities Meeting would be convened by DWAF, and include regional DWAF and DEAT officials and any other affected Department.

Artificial recharge projects can be authorised within the existing structures and systems of DWAF and DEAT. Technical support on artificial recharge issues would be required in the regions and it is proposed that DWAF head office ensure that an artificial recharge “expert” is available to attend Authorities Meetings with the regional DWAF and DEAT case officers. Both the NWA and NEMA require that authorisation processes are harmonised across departments and thus a single process for both authorisations (DWAF and DEAT) is proposed.

The Authorities Meeting is required at least twice during the process of artificial recharge scheme development:

1. The first is prior to the testing phase, at the end of the Pre-feasibility Stage. The Authorities Meeting must decide whether the testing requires water use licensing (DWAF) and environmental authorisation (DEAT). Conditions for testing would need to be prescribed.

2. The second is after the testing period, on completion of the Feasibility Stage. The Authorities Meeting needs to consider the feasibility study report and decide on the legal, monitoring and reporting requirements for project implementation.

In addition to the above, the Authorities Meeting would need to convene after a period of operation to review the monitoring data and to consider licence renewal. This may also be required from time to time during the Operation and Maintenance Stage of the project.

Figure C.4 and Table C.8 describe the proposed process for artificial recharge water use licensing and environmental authorisation.

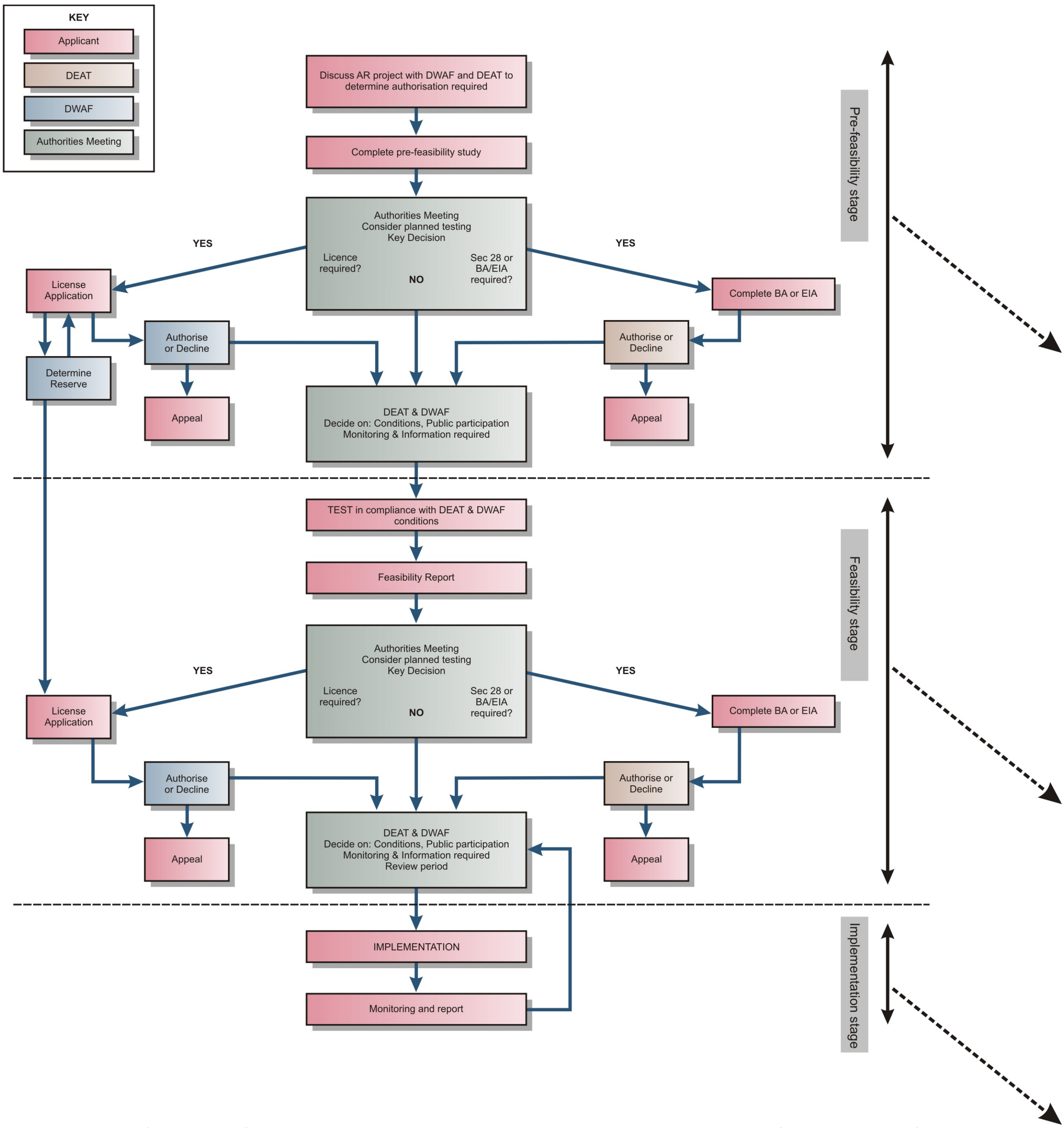
Below are a list of related references and guideline documents, some of which are described in Section C.3:

- Procedure for Approving and Licensing Groundwater Development and Use (Parsons, *et al*, 2006).
- Department of Water Affairs and Forestry, 2000. Water Use Authorisation Process for Individual Applications. Revision 3, Chief Directorate: Water Conservation.
- NEMA EIA Regulations Guideline & Information Document Series (DEA&DP, July, 2006 & November, 2006)
- Guidelines for Involving Hydrogeologists in EIA Processes (Saayman, 2005).

In addition to local guideline documents, recent documents pertaining to ASR that include authorisation issues are:

- Aquifer Storage Recovery: A Guide to Groundwater Recharge Through Wells. (Pyne, 2005).
- Draft Code of Practice for Aquifer Storage and Recovery. (Dillon, 2005).

Figure C.4/……..



Note: If a licence or Sec 28 or BA/EIA is not required prior to the Feasibility or Implementation Stages, conditions for testing/implementation should be set immediately at the "Authorities Meeting"

Figure C.4: Proposed artificial recharge project authorisation process

Table C.8: Summary of tasks for proposed artificial recharge authorisation

	TASKS FOR APPLICANT	TASKS FOR DWAF	TASKS FOR DEAT
Pre-feasibility Stage	Meet with DWAF and DEAT to discuss the project and authorisation requirements. Compile a Pre-feasibility report including the items listed below: • A conceptual design of the project, information currently available and existing permits and licences. • A description of existing data and the current systems in place for data collection. • An assessment of the AR potential based on existing information and the 10 criteria for successful implementation. Identify the information gaps and how these will be addressed in the Feasibility Stage. • A proposed sequence of tests for establishing the AR potential and a description of the activities requiring environmental and water use authorisation. • A description of the work required and costs to undertake the feasibility study. Establish whether a water use licence and an environmental permit is required for **conducting AR tests** (to be carried out in the Feasibility Stage), and if so, apply to DWAF and DEAT for the necessary permission.	Meet with the applicant to discuss the project and authorisation requirements. Provide the applicant with guidance on the compilation of a Pre-feasibility report. On receipt of the application and/or Pre-feasibility report, undertake the following activities: • Acknowledge receipt of the application and/or Pre-feasibility report within 14 days. • Send DEAT regional authority a copy of the application. • Review the application and/or Pre-feasibility report and request further details or clarification from the applicant if needed. Consult with AR specialists as required. • Formulate DWAF requirements and conditions for proceeding with AR testing. • Convene an Authorities Meeting with DEAT and other affected Departments within 30 days of acknowledging receipt of the application. • Set conditions for AR testing during the Feasibility Stage and describe the public participation processes requirements. • Specify monitoring and reporting requirements (including pre-testing/baseline monitoring; monitoring requirements during testing; and post-testing monitoring). • Inform the applicant of DWAF/DEAT requirements within 10 days. • Process the licence application and initiate a reserve calculation if required. • Set a time period for the validity of the AR testing.	On receipt of the application and/or Pre-feasibility report from DWAF, undertake the following activities: • Review the Pre-feasibility report and request further information or clarification from the applicant if needed. • Formulate DEAT requirements for the testing activities proposed. Establish whether a Basic Assessment or an EIA is required. • Participate in the Authorities Meeting. • Set conditions for AR testing during the Feasibility Stage and describe the public participation processes requirements. • Specify monitoring and reporting requirements (including pre-testing/baseline monitoring; monitoring requirements during testing; and post-testing monitoring). • Process the required environmental permits.
Feasibility Stage	If necessary, obtain a water use licence and an environmental permit from DWAF and DEAT **for AR testing**. Initiate a public participation process as and if required. Undertake monitoring and AR testing based upon the plans in the pre-feasibility study and the conditions set by DWAF and DEAT. Produce a Feasibility report including the following: • An assessment of the AR potential based on the results of the AR tests, all available information and the 10 criteria for successful implementation. • A preliminary infrastructure design. • A description of project implementation phases and time frames, and clarify which phase the authorisation application covers. • An economic assessment including estimates of the project implementation costs using lifecycle costing and comparing with alternative water supply options. • A list of funding sources (ensure the feasibility study complies with all requirements of the proposed funder). • A project implementation plan. Apply to DWAF for a water use licence **for implementing and operating** the AR scheme, and to DEAT for environmental authorisation.	Be available to clarify and discuss issues with the applicant. On receipt of the feasibility report: • Schedule and convene an Authorities Meeting with DEAT and other affected Departments within 30 days of receipt of the Feasibility report. • Review the Feasibility report. • Establish whether the conditions for carrying out AR testing were met. • Formulate DWAF's licence requirements for project implementation and production. • Describe the public participation processes requirements. • Stipulate monitoring and information reporting requirements. • Inform the applicant within 10 days of the decisions taken at the Authorities Meeting.	Be available to clarify and discuss issues with the applicant. On receipt of the feasibility report: • Review the Feasibility report. • Establish whether the conditions for carrying out AR testing were met. • Participate in the Authorities Meeting. • Formulate DEAT's requirements for project implementation and production. • Describe the public participation processes requirements. • Stipulate monitoring and information reporting requirements.
Implementa -tion Stage	Implement the project. Report to DWAF and DEAT as per the authorisation agreements.	Review the compliance monitoring reports. Review the licence conditions at the interval stipulated in the licence agreement.	Review the compliance monitoring reports. Review the authorisation conditions.

C.3 GUIDELINE DOCUMENTS

Most artificial recharge schemes have been implemented in unconsolidated, primary aquifers and porous hard-rock aquifers. Very few schemes exist in fractured, hard-rock aquifers. The research and documentation regarding artificial recharge schemes, including guideline documents, reflect this, and thus what is presented here is based primarily on studies in primary aquifers. The exceptions are carbonate aquifers, in which large-scale schemes exist and information derived from studies on these schemes have been incorporated into guideline documents.

Guideline documents, however, need to be used with caution, as there are usually more differences between schemes than aspects in common. This observation has led to statements such as: "…artificial recharge should be tuned to each individual setting. Guidelines have a narrow significance and cannot be applied in general" (Peters, 1996); and "…it was concluded that due to lack of knowledge …..it was not possible to set quality criteria for surface water" (Dahlstrom and Pedersen, 1996). Such comments should not down-play the significance of guideline documents, since the international knowledge pool will develop as the lessons for successful implementation are documented and common "success factors" understood. However, it must be noted that each scheme has site-specific factors that need to be understood and the complexities of natural processes cannot be simplified into generic guidelines.

Sections C.3.1 and C.3.2 provide a summary of general and issue-based artificial recharge guideline documents. The key issues raised in these guideline documents are discussed in Section C.1.

C.3.1 General artificial recharge guideline documents

C.3.1.1 Draft Code of Practice for Aquifer Storage and Recovery

Reference:	Dillon (2005). Draft Code of Practice for Aquifer Storage and Recovery. CSIRO Land and Water, Australia.
Availability:	This is an updated version of the document of the same title by the South Australia Environmental Protection Agency (2002).
Number of pages:	24 (paper size: A4).

Major issues:
The following issues are listed as "Guiding Principles for Best Practice":

1) *Risk management.* This should account for uncertainty in aquifer characteristics, variations in water source quality and quantity, and changes in land uses and management that may take place over the operating life of the ASR scheme.
2) *Prevention of irreparable damage.* Although it is recognised that all the information required to predict the performance of an ASR/ASTR site will not be available until the site is operational, it is nevertheless necessary to identify all foreseeable modes of failure, take preventative action to ensure that these do not occur, and identify contingency plans to prevent irreparable damage.
3) *Demonstrations and continuous learning.* Emphasis is placed on monitoring in order to understand the systems better.

4) *Informed precautionary principle.* A risk management approach should be adopted after identifying all potential problems.
5) *Water quality requirements.* The quality of the water injected should be determined by the designated environmental values (beneficial uses) of native groundwater in the aquifer.
6) *Attenuation zone.* Cognisance of attenuating properties of aquifer media (to reduce contaminant properties) should be taken into account.
7) *Rights of water bankers and recoverable volumes.* The guiding principle should be that water stored in the aquifer is available to the operator of the ASR scheme.
8) *Finite storage capacity of aquifers and interference effects between sites.* In licensing ASR schemes, the aquifer's storage capacity and the spacing of adjacent ASR schemes must be taken into account.

Comment on the document:
This Code of Practice outlines the requirements of the Environmental Protection Agency and the Department for Sustainable Development within the State of Victoria, Australia. It provides guidance for projects intended to store water for drinking, irrigation, industrial and ecosystem support purposes, but not for waste water disposal purposes. Source waters include drinking water, stormwater, reclaimed water and groundwater.

Much of the focus on ASR in Australia has been on water quality issues, and hence the Code of Practice covers these issues in greater detail than other issues such as the ability of aquifers to receive injected water (hydraulic issues).

The document refers to the challenge of coordinating environmental regulation and water resource management roles in the approval of new projects.

The Code of Practice includes, amongst other topics:

- Groundwater protection policies in relation to ASR (including injectant water quality criteria)
- Procedure for licence application
- The components of ASR systems
- A generic plan to assess and manage the risk of polluting groundwater and failure to meet required water quality criteria for the recovered water (the Hazard Analysis and Critical Control Point Plan – HACCP) .

C.3.1.2 Standard Guidelines for artificial recharge of Groundwater

Reference:	American Society of Civil Engineers. 2001. Standard Guidelines for artificial recharge of Ground Water, EWRI/ASCE 34-01. ISBN: 0784405484.
Availability:	ASCE website: www.asce.org (bookstore: www.pubs.asce.org).
Number of pages:	106 (paper size: A4).

Major issues:
This document provides a comprehensive overview of the issues that affect the planning, design, construction, operation and closure of various types of artificial recharge scheme. In so doing, it identifies many issues that have to be dealt with for the successful implementation of an artificial recharge scheme. These include technical, environmental, legal, economic and social issues.

Comment on the document:
This document summarises the issues that need to be considered when taking an artificial recharge project from its conception stage, through construction and operation, to closure. The chapter headings are:

1) General (including purpose and types of schemes)
2) Planning
3) Field investigations and field testing
4) Design
5) Regulatory and water rights issues
6) Environmental issues
7) Economics
8) Construction
9) Start-up, operation and shutdown procedures
10) Operation, maintenance and closure

The document does not claim to provide a comprehensive "how to" guideline on each topic, but rather aims to describe the many steps required to develop, operate and maintain an artificial recharge project. In this regard, it is comprehensive, and although it generally offers little information on how to address the issues, it goes into greater depth on certain topics, such as those regarding the use of treated waste water.

This document can be used as a good checklist of issues that need to be taken into account when planning an artificial recharge scheme.

C.3.1.3 Groundwater Recharge and Wells: A Guide to Aquifer Storage and Recovery

Reference:	Pyne, R.D.G. 2005. Aquifer Storage Recovery: A Guide to Groundwater Recharge through Wells. Second Edition. ASR Press, Florida, USA.
Availability:	ASR Systems, PO Box 969, Gainsville, Florida, 32602, USA.
Number of pages:	608 (paper size: between A4 and A5).

Major issues:
The book raises and addresses most of the issues pertaining to ASR schemes. A major focus is on implementation stages, scheme design, water quality and geochemistry (and associated issues such as clogging), and the book includes information on a number on other technical and non-technical issues.

The book is divided into the following chapters:
Introduction

1) ASR Programme development
2) Design of ASR systems
3) Selected ASR technical issues
4) Geochemistry
5) Selected ASR non-technical issues
6) Alternative ASR applications
7) Selected case studies
8) Future directions

Comment on the document:
The book provides a comprehensive description of all the key issues affecting ASR schemes. It has been updated to include, amongst other topics, the considerable research that has gone into assessing the fate of pathogens during subsurface storage.

The book describes how to undertake feasibility studies and has an in-depth section on design issues. It includes an in-depth section of water quality issues, including pre- and post-treatment, geochemical issues and clogging.

This is the definitive guide to ASR, accompanied by numerous case studies.

C.3.1.4 Artificial Recharge of Groundwater: Hydrogeology and Engineering

Reference:	Bouwer, H. 2002. Artificial recharge of groundwater: hydrogeology and engineering. Hydrogeology Journal (2002) 10:121-142. Springer, Heidelberg, Germany.
Availability:	Hydrogeology Journal.
Number of pages:	21 (paper size: A4).

Major issues:
In this paper, Herman Bouwer summarises the key issues that affect the design and operation of artificial recharge schemes. Emphasis is placed on infiltration basins, on which subject Prof Bouwer has vast experience.

The key topics covered include:
- The mathematics of, and the factors that affect, infiltration from surface recharge schemes (including soil clogging)
- The role of recharge in water reuse.

The governing equations of infiltrating water are summarised in this paper, but are dealt with in greater detail in numerous other groundwater and engineering text books. These include those written, or contributed towards, by Prof. Bouwer in Huisman and Olsthoorn (1983) and in other journal papers.

Planned water reuse is expected to become increasingly important in future, and artificial recharge is identified as a cost-effective means to utilise surplus waste water. This option is "often cheaper than the treatment for discharge into surface water that is necessary to protect in-stream and downstream users of that water against unacceptable pollution".

The paper presents a practical approach to implementing artificial recharge schemes: "Design and management of artificial recharge systems involves geological, geochemical, hydrological, biological and engineering aspects."

> *"Because soils and underground formations are inherently heterogeneous, planning, design and construction of groundwater recharge schemes must be piecemeal, first testing for fatal flaws and general feasibility and then proceeding with pilot and small-scale systems until the complete system can be designed and constructed." Bouwer, 2002.*

Comment on the document:
Prof. Bouwer is one of the world's leading experts on surface recharge schemes. This paper consists of a summary of the key issues affecting flow from surface recharge facilities. For an aquifer to receive recharged water, it needs to be sufficiently transmissive, and this must be established by field investigations.

This document provides a succinct summary of concerns regarding the use of waste water in artificial recharge facilities, and summarises the advantages (water quality improvements) associated with soil aquifer treatment.

C.3.1.5 Artificial Recharge: A Technology for Sustainable Water Resource Development

Reference:	Murray, E.C. and Tredoux, G. 1998. Artificial recharge: A technology for sustainable water resource development. Water Research Commission, Report No 842/1/98. Pretoria, South Africa.
Availability:	Water Research Commission.
Number of pages:	152 (paper size: A4).

Major issues:
The key issues identified and discussed are:

1) Hydrological factors:
   - Recharge water sources: quantity, quality and reliability
   - Soil matrix chemistry and water quality issues
   - Hydraulic factors
   - Clogging potential
   - Numerical modelling
   - Recovery efficiency
2) Socio-Economic issues:
   - Economic
   - Management
   - Legal
   - Social

Comment on the document:
The document includes a section on "Guidelines for establishing artificial recharge schemes". The document is divided into the processes that are required for planning recharge basins and ASR schemes.

C.3.1.6 Artificial Groundwater Recharge

Reference:	Huisman, L. and Olsthoorn, T.N. 1983. Artificial Groundwater Recharge. Pitman Advanced Publishing Programme, Boston, London, Melbourne.
Availability:	Pitman Advanced Publishing Programme, Boston, London, Melbourne.
Number of pages:	310.

Major issues:
This text book covers the key technical issues relating to artificial recharge.

C.3.1.7 Guide on Artificial Recharge to Ground Water

Reference:	Central Groundwater Board. 2000. Guide on Artificial Recharge to Ground. Ministry of Water Resources, New Delhi, India.
Availability:	Central Groundwater Board, Ministry of Water Resources, New Delhi, India.
Number of pages:	93.

This document covers the planning of artificial recharge projects; artificial recharge techniques and design; project monitoring; and case studies. The appendices include a format for preparation of artificial recharge projects; a checklist for planning artificial recharge projects; and guidelines for evaluating artificial recharge projects.

C.3.2 Issue-based artificial recharge guideline documents

C.3.2.1 Clogging and artificial recharge of groundwater

Reference:	Pérez-Paricio, A. and Carrera, J. 1999. Clogging Handbook. EU Project on artificial recharge of groundwater. Contract ENV4-CT95-0071. Technical University of Catalonia (UPC), Barcelona, Spain.
Availability:	Uncertain.
Number of pages:	184 (paper size: A4).

Major issues:
All forms of clogging.

Comment on the document:
This is the most comprehensive document on all aspects of clogging in both surface and borehole recharge schemes. It includes clogging processes, prevention, redevelopment practices, how to detect and measure clogging, and empirical and numerical models for predicting clogging.

C.3.2.2 Guidelines on the Quality of Stormwater for Injection into Aquifers for Storage and Re-use

Reference:	Dillon, P.J. and Pavelic, P. 1996. Guidelines on the quality of stormwater and treated wastewater for injection into aquifers for storage and reuse. Urban Water Research Association of Australia. Research Report No. 109. ISBN 1 876088 13 3.
Availability:	Centre for Groundwater Studies, Flinders University, GPO Box 2100, SA 5001, Australia.
Number of pages:	48 (paper size: A4)

Major issues
The guidelines cover:

- Licensing
- Pre-treatment
- Monitoring
- Guidance for maximum contaminant concentrations in injectant
- Residence time prior to recovery
- Management of ASR operations.

Comment on the document:
The document reviews international practice and guidelines for artificial recharge of reclaimed waters by injection. It differs from other guidelines in that it does not assume potability as an essential objective, and it caters for treatment of the water by natural processes in the aquifer.

C.3.2.3 Guidelines for the Use of Reclaimed Water for Aquifer Recharge

Reference:	DNDE 1982. Guidelines for the use of reclaimed water for aquifer recharge. Department of National Development and Energy. Australian Water Resources Council: Water Management Series No. 2, Australian Government Publishing Service, Canberra. ISBN 0 644 01892 5.
Availability:	Uncertain.
Number of pages:	103 (paper size: A4).

Major issues:

1. Reclaimed water characteristics:
   - Degree of treatment
   - Toxic contaminants
   - Salinity
   - Biochemical oxygen demand
   - Suspended solids
   - Temperature.
2. Aquifer characteristics:
   - Aquifer types – confined/unconfined
   - Aquifer zones – saturated/unsaturated zones.

3. Infiltration effects:
    - Chemical effects of infiltration through the unsaturated zone
    - Effects of infiltration on biological characteristics
    - Product water quality
    - Disinfection
    - Long-term effects on recharge.

Comment on the document:
Rather than providing clear guidelines, the document describes the issues that affect artificial recharge using reclaimed water. It provides information on operation and management, including:

- Hydraulic loading and treatment
- Nitrogen removal
- Phosphorus removal
- Pathogen removal
- Sampling and examination of water
- Monitoring the water table.

C.3.2.4 Artificial Groundwater Recharge – State of the Art

Reference:	Frycklund, C. 1992. Artificial Groundwater Recharge – state of the art. VA-FORSKs Raport Series, Sweden. ISBN No. 91-88392-08-2.
Availability:	Uncertain.
Number of pages:	55 (Paper size: A4)

Major issues:
This document focuses on the precipitation of iron and manganese, including bacterial activity that promotes iron and manganese oxidation and precipitation.

Comment on the document:
The document provides a thorough description of the chemical evolution of iron and manganese during recharge processes.

C.3.2.5 The Potential for Aquifer Storage and Recovery in England and Wales

Reference:	Jones, H. K. Macdonald, D. M. J. and Gale, I. N. 1998. The potential for aquifer storage and recovery in England and Wales. British Geological Survey. Technical report No. WD/98/26.
Availability:	British Geological Survey.
Number of pages:	36, excluding appendices (paper size: A4).

Major issues:

1) The development of an approach to establish an aquifer's ASR potential
2) Guidance on dealing with authorisations for artificial recharge and recovery schemes (Appendix J).

Comment on the document:
This report identifies and describes briefly the main factors that affect ASR schemes. It draws heavily from Pyne (1995).

The issues covered are:
- Recovery efficiency
- Clogging
- Aquifer properties
- Operational issues
- Regulatory issues
- Hydrogeological factors (aquifer properties; depth to formation; aquifer confinement; aquifer water quality).

The value of this document, outside of the United Kingdom, is twofold: Firstly, it attempts to develop an approach to assess ASR sites on a regional scale. Although the first approach is abandoned, it nevertheless describes the proposed criteria and weighting system, and this can be used as a starting point to further develop a regional approach to assessing ASR potential. The factors that were considered were aquifer properties, aquifer confinement, depth to the aquifer and aquifer water quality. The finally adopted approach was largely based on geology and transmissivity.

The second major value of this document is that it provides guidance on dealing with authorisations for artificial recharge and recovery schemes (Appendix J). The guide is "reasonably" generic, although it refers, in places, to UK-specific criteria or regulations. Supporting material includes:

- Issues that would need to be covered in an environmental impact appraisal (Appendix J1)
- A summary of (UK) authorisations required for developing artificial recharge schemes (Appendix J2)
- A decision matrix for abstraction consenting and licensing (Appendix J3).

This document provides a sound basis from which to develop a generic authorisation guide.

C.3.2.6 Groundwater Licensing Guide – application procedure for the development and use of groundwater

Reference:	Parsons R, Eichstadt L, Crowther J and Blood J, 2006. Groundwater Licensing Guide – application procedure for the development and use of groundwater. WRC Project K5/1510. Water Research Commission. Pretoria, South Africa.
Availability:	Water Research Commission (In press).
Number of pages:	28 (paper size: A4).

Major issues:
The groundwater licensing guide considers legislation applicable to groundwater use in South Africa, and identifies when a licence and environmental authorisation is required.

Comment on the document:
As updated environmental regulations have only recently been promulgated, definitions, procedures and processes have not been tested, and thus the recommended groundwater licensing guide itself still needs to be tested. The guide provides some useful tools and documentation related to licence applications.

C.3.3 Environmental guideline documents relevant to artificial recharge

C.3.3.1 Guidelines for involving hydrogeologists in EIA processes

Reference:	Saayman, I (2005) Guidelines for involving hydrogeologists in EIA processes - Edition 1; CSIR Report No ENV-S-C 2005 053 D. Republic of South Africa, Provincial Government of the Western Cape, Department of Environmental Affairs & Development Planning, Cape Town.
Availability:	This document can be downloaded from the DEADP website: http://www.capegateway.gov.za/eng/yourgovernment/gsc/406/publications
Number of pages:	54 (paper size: A4).

Major issues:
This document is one of a series of guideline documents pertaining to the EIA process in South Africa. It aims to give guidance as to when a qualified geohydrologists should be involved. It identifies three triggers that require the EIA practitioner consult a hydrogeologists:

- Where influent or chemicals with the potential to change groundwater quality is handled as part of the project or discharged into the environment due to the project.
- The volume of groundwater in storage or entering groundwater storage is changed beyond what is allowed by the DWAF general authorisations.
- The groundwater flow regime is changed.

Once the need for a hydrogeologists to be involved in the project is assessed, the document provide some guidance for drawing up terms of reference, specific tasks that the hydrogeologists may be involved in and specialised input and management actions.

Comment on the document:
The guideline document is unlikely to be particularly useful in any projects involving artificial recharge as a hydrogeologist would always be involved. However, the document provides useful guidance on how to review specialist report, how to address issues such as cumulative impacts and communicating the findings of specialist inputs.

C.3.3.2 Guideline on the interpretation of the listed activities requiring environmental authorisation

Reference:	DEADP (2006) Guideline on the interpretation of the list of activities; NEMA environmental impact assessment regulations guideline and information document series, Department of Environmental Affairs and Development Planning, Cape Town.
Availability:	This document can be downloaded from the DEADP website: http://www.capegateway.gov.za/eng/yourgovernment/gsc/406/publications
Number of pages:	70 (paper size: A4).

Major issues:
In response to promulgation of new regulations pertaining to environmental impact assessment, DEADP produced a guide document on the interpretation of listed activities. Artificial recharge is not addressed directly in the guide, but associated listed activities that may be applicable to artificial recharge projects are.

Comment on the document:
The guide is useful in that it provides an interpretation of listed activities that may be relevant to artificial recharge. It also lists activities that may be pertinent to groundwater abstraction, such as the construction of pipelines, the transformation or removal of indigenous vegetation of 3 ha or more, and the off-stream storage of water of 50 000 m^3, or more.

In addition to these documents, the recently completed Water Research Commission project by Parsons *et al* (2007) describes procedures applicable to groundwater. The report has not yet been published.